प्रायोगिक जलभृत प्रतिचित्रण परियोजना का प्रतिवेदन

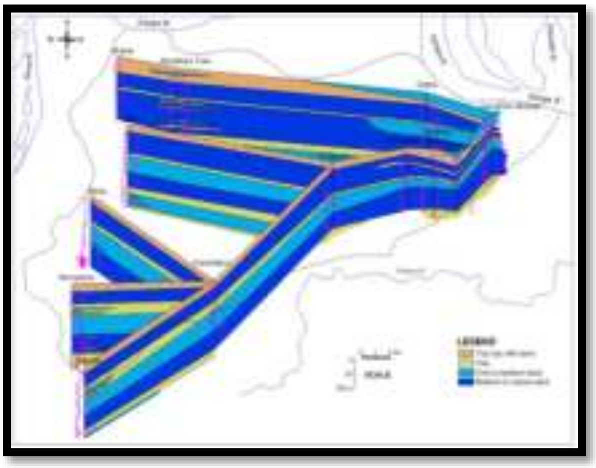
मनेर-खगौल क्षेत्र, पटना जिला, बिहार

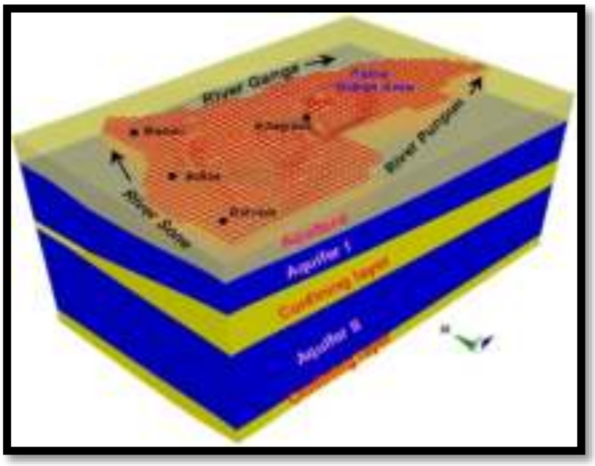
Report

on

Pilot Project on Aquifer Mapping in Maner-Khagaul Area, Patna District Bihar

(Watershed -GNDK013)





केंद्रीय भूमिजल बोर्ड

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CENTRAL GROUND WATER BOARD

MINISTRY OF WATER RESOURCES, RIVER DEVELOPMENT & GANGA REJUVENATION

GOVERNMENT OF INDIA

MID EASTERN REGION, PATNA

DECEMBER 2015

K. B. Biswas
Chairman

केन्द्रीय भूमि जल बोर्ड
जल संसाधन, नदी विकास
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Central Ground Water Board
Ministry of Water Resources,
River Development and Ganga Rejuvenation
Government of India
New Delhi

FOREWORD

Increasing development of ground water to meet the requirements of various segments has resulted in the over-exploitation of this vital natural resource in parts of the country and consequent adverse environmental impacts include, deepening water levels and drying up of shallow wells, reduction in sustainability of wells and seawater ingress in coastal freshwater aquifers. Contamination of ground water due to natural and anthropogenic causes has also increased substantially in the recent decades. The anticipated impact of global warming and climate change are also considered to add to further complicate the issues plaguing the water resources sector in India in the not so distant future. Sustainable development of ground water through judicious management interventions becomes very important to ensure the water security of the future generations.

It is in this context that the Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India decided to take up the National Aquifer Mapping and Management (NAQUIM) Programme, aimed at detailed and systematic study of the major aquifer systems in the country and formulation of management plans for sustainable development of their ground water resources. The Programme envisaged various activities such as compilation of all available data, analysis of data gaps and generation of additional data to fill them, preparation of detailed aquifer maps and formulation of management plans. Various conventional and modern techniques of field data generation, data processing and analysis including integration of data on a GIS platform and numerical groundwater modelling were expected to be used for the programme.

With a view to understand the applicability and efficacy of the above-mentioned techniques in different hydrogeological settings, pilot projects on aquifer mapping were taken up in Six different Hydrogeological terrains in the states of Bihar, Rajasthan, Maharashtra, Karnataka and Tamil Nadu.CSIR-NGRI was engaged as a consultant by CGWB to facilitate use of advanced geophysical techniques in the programme. During the course of the study, groundwater issues have been identified by CGWB specific to the area. With inputs from aquifer mapping studies, aquifer response models have been formulated and various strategies have been tested to arrive at optimal aquifer management plan for sustainable management of precious resources.

This is one among the six reports being brought out based on the studies taken up in the pilot projects. The findings are brought out in the report very coherently and I would like to place on record my appreciation for the excellent work done by the team. I fondly hope that this report will serve as a valuable guide for sustainable development of ground water in the area.

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PREFACE

A pilot study on Aquifer Mapping in six representative hydrogeological terrains of the Country was taken up by Central Ground Water Board with an objective to identify and map the aquifers at micro level, quantify the availability of the ground water resource and suggest aquifer management plans compatible with the demand, the aquifer characteristics and the basic issues of the area. The representative area for the alluvial aquifer was taken in the State of Bihar spreading over the Maner-Khagaul area (521 sq.km), falling in the watershed GNDK013, Patna District, Bihar.

As part of the study, the aquifer systems at a micro level in typical multi-aquifer system up to 300 m bgl have been delineated and characterised combining the results from the hydrogeological, hydrochemical and geophysical investigations carried out in the area. The State of the art geophysical techniques including the high resolution helicopter borne SKY-TEM surveys have also been carried out in the project area by the CSIR-NGRI. Isotope based investigations have also been carried out for understanding several groundwater issues like characterization of the movement of water and the complex recharge mechanism of the multi-aquifer system within the study area .

The study identifies the major groundwater issues in the area that need redressal through appropriate management plans for which groundwater flow modeling has also been carried out. The behavior of the aquifer system has been simulated under various generated scenarios and the modeled impacts have been evaluated and strategies for holistic management of groundwater in the area have been recommended on the basis of the output of the ground water flow modeling.

The efforts of the nodal officer and all the personnel from CGWB, in carrying out the study and bringing out this report are highly commendable. The work carried out by CSIR-NGRI, Hyderabad is really praise worthy and has helped immensely in bringing out this report. The support received from BARC, Mumbai; AMD, Jamshedpur; different central and state government agencies has helped a lot in completion of this project. I thank and congratulate all of them for such an exhaustive work and completing the work within scheduled timeframe.

The report deals with each aspect of the study carried out in much detail. It is expected that this report will be of immense help and interest to the planners, policy makers, professionals, academicians and researchers dealing with water resources in general and groundwater in particular.

Place: Patna **(G. K. ROY)**

Date: 23/12/2015 **Regional Director (I/C)**

Acknowledgement

Investigation team take this opportunity to express their deep sense of gratitude to Sh. K. B. Biswas, Chairman, Sh. K. C. Naik, Member (RGI), Sh. Sampat Kumar, Member (SML), Sh. G. C. Pati, Member (WQ &TT), CGWB for their continued guidance extending all possible support for successful completion of this flagship project of MoWR, RD & GR, Govt. of India.

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Abbreviation

AMD	Atomic Mineral Directorate
BARC	Bhabha Atomic Research Centre
CRM	Count Rate Meter
CSIR	Council for Scientific and Industrial Research
d-excess	Deuterium Excess
DOC	Depth of Confidence
EPF	East Patna Fault
ERT	Electrical Resistivity Tomography
GM tube	Geiger Müller Tube
GMWL	Global Meteoric Water Line
GNIP	Global Network for Isotopes in Precipitation
IAEA	International Atomic Energy Agency
IGRF	International Geomagnetic Reference Field
IMD	Indian Meteorological Department
LCI	Laterally Constrained Inversion
LMWL	Local Meteoric Water Line
MCM	Million Cubic Meter
mg/l	Milligram per Litre
MoWR, RD & GR	Ministry of Water Resources, River Development and Ganga Rejuvenation
NGRI	National Geophysical Research Institute
PHED	Public Health Engineering Department
PI	Permeability Index
RSC	Residual Sodium Carbonate
SAR	Sodium Absorption Ratio
SCI	Spatially Constrained Inversion
TEM	Transient Electromagnetic Method
Uc	Uniformity Coefficient
VES	Vertical Electrical Sounding
WHO	World Health Organization
WMO	World Meteorological Organization
GSI	Geological Survey of India
E.C.	Electrical Conductivity
T.H.	Total Hardness

Executive Summary

Maner-Khagaul area falling in the watershed GNDK013, Patna district, Bihar was taken as one of the six pilot project areas, representing the alluvial terrain, selected for pilot aquifer mapping by Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India. The objective of the project was to establish the methodology to identify and map the aquifers, type of aquifers, groundwater regime behaviour, hydraulic characteristics, and geochemistry of aquifer systems at a micro level in typical multi-aquifer system up to 300 m bgl using conventional method in integration with advance geophysical techniques to establish the utility, efficacy and suitability of geophysical surveys for countrywide up-scaling of aquifer mapping in similar terrain of the country, and to propose flow modelling based groundwater development and management plan.

Maner-Khagaul area, Patna, Bihar spreading over an area of 521 Sq. Kms covers part of seven administrative blocks in the western part of Patna district, Bihar. State of the art geophysical survey including the high resolution helicopter borne SKY-TEM surveys were carried out by the CSIR-NGRI to decipher the principal aquifers in apparently simpler alluvial terrainhaving multi- aquifer system. CSIR-NGRI, Hyderabad has been hired as consultant to carry out the geophysical survey.

For the proposed study, all the available data from CGWB and other agencies were collected and integrated to analyze the data gap pertaining to aquifer mapping project and thus for planning the further line of survey.

Drilling accompanied by bore well logging and construction of wells tapping different aquifers at six location were carried out across the area with objective of deciphering sub-surface lithological information and also correlating and validating the results of various geophysical survey viz. VES, ground TEM, ERT and heliborne SKY-TEM survey by NGRI, Hyderabad. Integration and validation of sub-surface data generated by different methods were done. Besides exploration, other hydrogeological survey like groundwater regime behaviour, hydraulic characteristics, and geochemistry were carried out for different "aquifer systems" to have an idea about the hydrogeological behavior of the sub-surface formation of the area. Geomorphological studies were carried out to identify the various geomorphic features, specially the palaeo-channels in the area which may act as a conduit for recharging groundwater system.

The exploration data and geophysical survey results clearly indicate existence of the two principal aquifer system of varying thickness up to 300 m depth. The top layers are highly mixed with sand and clay and behave like an aquitard layer. The principal aquifer merges at places. These conclusions about the aquifer characterization are also agreeable with the results of the SKY-TEM data.

In general, the quality of groundwater was found suitable for both drinking and irrigation purposes in the aquifer mapping area except the north western and north central part of the area where elevated arsenic concentration (> 50 ppb) was found in the top aquitard and upper part of the first principal aquifer.

Isotope based investigations were also carried out during pilot project for understanding of several groundwater issues like characterization of the movement of ground water, complex recharge mechanism of the multi-aquifer system within the study area.

Delineation of the aquifer geometry up to 300 m depth has been made. It has been found that the top sequence is highly heterogeneous in nature containing admixtures of clay and sandy clay. Spatially the thickness of the top aquitard layer varies from 20-30 m in major part of the area, and its thickness increases even up to 40 m and beyond at places. Underlying the top aquitard layer occurs the first principal aquifer with thickness varying from 50 to 80 m. The second principal aquifer is comparatively much thicker than the 1st principal aquifer, the general thickness of which remains around 100 m in major part of the area and reaches even 140 m in some parts.

Groundwater flow modeling was carried out in the project area for recommending strategies for holistic management of groundwater in the area. The study identifies the following major issues that need redressal through appropriate management plans. The identified issues are

(i) Concentrated groundwater extraction through heavy duty tube-wells in the intensively urbanized part of Patna urban area

(ii) High dependence of agriculture on groundwater and its likely continuance in future

(iii) Projected groundwater decline of 8-12 m in the agricultural area during the next 10 years if the cropping intensity is increased to 200% from the current 126%.

(iv) Projected decline of 12 m in the highly urbanized part even @ 2% increase in annual groundwater draft

(v) Arsenic contamination of groundwater affecting the aquitard and the upper slice of Aquifer-I in extreme north-western and north-central part.

To address the aforesaid issues, the study recommends the following interventions for proper management of groundwater resource in the area. The important recommendations are outlined as under

a. Increase in pumping @ 2% per annum in the study area can be made up to year 2025, however, it is strongly recommended to relocate the heavy duty municipal water supply wells concentrated in core urban area to suitable locations in and around Danapur and Punpun blocks. Further, artificial recharging of the deeper aquifer system through injection wells is recommended in the core urban area.

b. Reduction in groundwater draft in Patna urban area by 50 MCM/yr, as per the envisaged plan of Government of Bihar, to supplement water supply in urban area from the Ganga River is highly recommended. This would have a significant positive impact on the aquifer drawdown behavior and lead to improvement in the hydraulic head for both Aquifers I and II.

c. Increase in cropping intensity to 200% from the current 126% in the agricultural tracts has been found to lead to decline in hydraulic head in the agricultural belt by 6 m on an average and even up to 10 m in certain pockets. This scenario may be accepted by sinking additional tube wells for irrigation, however, a comprehensive artificial recharge plan is desirable through on farm-conservation practices and rain water harvesting in intensive agricultural pockets.

d. Industrial allocation and heavy duty deep tube wells in the northern part of Maner Block towards the confluence of Sone and Ganga should be discouraged, as this area has been found affected by arsenic contamination in the shallow aquifers. Any further increase in groundwater draft would lead to lowering of hydraulic head and possible mixing of arsenic safe water of the deeper aquifer with that of the shallow aquifer with contaminated groundwater.

CHAPTER-I
INTRODUCTION

1.0 Introduction

Central Ground Water Board, Ministry of Water Resources, River Development & Ganga Rejuvenation, Government of India, for mapping and managing the entire aquifer systems in the country has undertaken Pilot Project on Micro Level Aquifer Mapping in six places of five states representing different hydrogeological terrains of the country. One of the study areas is the Maner-Khagaul area falling in the watershed -GNDK013, Patna district, Bihar. The objective of this flagship project of MOWR,RD & GR, Govt. of India is to establish the methodology to identify and map the aquifers at the micro level in typical multi aquifer system of this alluvial area, to quantify the available groundwater resources, and to propose groundwater development plans appropriate to the scale of demand and aquifer characteristics, and the institutional arrangements for participatory management. The pilot study integrates multiple disciplinary and scientific approaches including remote sensing, hydrogeology, geophysics, hydrochemistry, drilling, ground water modelling and management plans.

1.1 Objective & Scope

The objectives of the project are:-

i. To define the aquifer geometry, type of aquifers, groundwater regime behaviours, hydraulic characteristics and geochemistry of multi-layered alluvial aquifer systems on 1:50,000 scale

ii. Intervention of new geophysical techniques and establishing the utility, efficacy and suitability of these techniques in different hydrogeological setup.

iii. Finalizing the approach and methodology on which National Aquifer Mapping programme of the entire country can be implemented.

iv. The experiences gained can be utilized to upscale the activities for micro level aquifer mapping.

SCOPE:

The activities of the Pilot Project on Aquifer Mapping can be envisaged as follows

(a) Data Compilation & Data Gap Analysis: One of the important aspect of the aquifer mapping programme was the synthesis of the large volume of data already collected during specific studies carried out by Central Ground Water Board and various Government organizations with a new data set generated that broadly describe an aquifer system. The data were assembled, analysed, examined, synthesized and interpreted from available sources. On the basis of available data, Data Gaps were identified.

(b) Data Generation: There was also a strong need for generating additional data to fill the data gaps for aquifer mapping. This was achieved by multiple activities such as exploratory drilling, geophysical techniques, hydro-geochemical analysis, remote sensing, besides detailed hydrogeological surveys. CSIR-NGRI has been hired as consultant to carry out geophysical studies including advance Heliborne Transient Electro Magnetic Method (Heli-TEM) to delineate multi aquifer system; to bring out the efficacy of various geophysical techniques and a protocol for use of geophysical techniques for aquifer mapping in different hydrogeological environs.

(c) Aquifer Map Preparation: On the basis of integration of data generated from various studies of hydrogeology & geophysics, aquifers have been delineated and characterized in terms of quality and potential. Various maps have been prepared bringing out Characterization of Aquifers, which can be termed as Aquifer maps providing spatial variation (lateral & vertical) with reference to aquifer extremities, quality, Ground water level, potential and vulnerability (quality & quantity).

(d) Aquifer Response Model: On the basisof aquifer characterization, issues pertaining to sustainable aquifer management in the area have been identified. Initially, a conceptual model has been developed for the pilot area and subsequently, a mathematical model has been formulated simulating the field situation, which was calibrated and validated with the field data. Various scenarios have been tested in the model to study the response of the aquifer to various stress conditions and predictive simulations have been carried out up to the year 2025.

(e) Aquifer Management Plan Formulation: Aquifer response Model has been utilized to identify a suitable strategy for sustainable development of the aquifer in the area.

1.2 Approach

The work plan for the aquifer mapping envisaged compilation, integration, validation and analysis of the entire existing database at one platform with a view to generate various thematic maps including administrative map, soil, rainfall, land use, geomorphology, geology, hydrogeology etc using geo-scientific computer softwares. Data were collected from all concerned agencies for preparing the background information and thus the status of data gap. Greater attention was paid on activities that required generation of additional data to fill the identified gap. CSIR-NGRI, Hyderabad has been hired as consultant to carry out geophysical studies using standard procedures and advanced geophysical technicques. Refinements of aquifer disposition were envisaged based on generation and integration of data.

1.3 Location

The study area is located in the western and south-western part of the Patna district, the most populous district of Bihar. Patna the capital ofBihar located on the southern bank of River Ganga is famous for its rich historical legacy and is 2nd largest city of eastern India. This city is located on the bank of river Gangaand in the region which was earlier known as Magadh region. It is the largest town & headquarters of Patna district.

The study area spreads over 521Sq Kms covering parts of seven administrative blocks (Patna Sadar, Danapur, Phulwari, Maner, Bikram, Bihta, and Naubatpur) ofPatna district, Bihar in the Middle Ganga Plain. The area lies between N latitudes $25^0$25′12″and $25^0$40′48″ and E longitudes $84^0$49′12″ and $85^0$13′12″ falling in Survey of India toposheet, 72G/2; 72C/14 and 72C/15.The location of the watershed (GDNK013) for aquifer mapping is shown in Fig. 1.1a. The distribution of the villages falling in the watershed is shown in Fig. 1.1b. Western parts of capital city Patna also falls under the Project Area. The population density of the study area is 3230 person per sq. km. The salient demographic details of the administrative blocks falling in the area and number of villages in the blocks falling under Pilot Aquifer Mapping area are given in Table 1.1a.

Table 1.1a: Demographic details of the administrative blocks falling under Pilot Aquifer Mapping area

Sl No	Block	Total Area (Sq.Km)	Population(as per 2011 census)			Area falling under Pilot Aquifer Mapping area(Sq.Km)	No. of Villages falling under aquifer mapping area
			Rural	Urban	Total		
1.	Bihta	193.92	205443 (79 %)	55984 (21%)	261427	91.52	65
2.	Bikram	148.15	147024 (87%)	22486 (13%)	169510	42.59	18
3.	Danapur	124.46	134909 (34%)	262908 (66%)	397817	71.52	27
4.	Maner	170.70	228930 (85%)	40068 (15%)	268998	42.51	31
5.	Naubatpur	167.74	178583 (88%)	25011 (12%)	203594	99.41	61
6.	Patna Sadar	156.66	83312 (4.7%)	1687828 (95.3%)	1771140	74.12	--
7.	Phulwarisarif	106.47	164829 (60.3%)	108300 (39.75)	273129	99.73	53

Fig. 1.1a: Location map of the study area

Fig. 1.1(b): Village map of the area

CHAPTER - 2
DATA AVAILABILITY & DATA GAP ANALYSIS

Data availability with respect to climatic features, soil characteristics, land use pattern, geomorphic setup, geology and various hydrogeological aspect including geophysical characteristics were compiled to identify the data gap pertaining to each items under consideration. The present chapter provides the details of data availability at the inception of the project and gap identified for fulfillment during the course of the project.

2.1 Climate

Climate records are available from the IMD database. It indicates that the watershed enjoys a typical subtropical climate. The winter season starts from the month of October and continues up to February. Summer season starts from April and continues up to mid –June. The rainy season continues from mid –June to the end of September, which receives the Southwest monsoon and accounts for about 90% of the total rainfall. The area receives an average normal monsoon rainfall of about 1100 mm/year.

2.2 Soil

Information collected from various sources indicates that soils of Patna are predominantly sandy loams with clay loam at places with low to medium nutrient status. It is generally alkaline with pH values ranging from 6.3 to 8.2. Traditionally, soils in the area are classified on the basis of mode of deposition and have accordingly been divided into two groups viz. (i) recent alluvium and (ii) older alluvium.

2.3 Land use

Land use and land cover have direct linkage to the water demand of any area. The most reliable land use statistics are available from the reports of the Agriculture Department, Government of Bihar (2009), which provides district wise information.

Out of the total geographical area of 317236 hectares of Patna district, the total cultivable area is 144551 hectares, out of which 86000 ha is under assured irrigation. The principal source of assured irrigation is by wells and tube wells, which together account for about 82 % of the total irrigation. Agriculture intensity of the district is 45.5 % and the irrigation intensity 59.5 %. The cropping intensity of the district as a whole has been found to be 126 %.

The land use data of the Patna district have been collected from the concerned department of state government. Considering Patna as a whole the total irrigated area is 86000 hectare.

2.4 Geomorphology

Physiographically, the area represents a monotonously flat topography. The topographical variation within the area indicates that the general slope is from south-west to north-east with minor variations.

The area is drained by the mighty river Ganga forming the northern boundary of the project area. Other rivers draining the area are Sone, Punpun and their tributaries. The River Ganga forms the levee or upland all along its southern bank. The area forms a part of the Sone megafan and the active channel of Sone is situated at its western side. At least 5 palaeochannels of Sone traverses the area. Unlike the active channel, the palaeochannels of Sone typically display moderate meanderings and migration at few stretches. The active East Patna Fault (EPF) lie immediately east of the area and it is suspected that another active faulted lineament lies along Bishunpur - Khagaul within the area. It has been stated that uplift along EPF and subsidence at the North/North Western part has induced avulsions in the Sone channel in discrete steps Westwards.

Interestingly within the study area, not a single stream flows northward or westward to join either Ganga or Sone. The remnants of Sone palaeochannels at patches presently serves as ‘pynes’. Depressions in the palaeochannels still form temporary water bodies.

The Ganga River, which has entrenched on to the Sone megafan, flows along the Northern boundary of the area. From Bahura, where Sone joins Ganga, up to Danapur, it is observed that channels stretches are alternatively occupied by Sone and Ganga, e.g. - the SoneRiver indicated in the survey of India topographical map (1976) has presently been occupied by Ganga River. Slope disruption in the Ganga River channel due to uplift along the Bishunpur - Khagaul Fault has created a large broad island on Ganga due to multiple channelling

Data gap

Following data gaps have been identified:

- Last ten years meteorological data.
- Soil map of the area.
- Land use landcover map.
- Geomorphological map showing different geomorphic unit present in the area.

2.5 Geology

The area forms a part of the Gangetic plain underlain by immensely thick alluvial deposits comprising sediments (sand, gravel and clay) of Quaternary age deposited unconformably over the Precambrian basement. The stratigraphic sequence of the geological formation in Patna district is published by GSI is as follows

Age	Formation
Quaternary(Pleistocene to Recent)	Newer alluvium
	Older Alluvium
---------------Unconformity------------------------	--
Archaean	Crystallines-Granites and Gneisses
	Quartzites etc.

Archaean Formation

The granites, gneisses and quartzites of Archaean age occurring in the Southern districts of Bihar state namely Munger, Nalanda and Gaya seem to extend northward up to the Ganga in Patna district and beyond are overlain unconformably by the quaternary deposits. The Quaternary deposits unconformably overlie the Precambrian basement as revealed by seismic refraction study. The thickness of the alluvial cover overlying the Precambrian basement in the area is believed to be more than 700 m.

Older Alluvium

The Older Alluvium (called Bhangar in the Ganges valley) forms slightly elevated terraces, occurs generally above the flood level. These are dark coloured and in general are rich in concretion and nodules of impure calcium carbonate known as *'kankar',* of various shapes and sizes.

Newer Alluvium

The Newer Alluvium is in general, light coloured and poor in calcareous matter. It contains lenticular beds of sand and gravel and peat beds. The newer alluvium of the area is morphostratigraphically classified as Fathua formation of Middle to Upper Holocene age. The Recent deposit of the area is classified as Diara formation. The morphostratigraphic units map on 1:50,000 for the area is shown in the fig.2.5a.

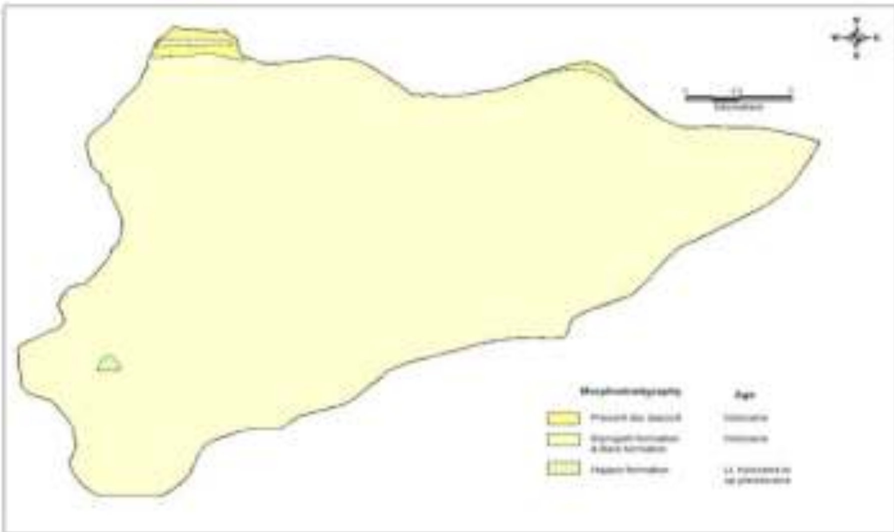


Fig 2.5 a: Morphostratigraphic units of the watershed area on 1:50,000 (Source: GSI)

The watershed is located in the central axial part of Middle Ganga Plain occupying the central part of the GangaBasin. The Ganga basin is an active foreland basin formed in response to the uplift of Himalaya due to collision of the Indian and the Asian plate. The Middle Ganga Plain lies between the Munger-Saharsa ridge in the east and Faizabad ridge in the west exhibiting an asymmetrical sediment wedge, with thickness varying from less than a meter in basin margin areas with Peninsular craton to more than 5 km near the Himalayan orogen. The area forms a part of the Gangetic plains underlain by immensely thick alluvial deposits. Delineation of aquifer geometry based on the available data reveals presence of a thick pile of alluvial sediments of Quaternary age comprising various grades of clay, silt and sand which constitutes the ground water reservoir. The entire alluvial thickness overlying the Precambrian basement in the area is expected to be over 700 m as inferred through deep seismic refraction survey in the southern part of Patna district (Fig.2.5 b).

Towards north, around Patna urban area, sharp drop in bedrock depth forming a deep trough of unconsolidated alluvium is indicated.

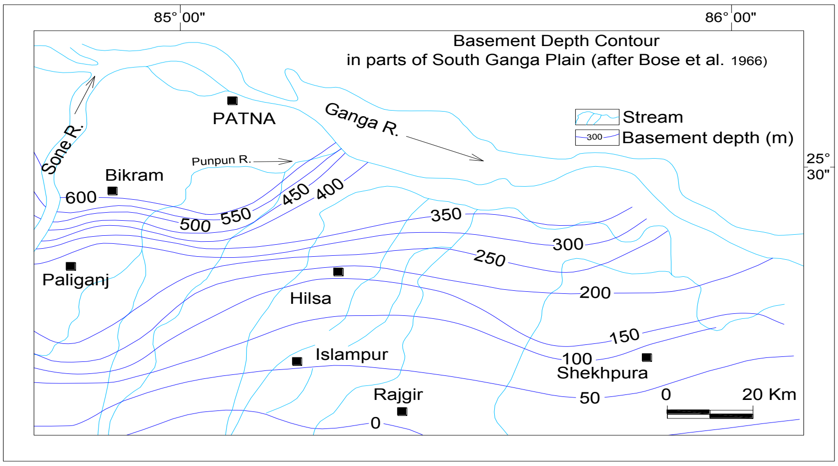


Fig 2.5 b: Basement depth contour in parts of South Ganga Plain.
(Source: Bose et al 1966)

2.6 Geophysics

Available VES data carried out by CGWB in the Pilot project area, Patna were collected to have sub surface information. The available records of the geophysical surveys carried out by CGWB comprising 23 Vertical Electrical Soundings (VES) with electrode spacing varying from 120 to 700m. These records provide information of limited depth owing to smaller electrode spacing. The information is available for a maximum depth of 133.5 m only. VES locations have been shown in Fig. 2.6a.

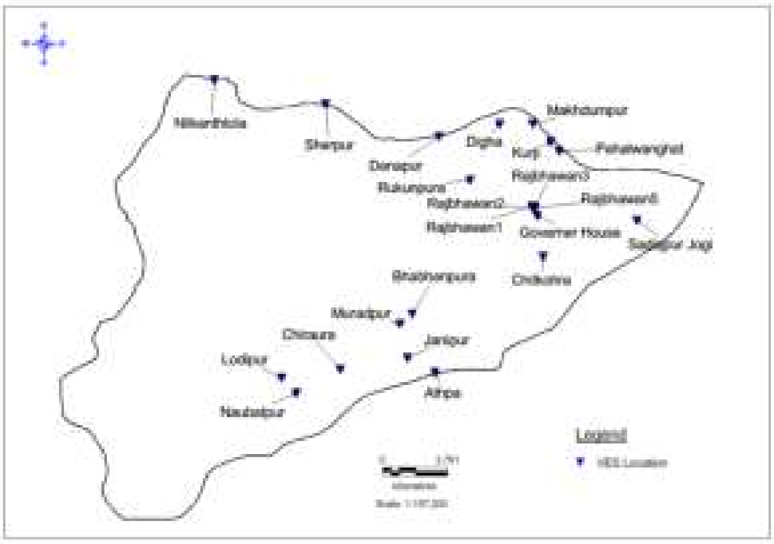


Fig. 2.6a: VES Locations at the inceptions of Pilot project

Table 2.6 (a): Location details andLayer Parameter of available VES

VES	Location	Longitude	Latitude	Individual Resistivity (ohm-m)					Individual Thickness (m)				Depth (m)	AB (m)
				ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4		
1	Lodipur	84.955634	25.512036	19	31	9	39		2.51	2.73	17.7		22.9	400
2	Naubatpur	84.964266	25.503993	62	9	73	7	50.2	1.8	1.7	5	9	17.4	400
3	Janipur	85.029109	25.522576	13	9.3	48			1.2	22			24	400
4	Athpa	85.045303	25.515137	9	65	37			21	36			58	400
5	Bhabhanpura	85.031877	25.545668	24	14	8	33		1	8	10	54	74	400
6	Muradpur	85.024824	25.540529	68	140	32	72		1	11	34		49	400
7	Chiraura	84.98997	25.516512	53	29	50	18	63	2.5	2.8	18.3	25	48.5	400
8	Makhdumpur	85.102215	25.645906	217	1946	203	648	20.3	1.2	1.26	8.31	10.9	21.7	360
9	Pahalwanghat	85.1175	25.6317	926	2430	610	19.5	111	2.03	3.9	15.1	15.2	36.3	400
10	Danapur	85.0477	25.6393	54.02	12.74	20.17			1	10.97	58.84		70.84	600
11	Sherpur	84.9812	25.6563	335.6	144.7	47.09	77.99		2.471	17.64	113.4		133.5	600
12	Nilkanthtola	84.9161	25.6692	89.5	337	154	533	54.7	1.1	2.93	9.81	18.7	32.5	700
13	Digha	85.0833	25.6458	16	350	14	450		0.8	1	3.2		5	120
14	Kurji	85.1175	25.6389	7	8.5	220			4.2	10.8			15	600
15	Rukunpura	85.0657	25.6164	10	18	16	24		2.5	5.5	27		35	500
16	Governer House	85.105	25.5978	19.4	3.3	429			1.4	1.3			2.7	120
17	SadiqpurJogi	85.1632	25.595	6	43	150	8	146	1	1.5	1	8.5	12	120
18	Chitkohra	85.1086	25.5758	5	4	160			1.4	3.6			5	120
19	Rajbhawan1	85.1022	25.6025	13	11	25	-		1	13			14	200
20	Rajbhawan2	85.1035	25.601917	16	5	12	35		1.3	5.5	26		32.8	220
21	Rajbhawan3	85.103472	25.601306	23	35	16	80		1.7	7.8	32		41.5	280
22	Rajbhawan4	85.103306	25.600278	22	110	14	75		3.6	7.2	20.1		30.9	300
23	Rajbhawan5	85.102278	25.601694	17	14	25	65		1	3.1	44		48.1	220

(Source-CGWB)

Data Gaps

Following data gap pertaining to geophysical survey (VES) has been observed:

(a) Perusal of Fig 2.6(a) indicates that VES data/ information were available only along the northern and eastern boundary of the area

(b) Table 2.6(a) indicates that the VES informations available were mainly of small spread.

From the identified data gap, the requirement for additional geophysical survey (VES) of large spread for aquifer characterization up to 300m bgl depth has been envisaged for the study area.

2.7 Sub surface lithological information

Sub-surface lithological information (> 200m, bgl) from the available drilling records of exploratory well of CGWB have been tabulated in Table 2.7a. The lithologs and e-logs of wells are given in annexure 3.5(a) and Annexure-3.5(b) respectively.

These apart, there are piezometers at three locations in the Patna urban area of which the two piezometers occur in pilot project area (Table 2.7 b).

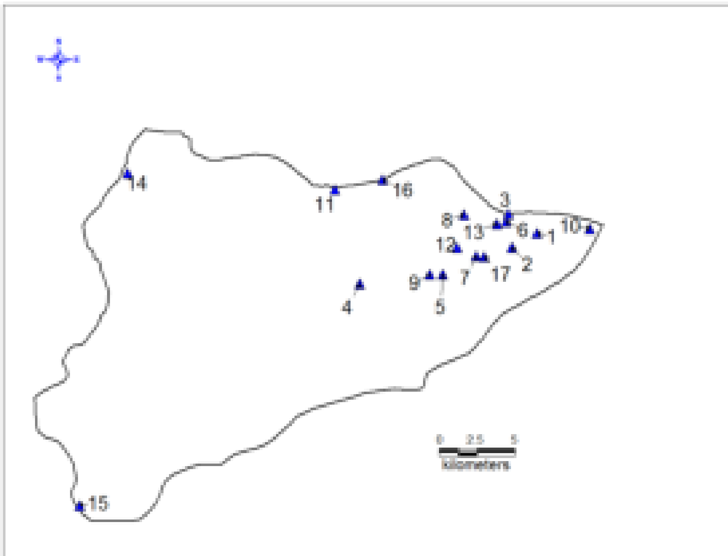


Fig 2.7 a: Locations of exploratory wells (drilled by CGWB)

Table 2.7 a: Location detail of wells drilled by CGWB

S No	Location	Longitude	Latitude	Depth drilled (m,bgl)
1	Congress Maidan	85.1585	25.6099	251.7
2	Karbighiya	85.1421	25.6013	250
3	Golghar	85.1394	25.6212	277.78
4	Khagaul	85.0414	25.5793	262.27
5	Anishabad	85.0963	25.5851	230
6	Chagubagh	85.138	25.6167	196
7	Harding Road	85.1183	25.596	245.4
8	Digha (near A.N.College)	85.1102	25.6209	225
9	PhulwariShariff	85.0875	25.5848	230.62
10	NooraniBagh	85.1937	25.6123	225

S No	Location	Longitude	Latitude	Depth drilled (m,bgl)
11	DanapurCantt	85.0247	25.6358	150.58
12	Raj Bhawan	85.1056	25.6011	162.61
13	Kidwaipur	85.132	25.6153	151.52
14	Maner	84.88767	25.64572	300
15	Bikram	84.85603	25.44667	252
16	Chaudhrana	85.05651	25.64168	192.55
17	Mithapur	85.12371	25.59549	247

Table 2.7 b: Location detail of piezometer drilled by CGWB

S. No.	Location	Longitude	Latitude	Depth drilled (m,bgl)
1	B N College	85.151428	25.621876	188
2	B V College	85.0872	25.5994	196

In addition to the CGWB data, liothlogs of 28 bore wells (fig. 2.7 b) from other agencies have also been collected, the locations detail of which are given in table 2.7c. The lithologs of these wells are given in annexure 2.7a. Perusal of table 2.7 c indicate that except five wells , the depth of these wells are mainly up to 100 m and hence providing lithological information limited to 100m bgl.

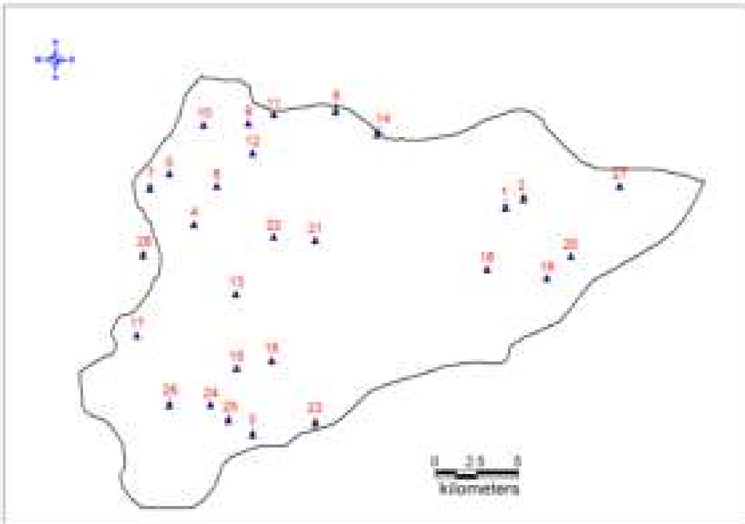


Fig 2.7 b: Location of wells from other agencies

Table 2.7 c: Location detail of bore well drilled by other agencies

S. No.	Location	Longitude	Latitude	Depth drilled (m,bgl)
1	Khajpura	85.0824	25.6007	70.4
2	Shekhpura	85.0931	25.6055	98.13
3	Dariyapur	84.9301	25.4772	99.39
4	Doghra	84.8948	25.5918	86.25
5	Madhopur	84.8801	25.6193	92.66
6	Bahpura	84.9085	25.6127	88.44
7	Anandpur	84.8683	25.611	91.2
8	Sherpur	84.9801	25.6528	93.57
9	Shadikpur	84.9276	25.6468	88.7
10	Mehdwan	84.9007	25.646	102.7
11	Darweshpur	84.9428	25.6514	101.47
12	Tilhari	84.93	25.6306	94.02
13	Gonawan	84.9202	25.554	78.5
14	Daudpur	85.0049	25.6407	96.93
15	Sarasat	84.9204	25.5137	75.6
16	Korawan	84.9416	25.5178	71.62
17	Amhara	84.86051	25.53152	102
18	Isopur	85.07114	25.56754	78.8
19	Hasanpura	85.10715	25.56239	81.8
20	Pakri	85.12186	25.57441	78.8
21	Rajpur	84.96773	25.58309	82.29
22	Ahiyapur	84.94273	25.5848	102.1
23	Abhramchak	84.96795	25.48368	80.77
24	Arap	84.90458	25.49383	77.72
25	Jagdishpur	84.91543	25.48504	97
26	Baliyari	84.88003	25.49341	80.77
27	KadamKuan	85.1512	25.6127	311.49
28	Ramnagar	84.8643	25.575	89.67

23 numbers of Vertical Electrical Soundings (VES) with current spacing of 200-600m (Fig. 2.6a) carried out by CGWB also provided insight about sub-surface lithological information for shallow depth in northern and eastern part of the area.

Data Gaps

From the above discussion, following data gaps were needed to be addressed:

- It was apparent that except two wells (one at Maner and one at Bikram) all wells drilled by CGWB are concentrated in the north and north-eastern part of the study area. These wells were constructed by tapping multiple aquifer zones.
- The liothlogs of 28 bore wells of the area collected from the state agencies are limited to only 100m depth (except one at Kadamkuan, Patna which drilled up to 311m bgl).
- VES information was not available for major part of the area and the VES were mainly of small spread.
- The objective of the project is to have a information up to 300m,bgl. It was apparent from the available sub-surface lithological information that there was data gap both in terms of space and depth.

2.8 Hydrogeology

Information regarding hydrogeology of the Project area was gathered from available literature of previous surveys of Patna district. The watershed is located in the central axial part of Middle Ganga Plain occupying the central part of the GangaBasin. The Ganga basin is an active foreland basin formed in response to the uplift of Himalaya due to collision of Indian and Asian plates. The area forms a part of the Gangetic plains underlain by immensely thick alluvial deposits. Delineation of subsurface aquifer configuration based on the available data reveals presence of a thick pile of alluvial sediments of Quaternary age comprising of various grades of clay, silt and sand. A pervasive layer of clay mixed sand constitutes the top of the succession. The presence of kankar and fine sand makes this clay layer semi pervious. The area is characterized by occurrence of fairly thick sands of various grades forming prolific aquifers.

Available data indicate presence of two aquifer system up to 250m, bgl. The deeper aquifer is made up of medium to coarse grained sand often grading to gravelly sand at the bottom.

Pumping test data of CGWB wells (Table-2.8 a and Table-2.8 b) indicate that the transmissivity values of the aquifers ranges between 4907and 15984 m^2day^{-1} with a mean of 8302 m^2day^{-1} indicating significant potentiality of the deeper aquifer. The specific capacity of the wells ranges from 56 to 100.4 $m^3hr^{-1}m^{-1}$ and the mean hydraulic conductivity (K) has been found as 86.9 m day^{-1} corresponding to that of coarse sand and coarse sand mixed with gravel. At two locations, A.N.College and Alamganj, the storage coefficient has been determined as 7.7 $x10^{-2}$ and $5.0x10^{-3}$ respectively indicating that the deeper aquifer remains in semi-confined condition because of the overlying aquitard zone.

Table 2.8 a: Summarized salient characteristic of the exploratory wells drilled by CGWB in the project area

S.No	Location	Depth drilled (m bgl)	Depth range of tapped Granular zones (m)	Discharge (m^3/hr.)	Draw down (m)	Transmissivity (m^2/day)	Storativity
1	Congress Maidan	251.7	105-213	224	4	5892	NA
2	Mithapur	215.31	080-188	125	2.5	NA	NA
3	Karbigahiya	250.64	068-209	176.2	2.88	8057	NA
4	Golghar	277.9	074-166	193.04	2.49	14113	NA
5	Khagaul	262.27	065-122	222.56	3.7	7000	NA
6	Anisabad	219.08	085-166	193.4	2.37	6621	NA
7	Chajjubagh	196	075-161	194.62	2.7	7114.64	NA
8	Harding Road	245.4	073-200	222.3	2.21	6820	NA
9	Chaudharana	190.32	085-173	211.43	2.9	15479	NA
10	A.N.College	225	093-181	208.93	2.15	7068	7.7 $x10^{-2}$
11	Phulwarisharif	230.62	056-162	179.63	2.46	7894.56	NA
12	Alamganj	225	076-160	180	0.58	9882.9	5 x 10^{-3}
13	Maner	300	80-170	188.7	2.67	9735.12	4.46 x 10^{-4}

Table 2.8 b: Hydrogeological details of Tube wells constructed by CGWB under deposit well program (1980-81)

Sl. No.	Location	Depth of Tw(m)	Depth range of tapped Granular zones (m)	Depth to static Ground water level (m bgl)	Discharge (m^3/hr)	DD (m)	Transmissivity (m^2/day)
1	Kadamkuan defence account building, Patna	117	55-80 82-107	8.23	112.3	1.36	4982
2	Kidwaipuri, P&T Building, Patna	138	49-78 85-135	6.70	237	3.10	4907
3	Rajbhawan, Patna	152	76-102 118-150	7.69	271.3	3.22	6989
4	Danapur cantonment, Patna	136	61-106 109-133	6.25	209	2.08	15984

In addition, the yield potential of the state tube wells, depth within110 m bgl (Table-2.8 c) constructed in the western and south-western part of the watershed area (Bihta, Maner and Naubatpur block) indicate that discharge of deeper aquifer varies from 159 to 222 m^3/hr for a drawdown of ~3.50 m indicating significant yield potential.

Table 2.8 c: Summarized salient characteristics of bore wells drilled in the area by State Govt. Department

Name of the Block	Depth of TW (m)	Discharge (m^3/hr.)	Drawdown (m)
Bihta	88.39 – 102.11	179 - 222	1.52 – 8
Maner	106.66 – 109.72	208	1.80 – 3.5
Naubatpur	88.39 – 103.63	208	1.52 – 3.65

Data Gaps

Following data gap have been observed:

- Aquifer characterisation
- Aquifer wise hydraulic parameters: The hydraulic parameters available from the pumping test of CGWB wells provide information of aquifers resting mainly in the northern and north-eastern part of the area. However, these wells were constructed by tapping multiple aquifers. The parameters of the individual aquifers are required.
- Aquifer-wise groundwater levels are not available. These are required for water table contour map of respective aquifer.

2.9 Aquifer disposition

The subsurface configuration of aquifer has been delineated based on available lithological logs of CGWB and State agencies along with interpreted records from VES survey. Several sections along different orientation have been prepared to depict aquifer geometry. The lithologs and the geophysical logs reveal the presence of a thick pile of alluvial sediments with alternating sequence of various grades of sand with clay and silt. The strip logs of 11 locations are shown in Fig.2.9 (a) revealing the thick granular zone encountered in the study area.

2.9.1 Aquifer disposition in the eastern part of the watershed around Patna urban area

The lithological logs of CGWB wells are shown in Fig 2.9 (a). Study of lithologs reveals occurrence of persistent sandy clay capping with thickness reaching up to 60 m from the ground level at places. The cumulative aquifer thickness up to the maximum explored depth of 300 m at some locations even reaches to 250 m.

A pervasive layer of clay with or without Kankar constitutes the top of the succession. Study of the lithologs of deep boreholes drilled by CGWB indicate that there are mainly 2 aquifer system (up to depth of 200m) separated by lenticular beds of clay ranging in thickness from 3m to 20m. The deeper aquifer which occurs below the intervening aquitard layer is made up of medium to coarse grained sand often grading to gravelly sand at the bottom. Fence diagram of the north-eastern part of the watershed depicting the 2 layered aquifer system is shown in Fig 2.9b.

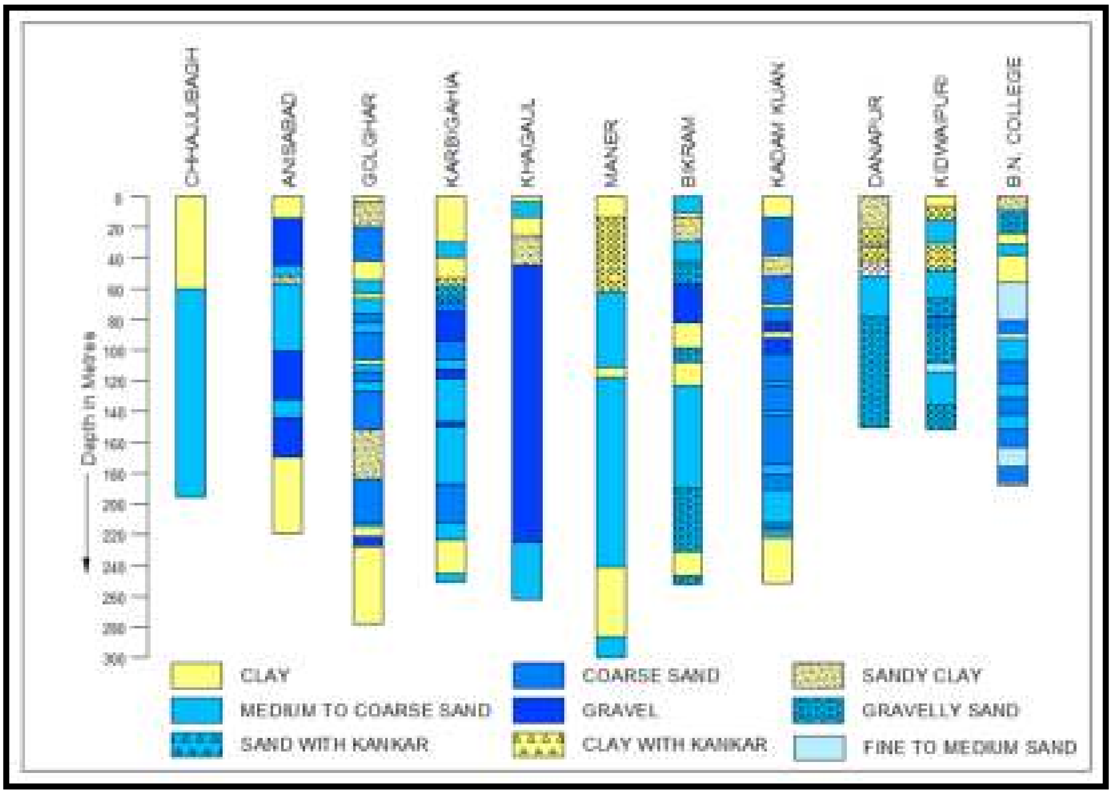


Figure 2.9 a: Lithologs of exploratory wells and piezometers drilled by CGWB

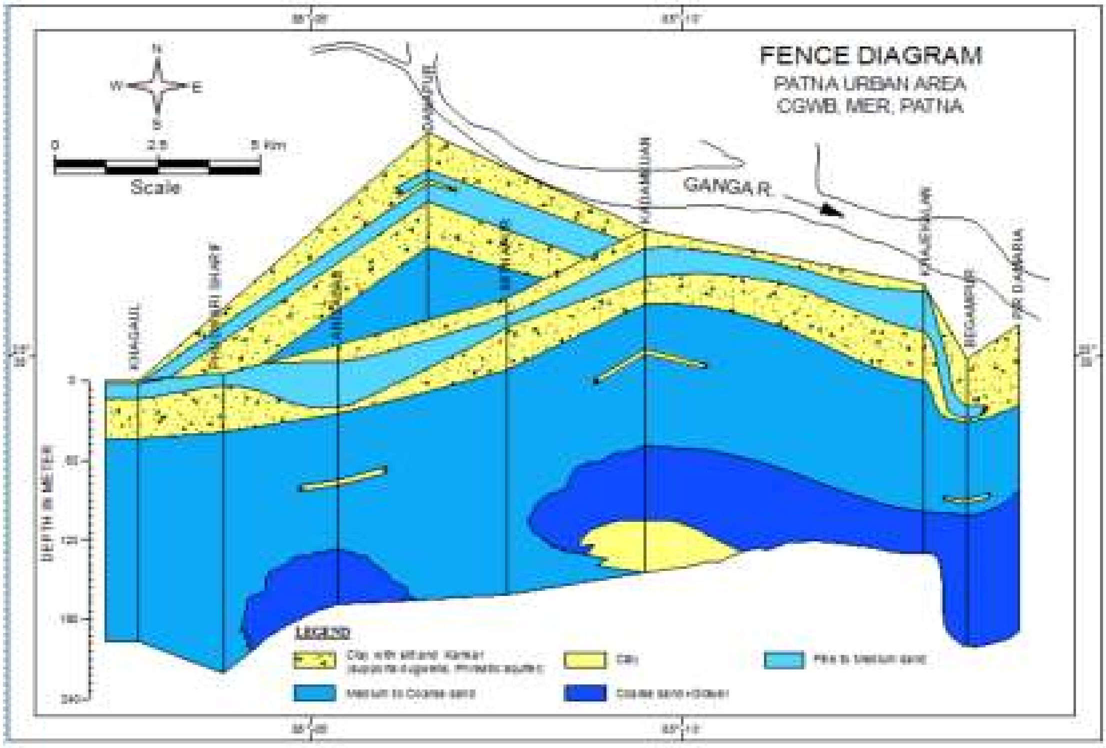


Figure 2.9 b: Fence diagram of the north-eastern part of the watershed (based on CGWB wells)

2.9.2 Aquifers in SW part of the area (Section DD')

The lithological log of borehole drilled by CGWB up to 252 m depth at extreme SW of the area at Bikram) indicate mainly three aquifers up to depth of 250m.

2.9.3 Aquifer disposition

Aquifer disposition have been studied based on the lithological section prepared along profile AA'. BB' CC' and DD' (fig2.9 c). These sections have been prepared on the basis of available information of litholog data and VES.

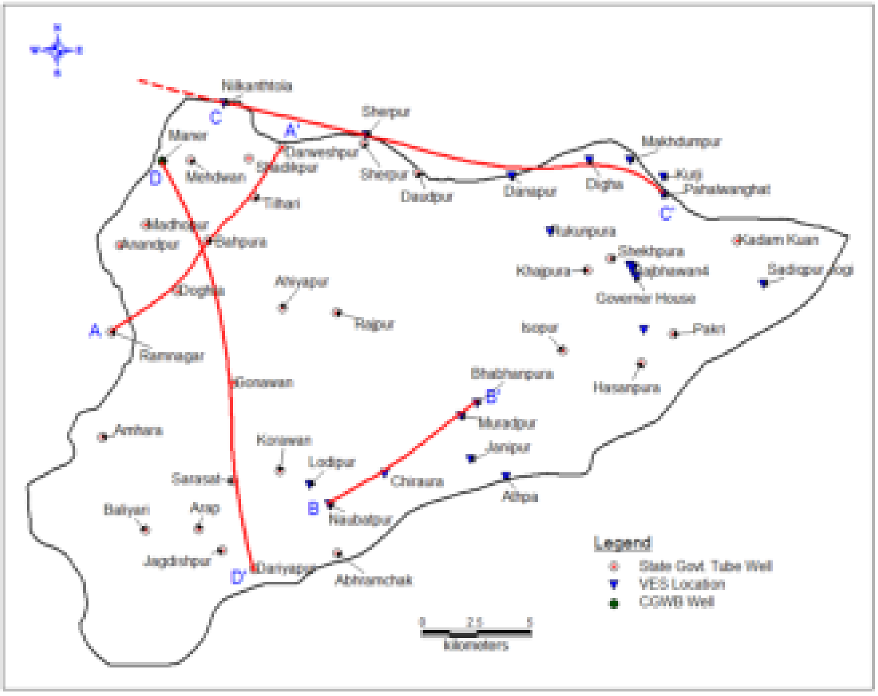


Fig. 2.9 c: Map showing profiles along which lithological sections prepared

(a) Aquifer disposition along profile AA'

Lithological section of about 12 km prepared along Ramnagar -Bahpura-Telhari-Darveshpur (profile AA') in NE-SW direction (based on boreholes data of wells constructed by state govt.) revealed the aquifer disposition up to 100m depth (Fig 2.9 d). It revealed top clay capping from the ground level to a depth varying from 5 m to 46 m and almost mono-aquifer system made up of medium to coarse grained sand commencing below this top layer, except in SW part there is intervening clay layer at about75m. The top layer is highly mixed (clay and sand layer) behaving like an aquitard layer.

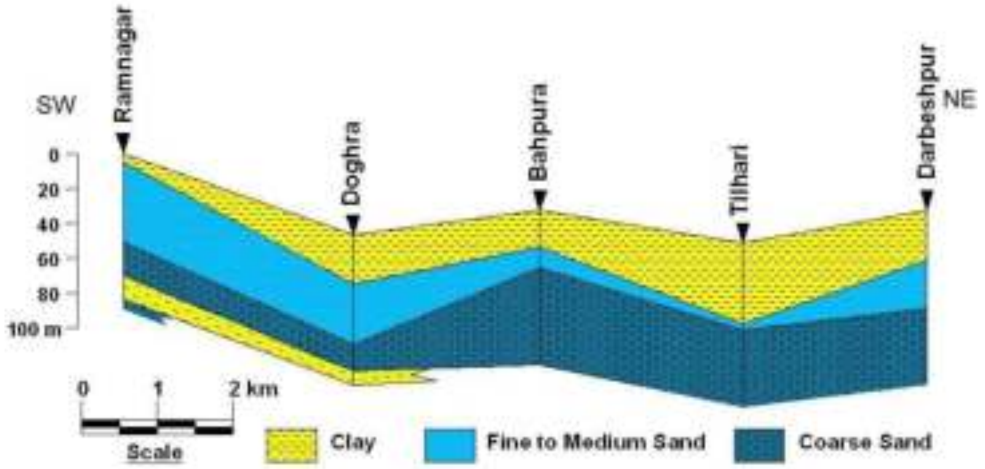


Fig. 2.9 d: Aquifer disposition along profile AA'

(b) Aquifer disposition along profile BB'(based on VES data)

Lithological section (N-S) (based on sounding results) along BB' revealed sub- surface information along the south eastern part of the project area (fig 2.9e). The maximum current electrode spacing (AB) was taken 400 m.The top soil layer thickness varies along the entire section. The second layer thickness also varies from Naubatpur to Bhabhanpura. The resistivity of the second layer varies between 11 and 152 ohm.m due to presence of clay and clay mixed with kankar. The resistivity of the last layer varied between 35 and 46 ohm.m and thus revealed the presence of medium to coarse sand.

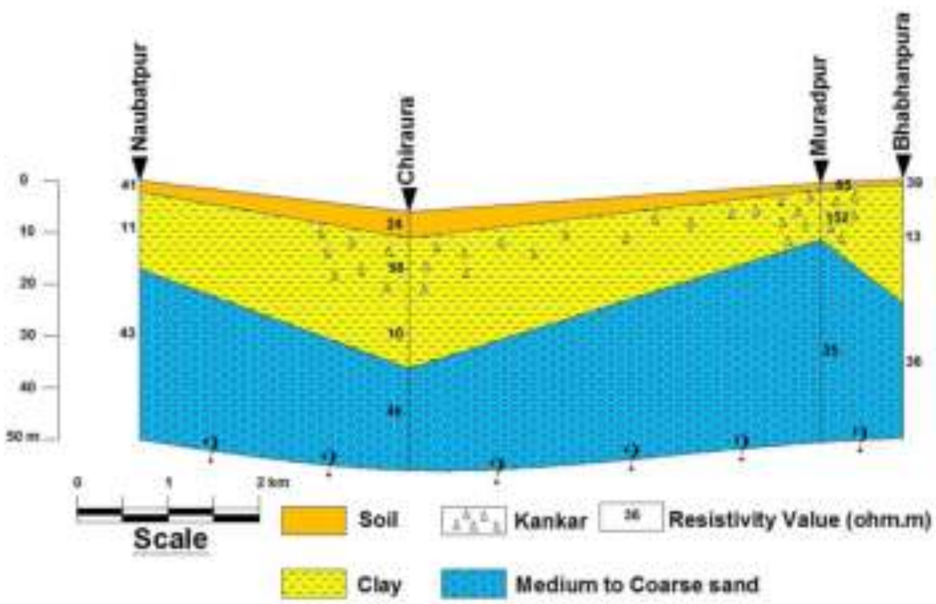


Figure 2.9 e: Aquifer disposition along profile BB'

(c) Aquifer disposition along profile CC'

Lithological section based on sounding results revealed subsurface information upto 80mbgl along the river in the east–west direction of the watershed (Fig.2.9 f). The maximum current electrode spacing (AB) was taken 500 m. It has revealed that there is a top soil layer and its thickness varies from Pahalwanghat to Haldichapra. Section indicates that there is persistent clay capping of variable thickness. The thickness of clay admixed with fine sand increases towards eastern direction of the section where it is about 60 m thick. Patches of unsaturated sand have been also encountered. Below the clay layer medium to coarse sand is observed.

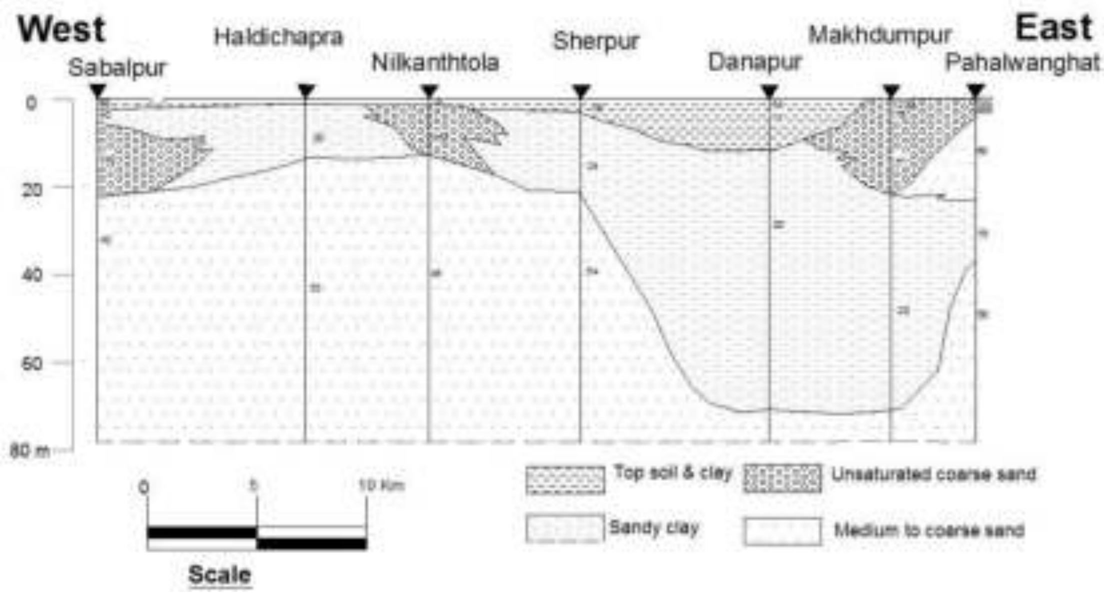


Figure 2.9f: Aquifer disposition along profile CC'

(d) Aquifer disposition along DD'

lithological section (prepared based on boreholes data of wells by state govt. and one well constructed by CGWB at Maner) along profile DD' revealed the sub surface information and aquifer disposition along Maner- Bahpura- Gonwan- Sarasat - Dariapur (fig.2.9 g) in N-S direction of about 20 km..

Section revealed clay capping from the ground level to a depth varying from 20 m to 60 m and single aquifer system made up of medium to coarse grained sand commencing below this layer up to about 100m. The litholog of Maner is up to depth of 300m bgl.

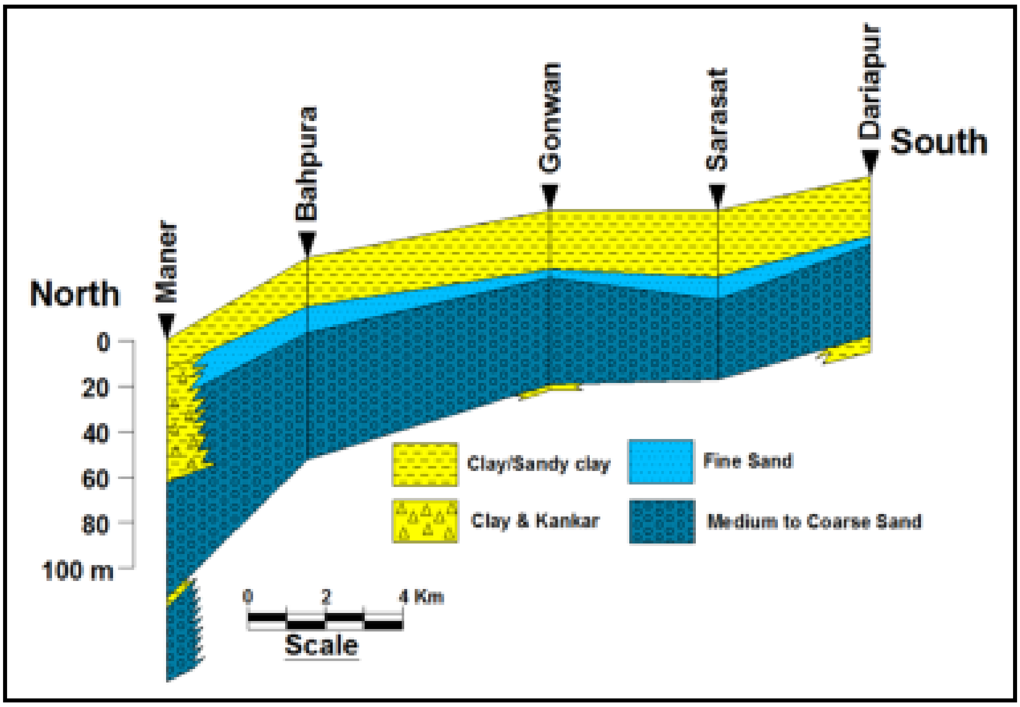


Figure 2.9 g: Aquifer disposition along profile DD'

Data Gaps

It was apparent that except the Lithological information from wells drilled by CGWB, the lithological information from other resource is available mainly upto 100 m, bgl. The Lithological information from wells drilled by CGWB were mainly confined into north and north-eastern part of the pilot project area .Hence The aquifer disposition below depth of 100 m from ground surface could not be ascertained due to non availability of data below this depth over the entire area. The objective of the project is to have information about aquifer disposition and its characterisation of the northern, western and southern part of project area up to 300m, bgl.

2.10 Ground water level

The groundwater occurs under water table condition near surface and occurs under semi-confined to confined condition at deeper level.

Ground water level behavior

Within the pilot project area, CGWB was measuring groundwater level at two groundwater monitoring stations (HNS) which are dug wells tapping the shallow aquifer and 10 piezometers tapping the deeper aquifers (Fig. 2.10a).

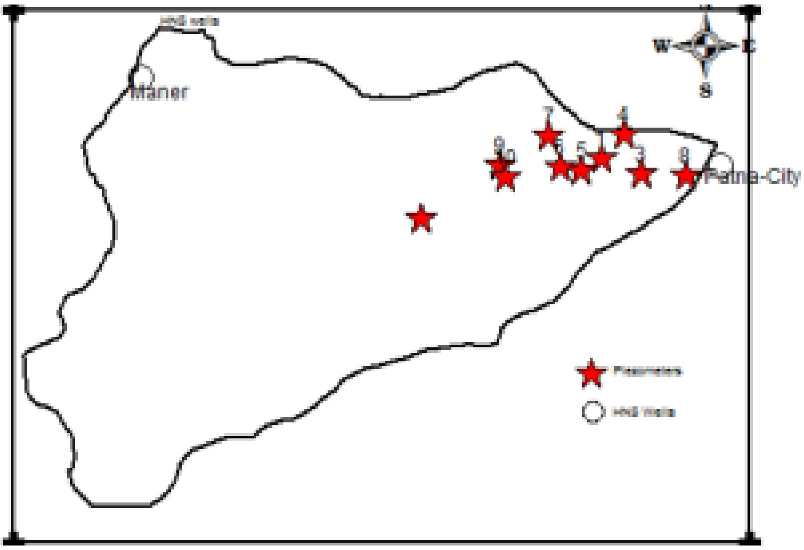


Figure 2.10 a: Location map of piezometers and HNS wells

The long term groundwater level trend of the shallow aquifer (HNS well) at Maner located in the peri-urban part shows a falling trend both during the pre-and the post-monsoon periods. However, the same for the HNS well at Patna city located within the urban part shows an almost stable trend for the post-monsoon season and a modest falling trend for the pre-monsoon season (Fig 2.10 b).

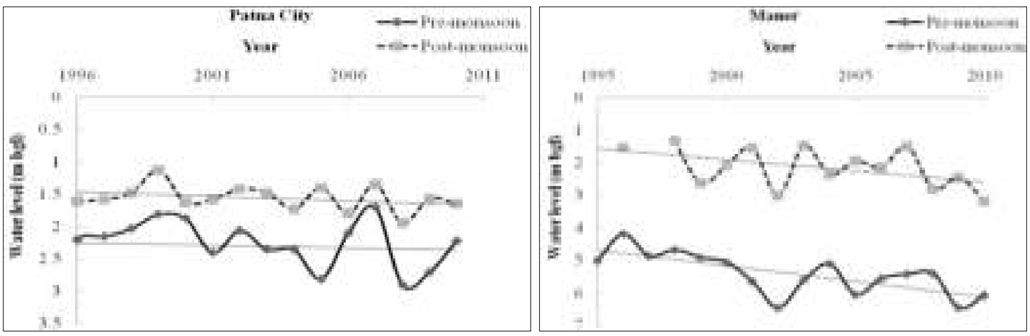


Fig 2.10 b: Long term groundwater level trend of shallow aquifer

Long term trend of the piezometric level of the deeper aquifer in the watershed area was not available. Systematic monitoring of the piezometric level of the deeper aquifer has commenced since June 2008.

Data Gap

- It was apparent that there were paucity of groundwater level data of project area. Within the pilot project area, there are only two ground water monitoring stations (HNS) (dug wells tapping the shallow aquifer) and 10 piezometers tapping the deeper aquifers.

- The groundwater level data of deeper aquifer were confined within the Patna urban area.
- Aquiferwise groundwater level data were not available.

2.11 Water quality

The historical chemical quality data of groundwater from different depths (dug wells, hand pumps and bore wells/ tube wells) of the project area has been collected and analyzed to get the idea of chemical quality variation in different aquifer. The chemical constituents available for the study are: pH, EC, TH, CO_3, HCO_3, NO_3, Na, K, SO_4, Fe & Mg.

2.11.1 Chemical characteristics of ground water (top aquitard layer)

The ranges of chemical parameters of groundwater of dug well /hand pump tapping top aquitard layer are given in Table 2.11 a. These samples locations were mainly confined in the Patna sadar, Phulwari and Danapur block.

Table 2.11 (a): Salient statistical details of the chemical parameters of top aquitard

Parameter	Concentration in ground water of Pilot aquifer mapping area		
	Max	Min	Average
pH	8	6.8	7.42
E.C (µmho/cm at 25^0C)	3050	260	825
TH as $CaCO_3$ (mg/l)	875	95	262
CO_3 (mg/l)	18	12	15
HCO_3 (mg/l)	1010	134	304
Chloride (mg/l)	461	7.1	84.60
Iron (mg/l)	0.6	0.04	0.19
Calcium (mg/l)	120	12	36
Magnesium (mg/l)	137	2.4	30.14
Sodium (mg/l)	250	15	69.38
Potassium (mg/l)	75	0.7	6.88

Perusal of Table 2.11 (a) revealed that the groundwater quality of top aquitard layer is suitable for driking and irrigation purposes. pH of the groundwater varied from 6.8-8 with average value of 7.42. In general, pH was neutral to slightly alkaline in trend. The EC of the groundwater varied from 260 to 3050 µS/cm with an average value of 825. Concentration of Ca and Mg is found within the highest permissible limits. TH values varied from 95 to 875 mg/l. The average value for TH was 262 mg/l. HCO3 was the dominant anions with a mean value of 304 mg/l. The chloride concentration varied between 71 and 461 mg/l. No data were available for sulphate, nitrate and fluoride.

2.11.2 Chemical characteristics of ground water (tube well tapping deeper aquifer)

The chemical quality data of groundwater of deep tubewell constructed by CGWB and other agencies (tapping multiple aquifers) falling in the Patna sadar, Danapur, Maner and Phulwarisarif block of Patna district were studied. These samples locations were mainly confined in the Patna sadar, Phulwari and Danapur block. Maximum, minimum and average concentrations of various parameters for deeper aquifers are given below (Table 2.11b).

Table 2.11b: Groundwater suitability for drinking purposes (deeper aquifer)

PARAMETER	Concentration in ground water of Pilot aquifer mapping area		
	Max	Min	Average
pH	8.52	7.0	7.7
E.C (µS/cm at 25^0C)	703	301	491
TDS(mg/l)	450	296	348
TH as $CaCO_3$ (mg/l)	260	95	184
Dissolved CO_2 (mg/l)	27.58	14.75	20.4
CO_3 (mg/l)	166	0	65
HCO_3 (mg/l)	580	67	29
SiO_2 (mg/l)	40	4	16.6
NO_3 (mg/l)	1.2	0.06	0.54
Chloride (mg/l)	34	4	12
SO_4 (mg/l)	40	1.9	18
Phosphate (mg/l)	0.16	0.04	0.08
Iron (mg/l)	0.20	0.02	0.07
Calcium (mg/l)	80	10	49
Magnesium (mg/l)	32	1.9	4.4
Sodium (mg/l)	30	12	23
Potassium (mg/l)	2.3	1.6	1.87

`

The study of the Table 2.11b revealed that, the pH of the groundwater of deeper aquifers are marginally alkaline and varied from 7-8.52 with average value of 7.7. EC with average value of 491 varied from 301 to 703µS/cm. The deeper groundwater is less mineralized than the shallow groundwater. Average concentration of Ca and Mg is found 49.3 and 14.40 mg/l respectively. TH values varied from 95 to 260mg/l. The average value for TH is 184 mg/l. The chloride concentration varied between 4 and 34 mg/l with average value of 12 mg/l. The average concentration of sulphate, nitrate and silicate are 18, 0.54 and 16.6 mg/l respectively.

It has been observed that the ground quality of deeper aquifer were also suitable for driking and irrigation purposes.

2.11.3 Ground water quality problem in the watershed

The major issue in the area is groundwater quality problem. High arsenic level in groundwater (> 50 ppb) was reprted by PHED, Govt. of Bihar in northern part of Maner, Danapur/Khagaul aligning the old and present course of the River Ganga and the river Sone. Analysis of groundwater sample by CGWB also revealed arsenic contamination in ground water adjacent to theproject area. One of the most widely discussed arsenic affected villages in Bihar is Haldi Chapra which is located just beyond the north-western part of the watershed and is about 7-10 km from Maner town. The interesting part of the arsenic contamination is the patchiness in arsenic distribution and wide spatial variability in their concentration.

Data Gaps

From the above discussion it is apparent that

- Groundwater quality data of shallow as well as deeper aquifer was available only for the small part of the watershed which extends over the Patna urban area.
- Groundwater quality data of deeper aquifer was from wells constructed by tapping multiple aquifers. Hence Aquifer wise water quality was not available.
- In most of the data all major parameters were not available .More and more data on arsenic concentration in groundwater of different aquifers were required.
- The environmental stable and radioactive isotope study of the groundwater samples of different aquifers in conjunction with the surface water and rain water were not available to account for the groundwater sources, its age, travel times, and flow paths and to determine the path and extent of contaminant movement in the water. The $\delta_{18}O$ & δD may be used to determine the recharge

location for a groundwater and to account for the water sources within the aquifer.

2.12 Recharge parameters

Recharge parameters indicate the rainfall, vertical hydraulic conductivity of the top layer and infiltration characteristic. Infiltration of precipitation probably accounts for the largest amount of recharge. Vertical hydraulic conductivity is a function of geology and lithology. Hence, surfacial geologic units are likely to represent a reasonable initial distribution of recharge. Though configuration of top layers were available for the limited part of the area, more detail about this for entire area were required to assign a reasonable initial distribution of recharge .

Data gap

Data gap observed were:

- Infiltration rate of the top soils
- Rainfall data
- River stage data
- Configuration of top layer present in the area
- Natural inflow
- Recharge through irrigation wells.
- Isotope analysis to know the source of recharge.

2.13 Discharge parameters

The main discharge input is the ground water pumping from the area within the project area. MI census data of the area was available. Records of pumping from the municipal corporation were also available.

Data gap

Data gap observed were:

- Pumping from wells
- Natural outflow
- Evapotranspiration

Map showing data availability and data gap in the area is given in fig. 2.11.Table 2.12 indicate the data availability at the inception of project and data generated during the project. Data generated during the project are described in chapter -3.

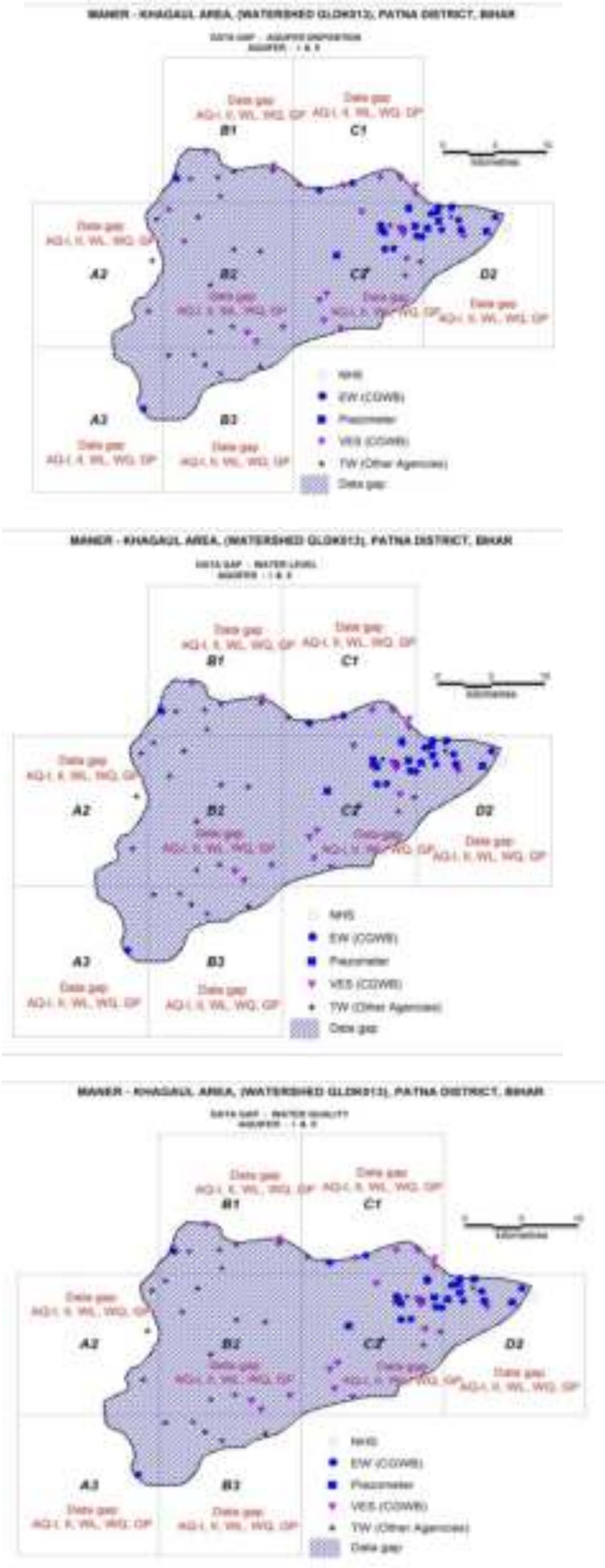


Fig 2.11: Map showing data availability and data gap in the area

Table 2.12: Data availability, data gap analysis and data generated, Maner –Khagaul area, Patna, Bihar (GNDK-013)

Sl. No.	Items	Data available	Data generated	Requirement
1	Groundwater Monitoring Stations	2 dug wells and 10 piezometer	50 dug well for aquitard layer, 19 for aquifer-1 and 7 for aquifer- 2	52 dug well for aquitard, 19 for aquifer-1 & 17 for aquifer-2
2	Groundwater Quality	from old literature	25 samples from dug well (aquitard layer), 42 samples from aquifer-1 and 14 samples from aquifer -2 for complete analysis, 128 samples from different aquifer for arsenic and iron analysis 42 samples for uranium analysis	25 samples from dug well (aquitard layer), 42 samples from aquifer-1 and 14 samples from aquifer-2 for complete analysis, 128 samples from different aquifer for arsenic and iron analysis 42 samples for uranium analysis
3	Geophysical Survey	23 VES (AB - 120 to 700m)	26 VES (AB - 1000m) by CGWB, 72 VES (AB -3000 m), 101 TEM, 8.32 l.km ERT, SKY-TEM (52 sq. km, out 521 sq.km of the project area) by NGRI, Hyderabad	72 VES101 TEM, 8.32 l.km ERT, and SKY-TEM in the area
4	Infiltration Test	Not available	17	17
5	Isotope analysis	Not available	35 from aquifer-1, 9 from aquifer-2 , 6 from surface water, 4 rain water	35 from aquifer-1, 9 from aquifer-2 , 6 from surface water, 4 rain water
6	Landuse/Land cover	Not available	Collected from state government and generated through image	--
7	Geomorphology	Not available	Generated through image	-
8	Exploration	19 (CGWB) confined mainly	16 wells constructed	35

Sl. No.	Items	Data available	Data generated	Requirement
	data	in NE part of area & 28 (from other agencies) maily up to depth of 100m bgl	at six location	

CHAPTER- 3

DATA GENERATION

3.1 Climate and rainfall

The 10 year monthly, annual rainfall and temperature data were collected from IMD, Patna and analysed. The rain gauge station is at Patna airport campus.

The rainy season continues from mid –June to the end of September, which receives South-west monsoon and accounts for about 87% of the total annual rainfall. The area receives an average normal monsoon rainfall of about 1187 mm/year.The table 3.1a shows annual monthly rainfall of last ten year (2003 to 2012). The ten year annual rainfall has been graphically shown in fig 3.1a

Table 3.1 a: Monthly Rainfall Data of Patna (in mm)
(Source: IMD, Patna)

Year	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec	Annual
2003	17.2	59.4	0.1	22.8	0	337.8	264.1	184.0	139.4	132.6	0	1.6	1159.0
2004	32.3	4.1	0.0	24.3	36.2	205.0	230.0	275.2	50.3	6.4	0	0.8	864.6
2005	22.4	29	4.4	1.2	14.7	31.5	405.7	190.8	67.1	40.3	0	0	807.1
2006	0	0	0	21	28.9	249.6	358.8	239.7	209.3	0	6.5	0	1113.8
2007	0	41.1	69	8.8	59.6	834.6	614	421.3	371.7	14.5	0	0	2434.6
2008	43.4	7.9	0	38.4	74.8	487.4	500.1	488	238.3	3.6	0	0	1881.9
2009	0	0	0	0	73	94.3	125.5	295.2	178.3	61.3	2.9	5.2	835.7
2010	0	21	0	0	81.9	45.2	215.2	229.4	112.9	96	0.5	0	802.1
2011	0.5	3.4	11.5	20.3	55.4	285.2	103.4	182.4	294.7	2.5	0	0	959.3
2012	11.9	0.8	5.7	8.6	0	24.6	385.9	292.6	231.5	47.3	0	-	1008.9
												AVERAGE	1187

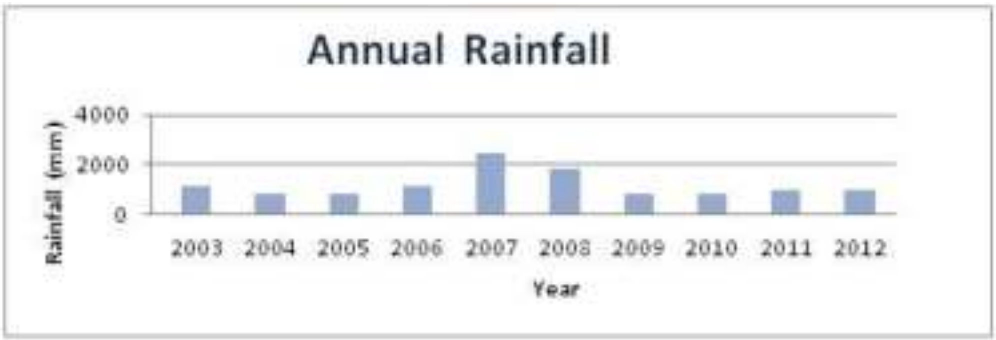


Fig 3.1a: Annual rainfall of Patna (raingauge at Patna airport)

Ten years average rainy days in the Patna are 79, out of which 62 rainy days occur during monsoon month, which is nearly 78% of the total rainy days. Month wise numbers of rainy days of last ten years are given in table 3.1b.

Table 3.1 b: Month-wise number of rainy days of last ten years

Year	Jan	Feb	Mar	Apr	May	June	July	August	September	October	November	December	Annual
2003	2	5	1	3	0	14	18	18	19	9	0	1	90
2004	3	1	0	2	4	16	17	22	9	3	0	1	78
2005	5	6	3	1`	3	6	22	17	10	6	0	0	78
2006	0	0	2	1	6	10	14	18	14	0	1	0	66
2007	0	5	6	2	7	9	22	21	18	4	0	0	94
2008	3	2	0	3	6	18	28	20	15	1	0	0	96
2009	0	0	0	0	9	7	19	19	9	5	2	1	71
2010	1	3	0	0	7	7	12	11	11	9	2	0	63
2011	1	3	3	3	4	11	15	17	18	3	0	0	78
2012	5	1	2	3	0	7	23	15	13	2	0	0	71
Average	2	3	2	2	5	11	19	18	14	4	1	0	79

3.2 Soil

Soils of the study area are predominantly sandy loams with clay loam at places with low to medium nutrients status. It is generally alkaline with pH values ranging from 6.3 to 8.2. Traditionally, soils in the area are classified on the basis of mode of deposition and have accordingly been divided into two groups' viz. (i) recent alluvium and (ii) older alluvium. The soil map of the Patna district is shown in fig 3.2a (source: Sabour Agriculture College)

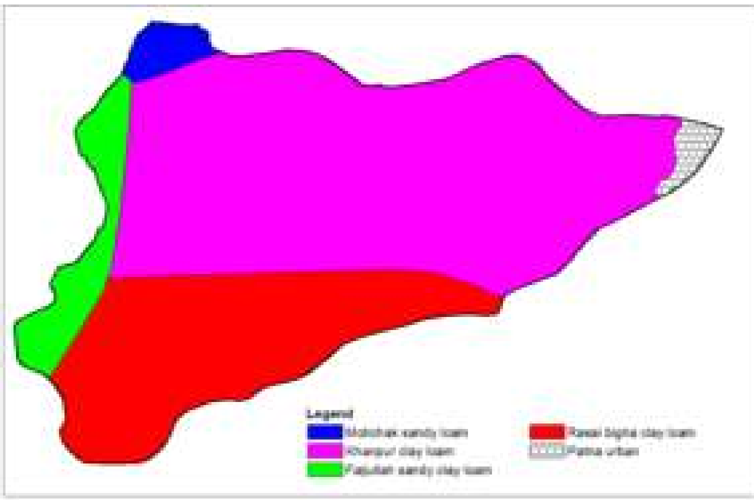


Fig 3.2a: Soil map of the Pilot Aquifer Mapping Area, Patna
(Source: Agriculture College Sabour, Bhagalpur, Bihar)

The soils map of the Patna district collected from AgricultureCollege, Sabour were studied for the area under Pilot aquifer mapping area of this district. Soils found under the different lithological regions are:

(a)MotichakSl/SSi, upland to medium upland, 0-3% slope, welldrained, pH-7.8 and flooded. It is in the northen part of Maner and Danapur block of the area.

(b)Khanpur clay loam, very deep, poorly drained, angular blocky, vertic characters, 0-3 % slope, smectite clay mineral, pH-7.7, iron-mangnese along with calcium carbonate nodules found in lower horizons. This soil type covers Patna sadar, Phulwari to southern part of Maner, Danapur and northen part of Naubatpur block.

(c)Faijullah sandy loam, very deep, granular, moderately drained, medium upland, 0-3% slope, pH-7.5, slightly effervescence with dilute Hcl, clear and smooth lower boundary. This type of soil occurs in the wester part of the area.

(d) RasaiBigha clay loam, very deep, ang. Blocky, 0--3 % slope, pH-7.3, no effervescence with dil. Hcl, clear and smooth lower boundary. This type of soil is in the southern part of the area (falling in the Naubatpur and BikramBlock)

The soils of the project area are moderately well drained to somewhat poorly drained, moderately acidic to slightly alkaline and medium textured to heavy textured soils. The soils of paddy lands have developed impervious layer of varying thickness and imperviousness varies from simple semi developed somewhat porous clay pans to practically very hard impervious thick layers with slickenside. The soils are poor to moderate in nitrogen and poor to moderately rich in available phosphorus and potash. The soils of medium low to low lands are comparatively more fertile.

3.2.1 Soil infiltration rate

Infiltration tests with falling head method were conducted across the area at 17locations using double ring infiltrometer (fig 3.2 b and c) in barren land of different soil types within Pilot Aquifer mapping area, Patna. The soil types encountered in the sites are clay, silt and sandy clay. The details of Location of test for Infiltration rate is given in table 3.2 a.

Fig 3.2 b : Infiltration rate test conducted in the field

The test was conducted for duration varying from of 80 to 150 minutes. In clayey soil, initial infiltration rate varied from 3 to 15 cm/hr and final infiltration rate was in the range of 0.2 to 0.6 cm/hr. In sandy clay, initial infiltration rate varied from 15 to 30cm/hr and final infiltration rate was in the range of 0.2 to 0.6 cm/hr and in Sandy soil, initial infiltration rate was in the range of 21- 45 cm/hr and final infiltration rate in the range of 0.2 to 0.4 cm/hr.Infiltration rates estimated from the tests conducted may be used in categorisation of soils from an irrigation point of view. Summary of results of infiltration test is given in table 3.2 b.

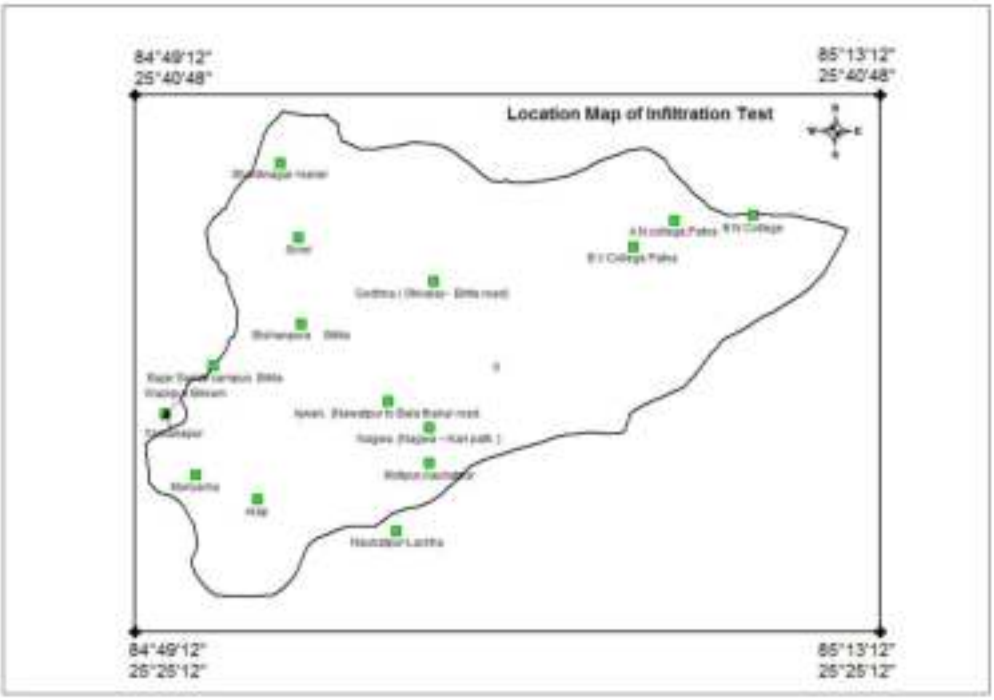


Fig 3.2 C: Map showing Infiltration test locations

Table 3.2 (a) Details of Location of Infiltration ratetest

Sl. No.	Site	Location	Landuse	Lattitude	Longitude
1	Yamanapur	Yamanapur	Barren land	25.52567	84.83585
2	WazirpurBikram	WazirpurBikram	Barren land	25.52567	84.83585
3	Shantinagar maner	Shantinagar maner	Barren land	25.64689	84.89811
4	Nagwa. [Nagwa – Kari path.]	Nagwa. [Nagwa – Kari path.]	Barren land	25.51907	84.97753
5	Godhna (Shivalay-Bihta road)	Godhna (Shivalay-Bihta road)	Barren land	25.58967	84.98
6	Brahampur Bazar	Brahampur Bazar	Barren land	25.55199	84.06911
7	Bishanpura Bihta	Bishanpura Bihta	Barren land	25.56921	84.90914
8	B V College Patna	B V College Patna	Barren land	25.60639	85.08742
9	Ajwan, [Nawatpur to Bala thakur road.	Ajwan, [Nawatpur to Bala thakur road.	Barren land	25.53158	84.95567
10	A.N.college,Patna	A.N.college,Patna	Barren land	25.61928	85.10939
11	Moriyama	Moriyama	Barren land	25.49625	84.85234
12	Simri	Simri	Barren land	25.61064	84.90764
13	Naubatpur-Lackha	Naubatpur-Lackha	Barren land	25.46885	84.96022
14	Arap	Arap	Barren land	25.48417	84.88578
15	Motipur,naubatpur	Motipur,naubatpur	Barren land	25.50195	84.97783
16	BajarSamiti campus Bihta	BajarSamiti campus Bihta	Barren land	25.54886	84.862
17	B.N.college	B.N.college	Barren land	25.62188	85.15143

Table 3.2(b) Summary of results of infiltration test

Sl.No.	Loaction	Type of Soil	Duration of test(m)	Initial Infiltration rate (cm/hr)	Final Infiltration rate(cm/hr)	Cummulative Infiltration(cm)
1	Yamanapur	Silty Clay	120	21	0.2	1.9
2	WazirpurBikram	sandy Clay	80	15	0.3	1.6
3	Shantinagar maner	Clay	90	12	0.4	1.4
4	Nagwa. [Nagwa – Kari path.]	sandy Clay	120	30	0.6	4.2
5	Godhna (Shivalay-Bihta road)	Clay	120	12	0.3	3.2
6	Brahampur Bazar	sandy	100	45	0.4	4.2
7	Bishanpura Bihta	sandy Clay	150	21	0.2	2.8
8	B V College Patna	Clay	110	12	0.4	1.9
9	Ajwan, [Nawatpur to Bala thakur road.	SandyClay	120	24	0.4	2.7
10	A.N.college,Patna	Clay	120	15	0.2	1.9
11	Moriyama	Sandy	120	39	0.3	4.1
12	Simri	Clay	120	12	0.3	1.9
13	Naubatpur-Lackha	Sandy clay	130	21	0.2	3.5
14	Arap	Sandy	120	33	0.3	4.1
15	Motipur,naubatpur	Clay	80	3	0.3	1
16	BajarSamiti campus Bihta	Sandy	135	27	0.4	3.2
17	B.N.college	Clay	120	6	0.6	2.5

Infiltration rate curve at different locations are shown in fig 3.2 (d).

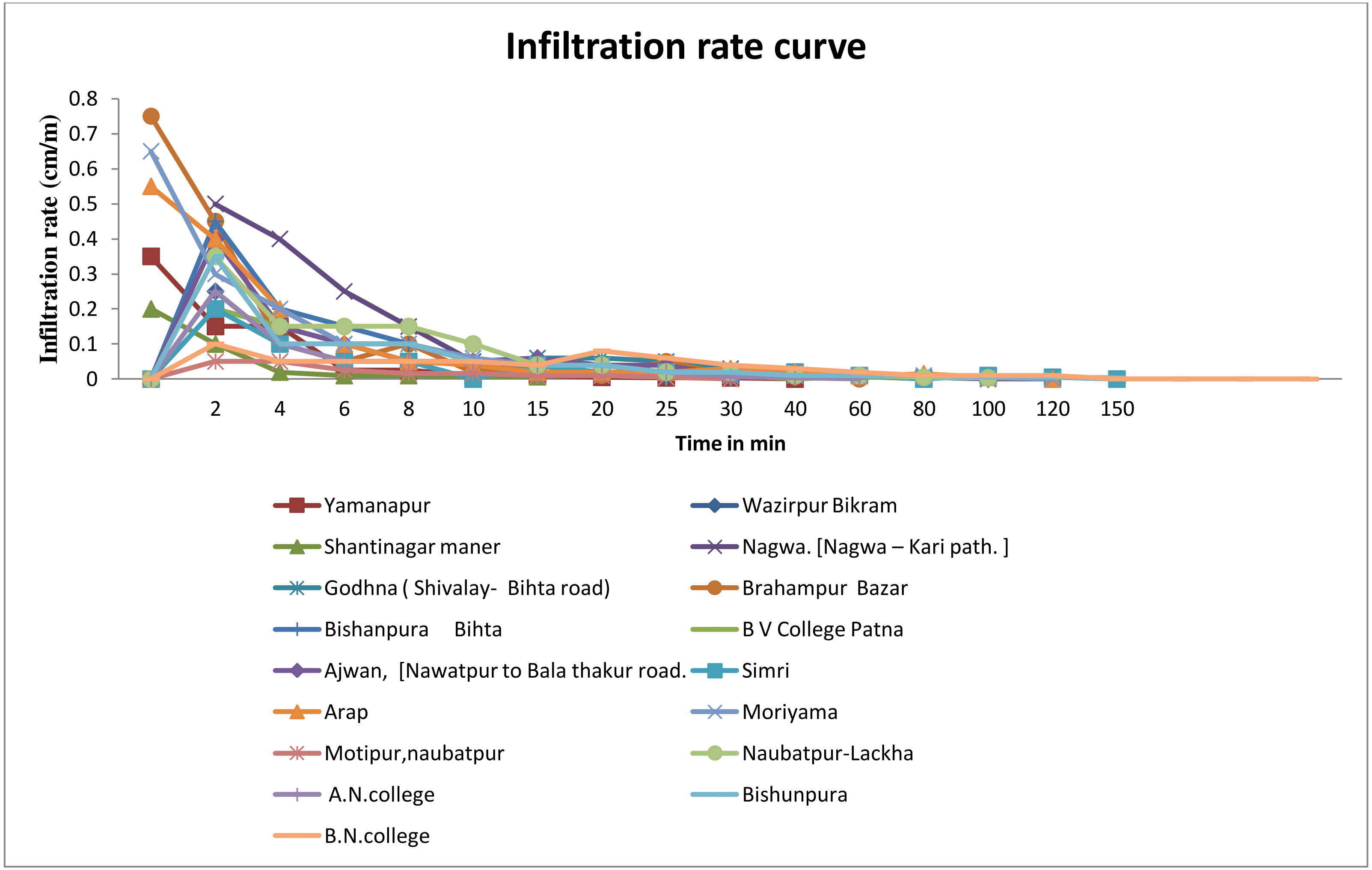


Fig 3.2 d: Infiltration rate curves at different locations.

3.3 Land use

3.3.1 Land utilisation

The western part of city of Patna- the capital of Bihar extends over the watershed (the study area). The landscape and land use of the watershed selected for aquifer mapping includes part of the Patna urban area, which is fast changing as the expansion of the city is bringing newer areas under the ambit of urbanisation. The area is having a genuine agricultural background and experiencing rapid urbanization. The total geographical area of blocks of Patna district falling under Pilot Aquifer Mapping is 106352.46 hectare. The land utilisation statistics of these are given in table 3.3 a.

Table 3.3 a: Land use land pattern detail of Patnadistrict (2008-2009) area in acre.

Geograp-hical Area	Forest Area	Land put to Non-agriculturable use				Barren Uncultur-able Area	Permanent Pastures & Grazing Land	Land under Misc. Tree crop&Groves not included in net area sown	culturable waste land	FallowLand			TotalNon-AgriculturalLand	Net Sown Area (3-16)	Total Cropped Area	Area Sown more than once
		Land Area	Water		Total col. 5, 6 & 7					Other FallowLand	Current Fallow land	Total				
			Parenial	Temporary												
3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
317236	56	64602	10333	2407	77342	12369	113	1002	764	1572	79467	81039	172685	144551	180688	36137

(Source: AgricultureDepartment, Govt. of Bihar)

Of the total geographical area of 317236 hectares of Patna district, the total cultivable area is 144551 hectares out of which 86000 ha is under assured irrigation. The principal source of assured irrigation is by wells and tube wells, which together account for about 82 % of the total irrigation. Agriculture intensity of the district is 45.5 % and the irrigation intensity 59.5 %. The cropping intensity of the district as a whole has been found to be 126 %.

Agriculture

Based on soil characterization, rainfall, temperature and terrain, four main agro-climatic zones have been identified in the state of Bihar.These are Zone –I, North Alluvial plain, zone –II, North East alluvial plain, zone-III A, South East Alluvial plain and zone –III B, South West alluvial plain. Patna district is situated in the south Bihar alluvial plains (Zone III B) among the four agro-climatic zones of divided Bihar. Agriculture is the mainstay of the people of the area. Agro-ecologically, the area spreads south of river Ganga. Areas under cultivation in four cropping seasons (in hectare) are given in table 3.3b.

Table 3.3b: Area under cultivation in four cropping seasons (in hectare)

Blocks	Bhadai	Aghani	Rabi	Garma
Patna sadar	51.32	270.46	248.70	47.82
Phulwari	250.27	1894.77	2960.81	313.06
Danapur	233.98	300.35	421.05	423.31
Bihta	123.02	5575.00	6702.75	150.25
Naubatpur	178.57	936.43	3268.38	241.16
Maner	798.28	3956.10	5446.87	1324.60
Bikram	142.63	4270.80	11370.56	53.10
Cropping season	April/May to august/ september	June to end of October	from end of October to the end of March	from end of March to the end of June

(*Source: Statistics Department, Govt. of Bihar)*

Generally Bhadai and Aghani form the Kharif season followed by Rabi and Garma.Rice and wheat are staple food of the people of the area. Paddy is the main crop grown in the Patna district. This accounts for one third of the gross sown area, followed by maize, pulses and Wheat besides Oil seeds and different kinds of vegetables. Potato is also an important crop grown in this district. Fig 3.3 (dto f) shows field photographs of Paddy, rapeseeds, and maize cultivation in the area.

Fig 3.3 d : Paddy cultivation in the area

Fig 3.3 e : Rapeseeds (sarso) cultivation in the area

Fig 3.3 f : Maize cultivation in the area

3.3.2 Land use land cover map using image interpretation

Land use land cover map (fig. 3.3 g) was prepared using LISS III (November 2009), SOI topographic map No. 72G/2, 72C/14 and 72C/15 (1: 50,000 scale), ERDAS IMAGINE 9.3 module and digital image processing. All data were integrated and analyzed to assess the landuse/landcover factors. The LISS III data for the year 2009 were used with 4 bands combination and were orthorectified.

The primary LULC classification scheme used for study area was derived from the Anderson classification system for a level one classification (Anderson et. al, 1976). The classification schemes utilized were as follows:

Class	Description
Settlement	Include all residential, commercial and industrial development.
Seasonal Water logged	Seasonally water logged area, major part used for agriculture also
Natural Vegetation	Bushes and hyacinth
Agricultural land	Area used for agriculture
Open scrub	Area devoid of vegetation growth.

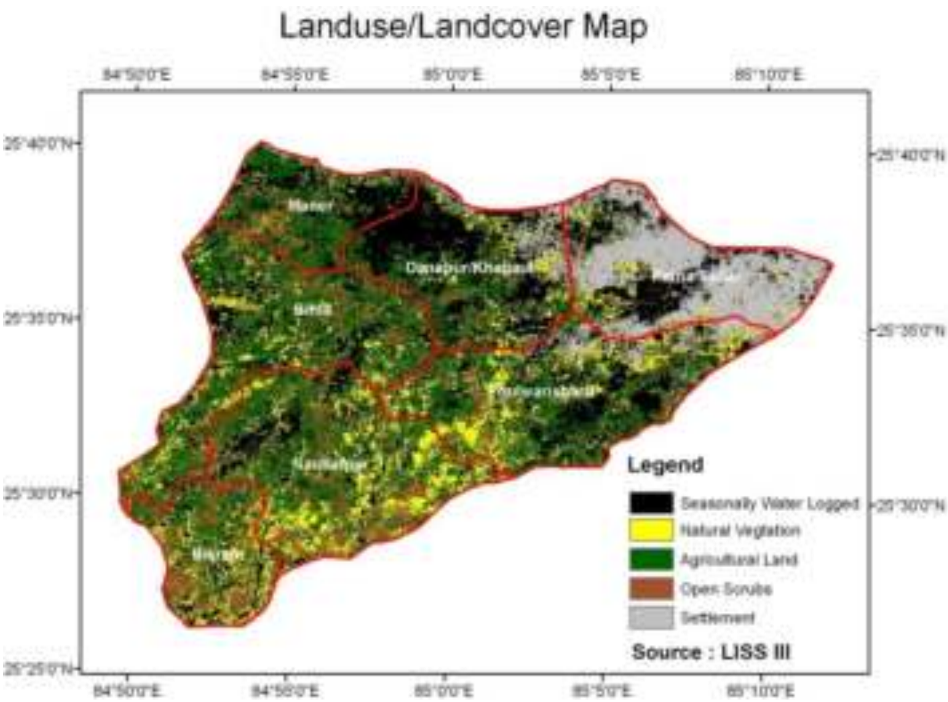


Fig 3.3 g: Land use Land cover map of area using LISS III image

The final classification product provides an overview of the major LULC features which are given below.

Class Name	Percentage (%)
Seasonal Water logged(Major part used for agriculture also)	31.71
Natural Vegtation	16.41
Agricultural land	27.42
Settlement	11.28
Open Scrubs	13.17
Total	**100**

Graphical representation of different land class existed in the area are shown in Fig 3.3 (h).

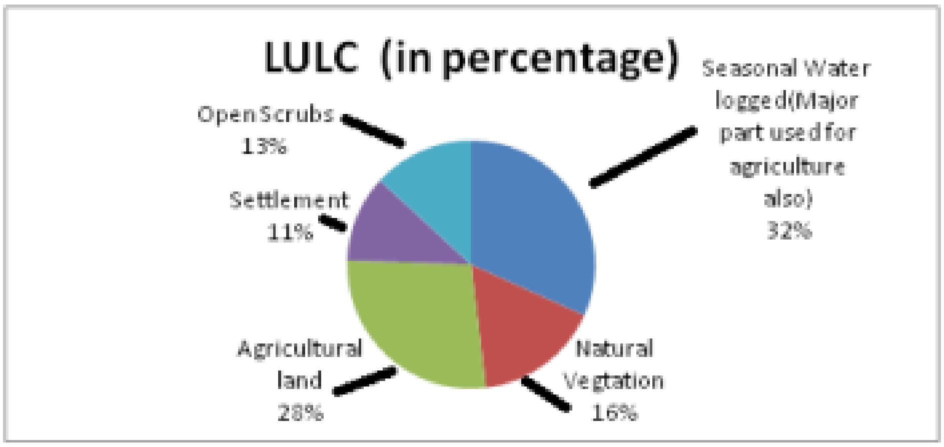


Fig 3.3 h: Graphical representation of different land class (in percentage)

3.4 Physiography, drainage and geomorphology

3.4.1 Physiography and drainage

Physiographically, the area represents a monotonously flat topography. The topographical variation within the area indicates that the general slope is from south-west to north-east and north with minor variations. The elevation of the area varies from about 46 m amsl to 62 m amsl. The elevation contour map is shown in (Fig 3.4a).

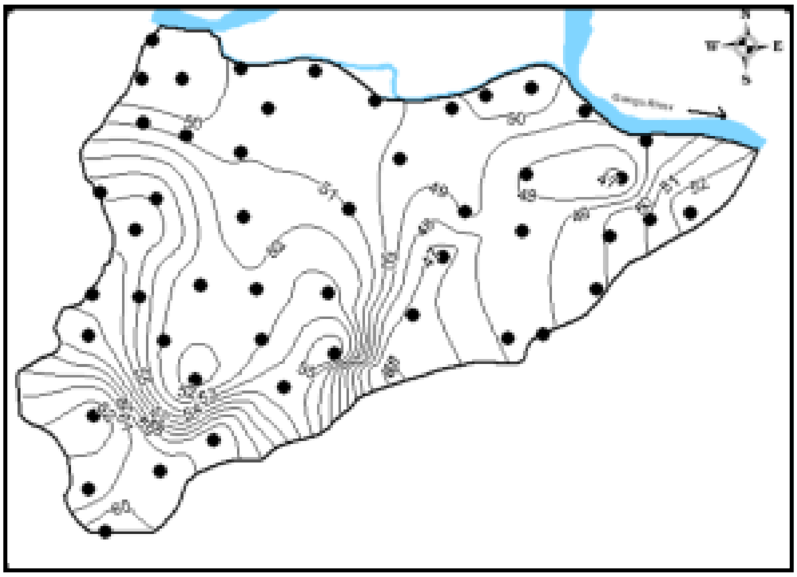


Fig 3.4 a: Elevation contour map of the project area

Patna district is drained, by the mighty river Ganga in the north, by the Sone in the West and their tributaries in the central part, but within the study area is characterised by absence of any active drainage (Fig. 3.4 b).The Ganga flows from west to east while Sone flows from south to north which finally joins Ganga at Rampur village. Punpun and Phalgu are the other two important rivers in the district which enter with a northerly flowing direction before they turn north-east and finally flow towards east. The mighty river Ganga forms the northern boundary of the project area. Other rivers Sone, Punpun and their tributaries are draining just outside the project area.

The River Ganga forms the levee or upland all along its southern bank along the northern boundary of the district and study area forming a barrier for the rivers flowing from the south and prevents them from having a direct access to the river Ganga.

All the rivers flowing in the district are maily effluent and as such perennial in nature, and base flows can be observed in some of them in the pre-monsoon period, but during the monsoon period they become almost brimful, and in places overtop the banks to flood in bordering areas and in even the some area of the project area.

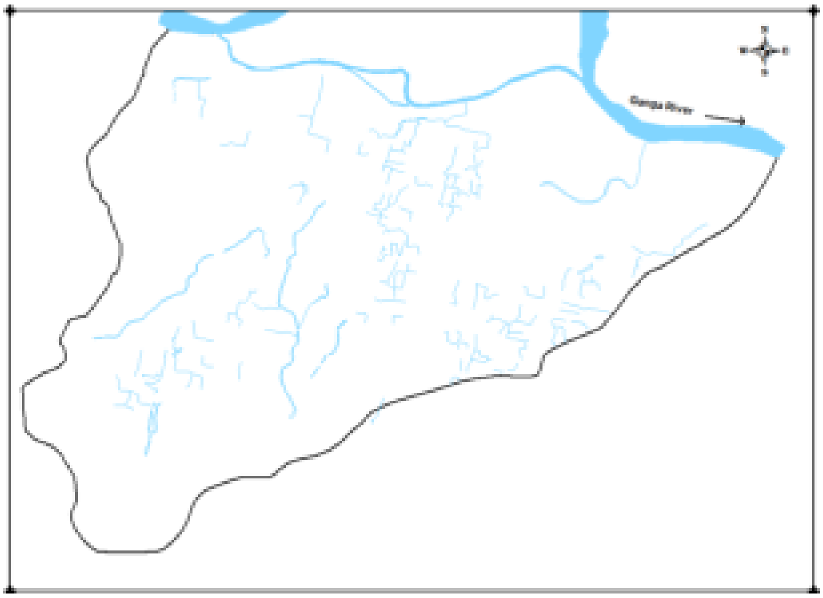


Fig 3.4 b: Drainage map of Pilot Aquifer Mapping Project area

The river Sone has a westward shifting history and has been shifted from east near Maner to further west to its present position which is evident from the presence of alluvial bars and deltas in the river course. Traces of its paleochannel can also be seen in the project area.

3.4.2 Geomorphology

The area forms a part of the Sone megafan and the active channel of Sone is situated outside of the area in its western part. Palaeo-channels of Sone traverse the area. Unlike the active channel, the palaeo-channels channels of Sone typically display moderate meanderings and migration at few stretches. Interestingly within the study area, not a single active drainage as well as not a single stream flows northward or westward to join either Ganga or Sone. All along the southern bank of the Ganga, the levee deposit form a barrier for the rivers flowing from the south and prevents them from having a direct access to the river Ganga.

The Sone palaeo-channels at patches presently serve as ‘pynes’. Depressions in the palaeo-channels still form temporary water bodies. The Ganga River, which has entrenched the Sone megafan, flows along the Northern boundary of the area.

Geomorphic map showing different geomorphic units present in the area has been prepared using LISS III data of November 2009 with 4 bands combination and

ERDAS 9.3 module software is shown in fig.3.4 c. Palaeo-channels, the conduit of natural recharge, dominates in the southern and western parts of the study area.

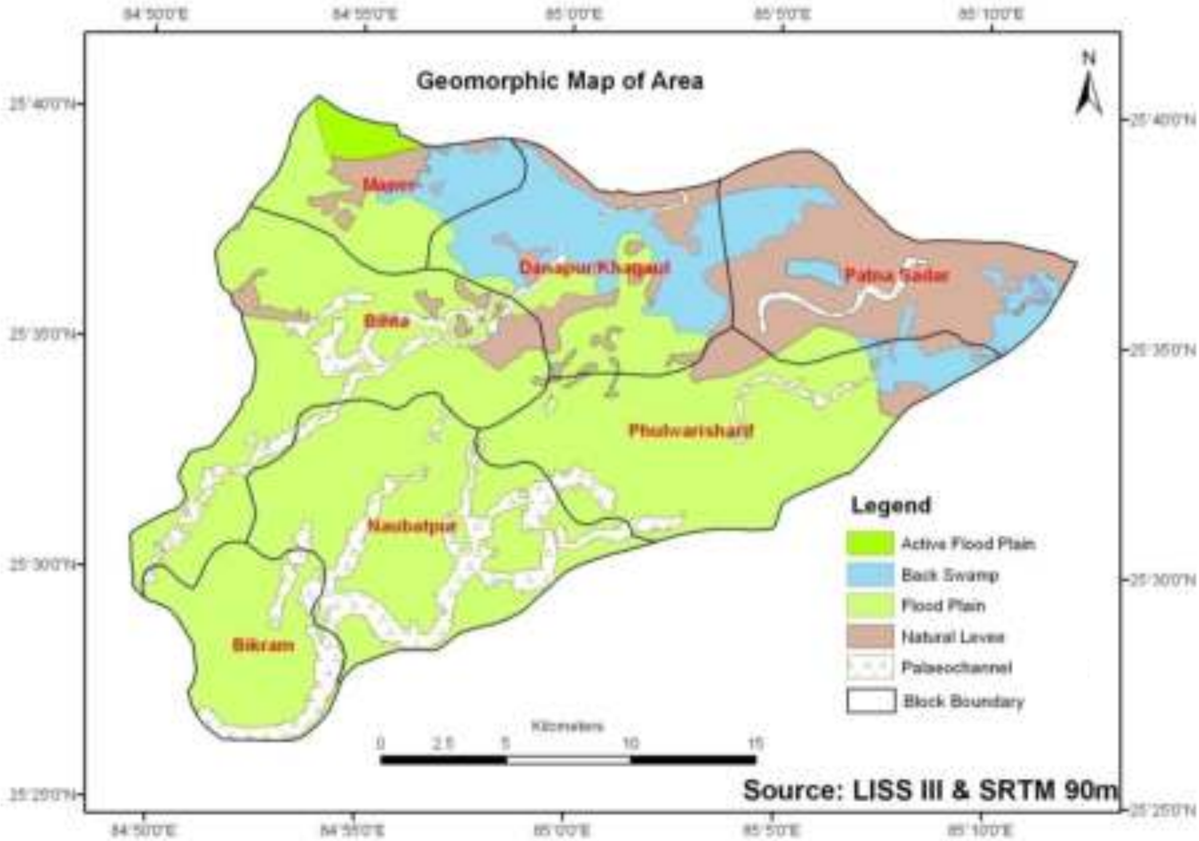


Fig 3.4 c: Map showing different geomorphic units in the area

The older flood plain and the present flood plain, which remained the domain of deposition during Quaternary, are well exposed in the area. Besides these, other geomorphic unit demarcated in the area are paleo-channels of the river Son, backswamps and natural levee and are described below.

(i) Natural Levee: The natural levees form the northern limits of city boundary along the right bank of River Ganga. The levee is well exposed along the river Ganga (figure 3.4 c).The general relief varies from 48.60 to 50.60 metres (source: SRTM). The average width is 0.75 km and Old city of Patna; Patna University, etc are situated on natural levee. The 26km length (east-west) of natural levee is running parallel to river Ganga.

(ii) Older flood plain - These plain are basically part of older flood plain of River Son.

(iii)Active Flood Plain – Active flood plain formed by recent activities confined to the extreme nort wester part of the project area.

(iv) Palaeo-channel - The Palaeo-channel are past channel of River Son which is flowing at present almost 35 km west of present Patna.

(V) Backswamp/Low Land – Backswamps are localized along the eastern and western margin of Patna Urban area.

Area (in sq.km) of different geomorphic units within pilot aquifer mapping area, Patna is given in table 3.4a.

Table 3.4a: Area (in sq.km) of different geomorphic units within pilot aquifer mapping area, Patna

Block Name	Active Flood Plain	Backswamp	Flood Plain	Natural Levee	Palaeo-Channel	Total
Patna Sadar	0.00	15.34	3.15	52.75	2.88	74.12
Danapur	0.00	33.33	21.37	15.49	1.34	71.52
Maner	5.59	10.13	19.84	6.92	0.00	42.49
Bihta	0.00	0.00	71.72	7.61	12.19	91.52
Bikram	0.00	0.00	33.68	0.00	8.93	42.60
Naubatpur	0.00	0.00	75.96	0.00	23.45	99.41
Phulwari	0.00	6.38	78.23	8.57	6.54	99.73

3.5 Geophysical investigation

3.5.1 Introduction

Twenty six surface electrical resistivity investigation (VES) was carried out by CGWB within the Pilot aquifer mapping areas in Patna district, Bihar (figure 3. 5 a.) as a part of the project. The field data were interpreted with the help of empirical curves (Master curves) based on curve matching technique and computer based software. On the basis of interpreted results 2 nos. of geoelectrical sections are prepared and vertical and horizontal disposition of granular zones of various grades are analysed within the investigated area. Besides surface electrical resistivity investigation (VES),18 nos. electrical loggings of bore wells (including the bore wells drilled under pilot project) were analysed to delineate the aquifer disposition which were required for fixing different parameters for Heliborne SKY-TEM survey. The subsurface electrical log data were interpreted and projected in the area and prepared three numbers of sections and one number of fence diagram to understand the subsurface information and aquifer geometry.

3.5.2 Surface geophysical survey:

In all 26 VES were performed within the aquifer mapping area (Fig. 3. 5 a. and 3.5 b.).The VES were performed in the field and the data were interpreted with computer and manual process. The interpreted VES data of the area is given in annexure 3.5b. The final results are analyzed and discussed in details below.

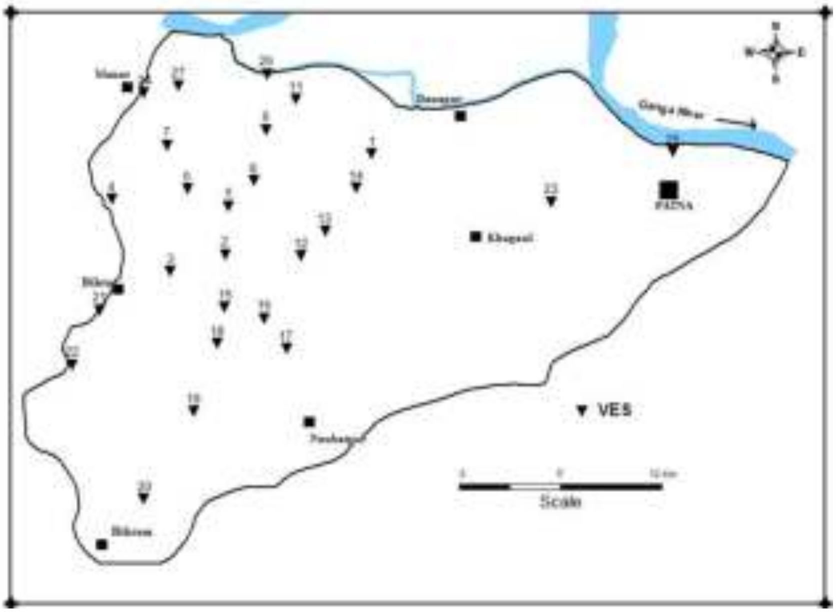


Fig 3. 5 a: Location of VES points within aquifer mapping area.

Fig 3.5 b : Geophysical Survey (VES) conducted within the Project area, Patna.

3.5.3 Instrument used

During the surface resistivity investigation a Syscal R2 resistivity meter (manufactured by IRIS, France) was used. The instrument measures potential differences between two potential electrodes when current is sent through two current electrodes and there by apparent resistivity is calculated automatically by the instrument.

3.5.4 Methodology adopted

Total 26 numbers of VES were conducted within the investigated area (Fig.3.5 a) using Schlumberger configuration. The maximum current electrode separation (AB) was kept 1000 meter to get the maximum depth of investigation.

The sounding curves are H, HA, HK, K, KH, KHK type. Some representative sounding curves are presented in fig. 3.5 c to 3.5 f.

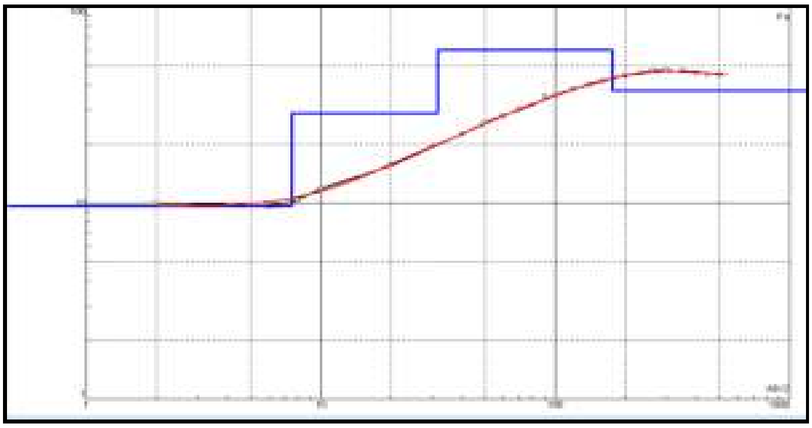


Fig.3.5 c: Field curve of the VES obtained at Hathiakhand

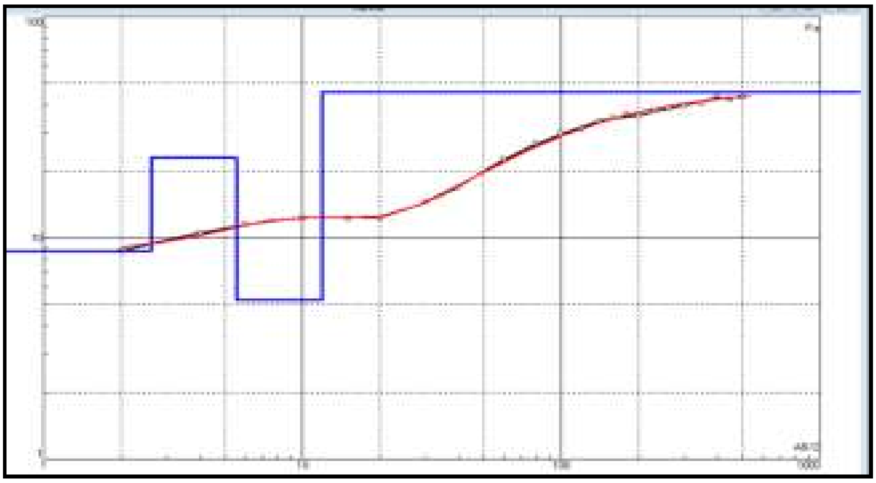


Fig.3.5 d: Field curve of the VES obtained at Runia

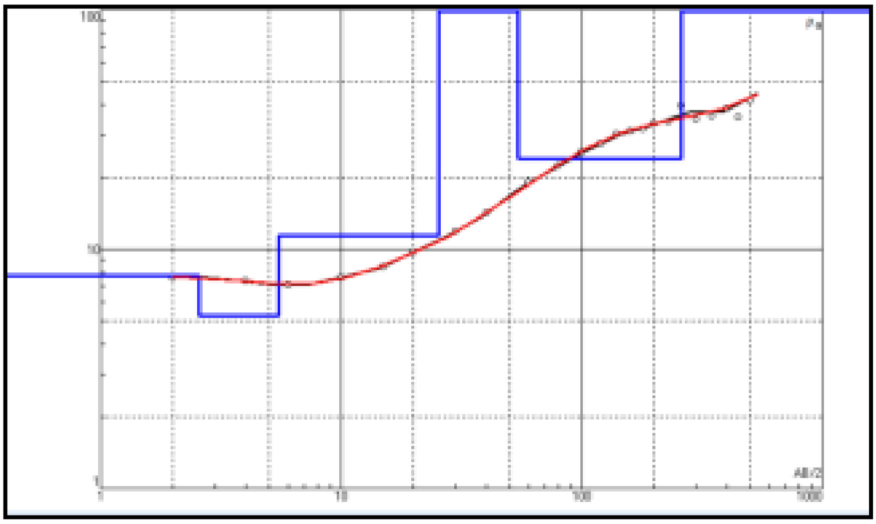


Fig. 3.5 e: Field curve of the VES obtained at Kalapur

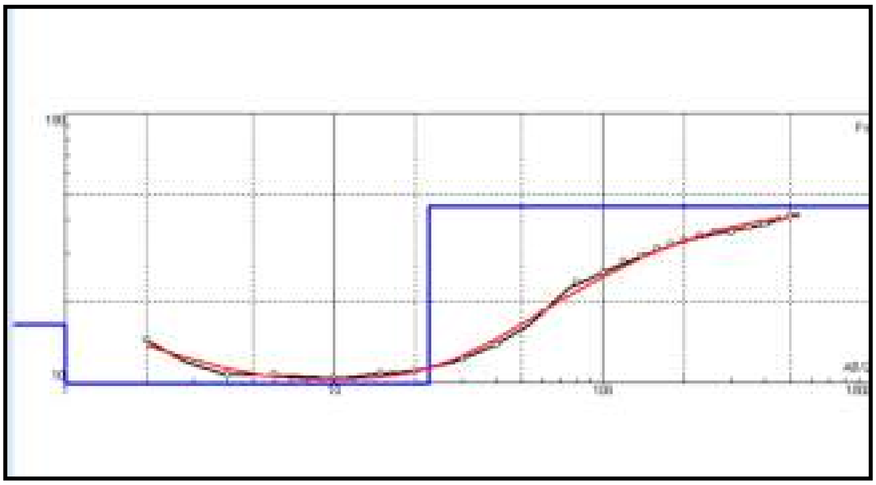


Fig.3.5 f: Field curve of the VES obtained at Sarasat

All the curves are interpreted with the help of partial curve matching technique and also by the resistivity sounding interpretation software. The interpreted data is correlated with the available borehole information near by the survey area and the following resistivity range with respect to lithology is given as follows:-

Resistivity range	***Lithology***
09 -15 Ohm-m	Clay
14-30 Ohm-m	Sand mixed with little clay
30 -50 Ohm-m	Medium to Coarse Sand
60-200 Ohm-m	Coarse sand mixed with gravel/Kankar
200-500 Ohm-m	Desaturated sand

All the interpreted results are tabulated in the Annexure-1. Based on these results of the VES, the sub-surface layered structure is identified.

3.5.5 Discussion of the results

Based on the interpreted results two nos. of geoelectrical sections are prepared to get a sectional view of the investigated area (Fig.3.5 g &3.5 h). The characteristics of the different zones /layers are discussed below.

3.5.5 (a) Geo electrical Section (Bikram-Bhatehari)

The section is elongated along SW to NE orientation and passes through the VES 20, 19, 18, 15, 2, 5, 8, 9 and 11. A clay and sandy clay layer of resistivity range 7 to 23 ohm m and thickness variation 24 to 48 m is observed just below the top soil with varying depths (Fig.3.5 g).This may be termed as aquitard layer. Below this clay/sandy clay layer, a sand layer (medium to coarse sand) of resistivity range 40 to 100 ohm m is observed down to the average depth range 80 to 140 mbgl. At some places the resistivity range is more and this may be due to presence of gravel content. Maximum thickness is observed at the VES 15. Below this layer another sandy clay layer of resistivity range 29 to 35 is available. This is the 1st impervious boundary.At VES 5, 8 and 9 coarse sand mixed with gravel/ kankar is available within the sandy clay. Below this sandy clay formation another medium to coarse sand layer (2nd major aquifer) is interpreted whose resistivity order is varied from 41 to 140 ohm m. Again below this thick sand bed another sandy clay bed of resistivity range 17 to 40 ohm m and variable thickness is present as 2rd impervious layer. Below this second sandy clay layer again a medium to coarse sand layer is occurred down to the depth of 400 mbgl. An interesting pattern of the sand and clay bed, especially in VES 18, 15, 2 and 5 are observed which may be due to the presence of fault or any lineament.

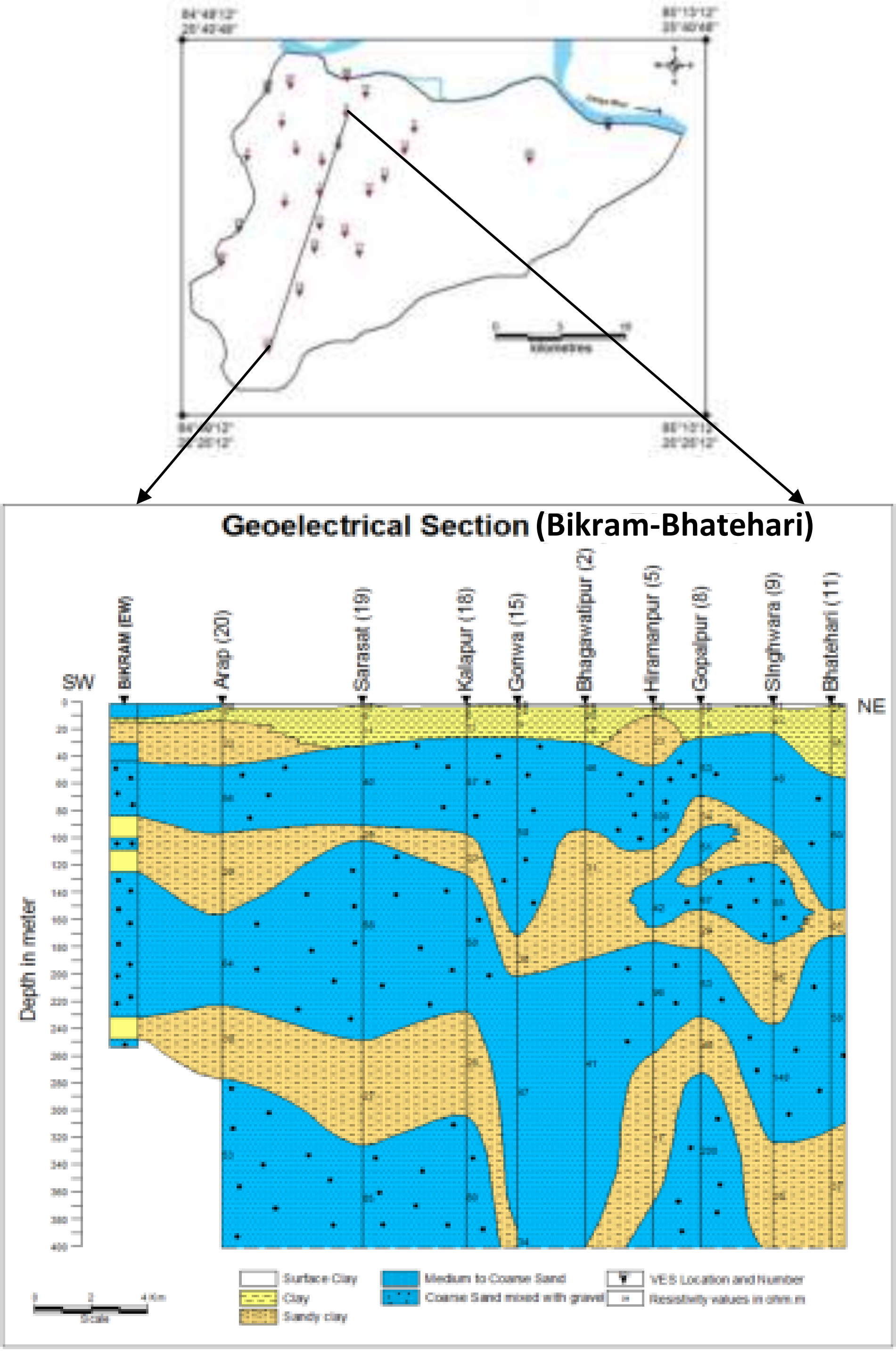


Fig. 3.5 g: Geoelectrical section along Bikram – Bhatehari

3.5.5(b)Geo electrical Section (Bikram-Hathiakhand)

The section is elongated along SW to NE orientation and passes through the VES 20, 19, 18, 16, 12, 13, 14 and 1. A clay and sandy clay layer of resistivity range 7 to 33 ohm m and thickness variation 20 to 48 m is observed just below the top soil with varying depths (Fig.3.5 h).This layer is also termed as aquitard layer. Below this clay/sandy clay layer, a sand layer (medium to coarse sand) of resistivity range 40 to 60 ohm m is observed down to the average depth range 80 to 100 mbgl. At some places the resistivity range is more and this may be due to presence of gravel content. Maximum thickness is observed at the VES 16. Below this layer another 2nd sandy clay layer of resistivity range 28 to 32 is available.

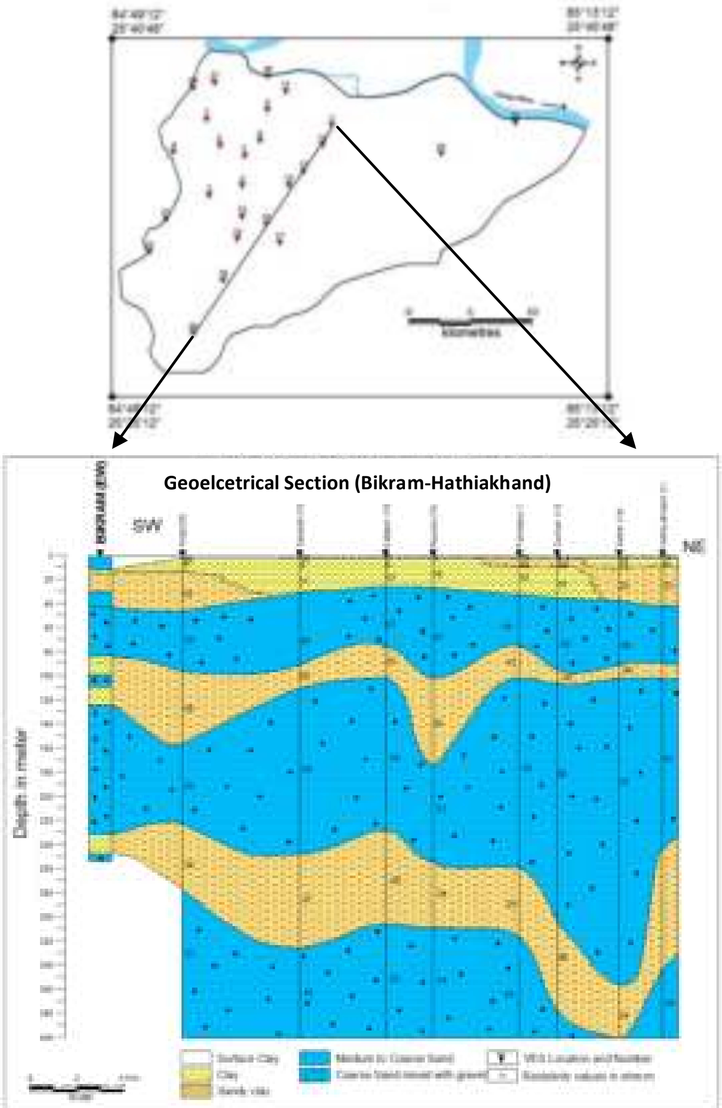


Fig. 3.5 h: Geoelectrical section along Bikram - Hathiakhand

This is the 1st impervious boundary. At VES 5, 8 and 9 coarse sand mixed with gravel/ kankar is available within the sandy clay. Below this sandy clay formation another medium to coarse sand layer (2nd major aquifer) is interpreted whose resistivity order is varied from 50 to 63 ohm m. Again below this thick sand bed another sandy clay bed of resistivity range 23 to 39 ohm m and variable thickness is present as 2rd impervious layer. Below this second sandy clay layer again a medium to coarse sand layer is occurred down to the depth of 400 mbgl. This is the third major aquifer within the pilot project area.

3.5.6 Sub-surface geophysical survey

18 nos. e-logs of the wells (annexure 3.5c) falling under the pilot project area (electrically logged by the UPTRON logger) were analysed to decipher the sub surface information and aquifer disposition (Fig.3.5 i).NGRI, Hyderabad carried out electrical logging at Naubatpur & Simri. The interpreted data with log were projected on area map and prepared a fence diagram and three nos. of sections within the investigated area. These diagrams are discussed and analyzed below.

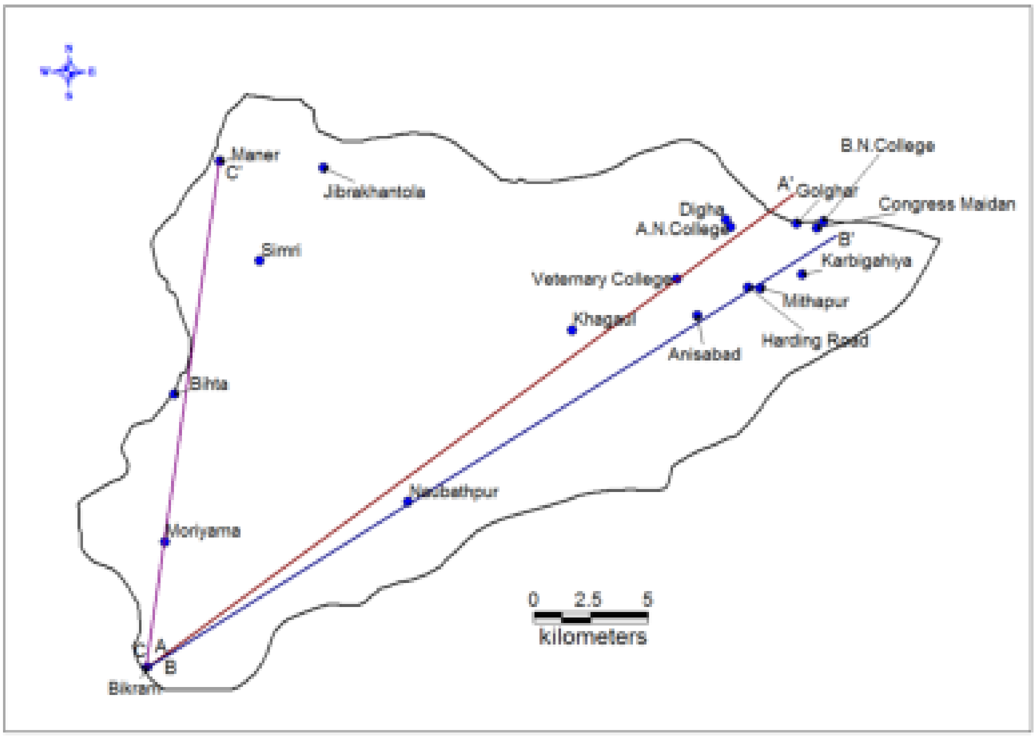


Fig.3.5 i: location map of Bore hole Logs in pilot aquifer mapping area

3.5.6 (a) Fence digram

This fence diagram is comprised of 13nos. of selected log data, namely Maner, Jibrakhantola, Bihta, Simri, Moriyama, Bikram, Naubatpur, Khagaul, Anishabad, Haording road, Mithapur, Cogress Maidan, Digha (Fig. 3.5 j). Due to the presence of river Ganga at the northern part and river Sone at the western part there were several transgression and regression in the past. Hence e- logs reveal frequent interfingering of sand and clay in the area.

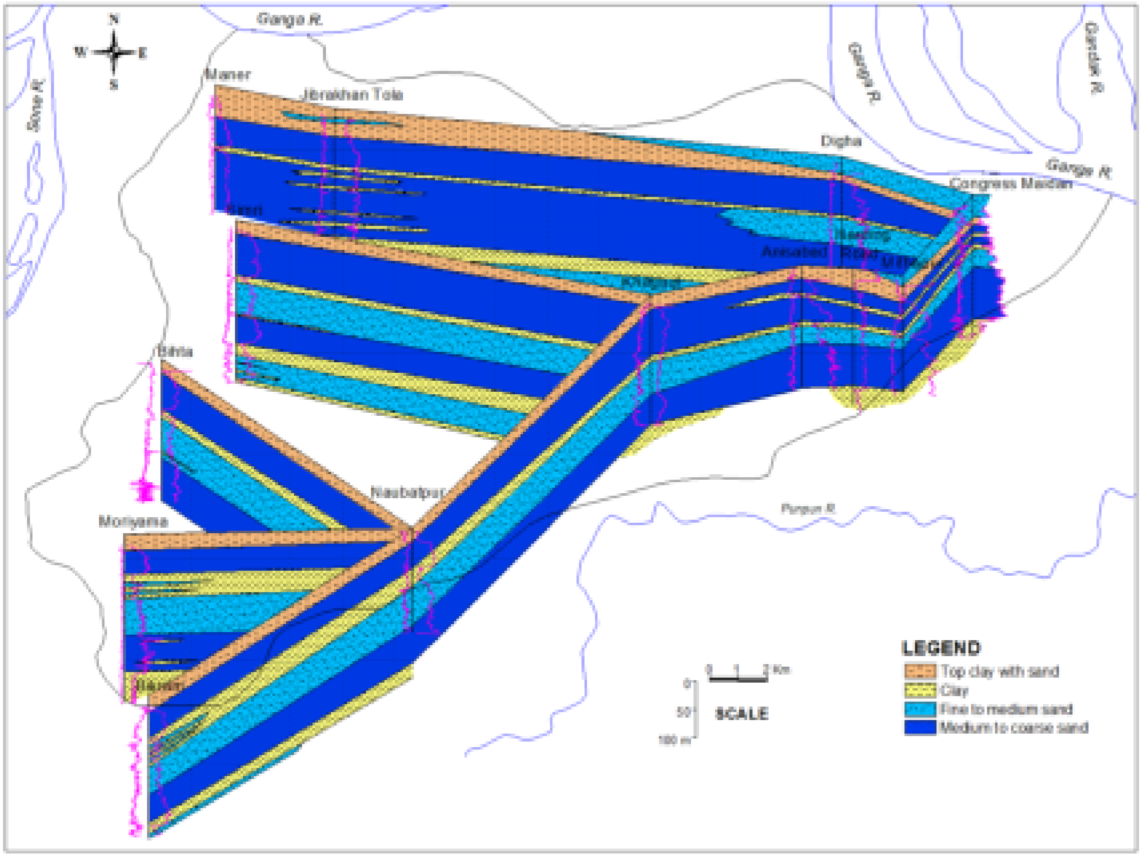


Fig.3.5 j: Fence diagram (based on electrical log data) of aquifer mapping area

Due to some instrumental constraint first 20 metre recording of data is not clearly available. However, from the overall data it may be presumed that almost down to the depth of 20 -40 m it is mostly clay besides some sand patches at places. At Digha, Congress Maidan and Mithapur e. logs show the presence of sand bed within the depth of 20 to 40 m above the top clay / sandy clay layer.This top highly mix with sand aand clay layer is termed as aquitard layer. Below this clay or sandy clay layer a medium to coarse grained sand layer is observed down to the depth of 70 to110 m bgl. Within this sand aquifer a clay patch is observed at the log Anisabad, Mithapur and Congress Maidan. Below this sand aquifer a major clay present in all the logs in the area with depth ranges, i.e., 70-90, 90-100,100-110 etc. At places like Moriyama, Bikram this clay layer is divided into parts. At Moriyama clay is having thickness 70-115 mbgl and three very thin sand layers exist in between. The second major sand aquifer below this clay bed is identified from the little lesser resistivity log signals in most of the logs. Therefore this layer is termed as layer of fine to medium sand. At Jibrakhantola and Digha thin clay patches are observed within this fine to medium sand bed. Below this bed another little higher resistivity log deflection is shown in almost all the logs indicating a medium to coarse sand bed. It is also observed that there is an indication of a clay bed between these two sand beds only in a few logs i.e, at Simri (160-170mbgl) at Moriyama (172-180mbgl) at Khagaul (165-175mbgl) etc. As this bed is not prominent this is not shown as a major clay bed in all the logs. This 2nd major aquifer is extended down to the depth 210 to 240 mbgl. Some clay patches are available within this sand aquifer in the log Moriyama. The second clay is considered at the depth 210 to 230 nbgl in general. At Moriyama this clay starts from 245mbgl and extends down to 297mbgl.At Congress Maidan and Bikram it starts from 225mbgl, at Harding road it starts from 215mbgl. Hence the depth varies from place to place. At Simri this layer is little fragmented in different parts. Below this clay layer another sand layer is visible at Bikram and Simri. It is also found in the log of Jibrakhantola and Digha, but not exposed in this diagram.

5.5.6 (b) Section AA′ (based on e-logs)

The section AA′ runs through the locations Bikram, Naubatpur, Khagaul, Veternary College, Digha, Golghar and B.N.College along SW-NE orientation (Fig.3.6 k). It is observed that in the south-western part of the section, the top clay/ sandy clay layer is extended down to the depth 20-30 mbgl. But in the north -eastern part near the locations Golghar, B.N.College, it is found that the clay layer comes down to 35 to 55 mbgl. At this part top 20-30 mbgl is sand aquifer with some clay thin layers. Below this clay/sandy clay layer (aquitard) formation thick sand (medium to coarse) is observed. It is noticed that the depth of this layer is more at the N eastern part. It is minimum at Naubatpur (70mbgl) and maximum at Khagaul (115mbgl).Another feature is observed that at N Eastern part (from Digha to B. N college) a little lower resistive layer i.e., sand fine to medium of 10-15 m thick is present above the coarse sand. Again below this sand aquifer a thick clay bed is identified at S Western part of the area (Bikram& Naubatpur) whereas at N Eastern part i.e., from Khagaul to B.N.College this clay layer became very thin. The thickness of this clay layer reduces from 40 to 4 m. At Bikram, it is found that there are thin sand beds within the thick 40 metre clay. Below this clay another thick sand aquifer is encountered down to the depth of 220 to 230 mbgl. The kin observation of the logs reveals that down to the depth of 155 to 175 mbgl the resistivity logs shows little lesser deflection with some very thin fine sand layer. Hence this layer is termed as fine to medium sand layer. Within this layer there may be thin clay patches at places. Down to the depth of 220 to 230 medium to coarse sand layer is available. Below this sand aquifer the 2nd clay layer is identified at the depth range 220 to 260 mbgl. This layer is narrow at the Bikram. Again at a few places i.e., Bikram, Digha and Golghar another sand bed is detected below this clay bed. This sand bed is 40 to 45 m thick at DighaGolghar area whereas 10 m thick at Bikram area. Another clay bed is inferred at Digha area within the depth range 295 to 323mbgl.

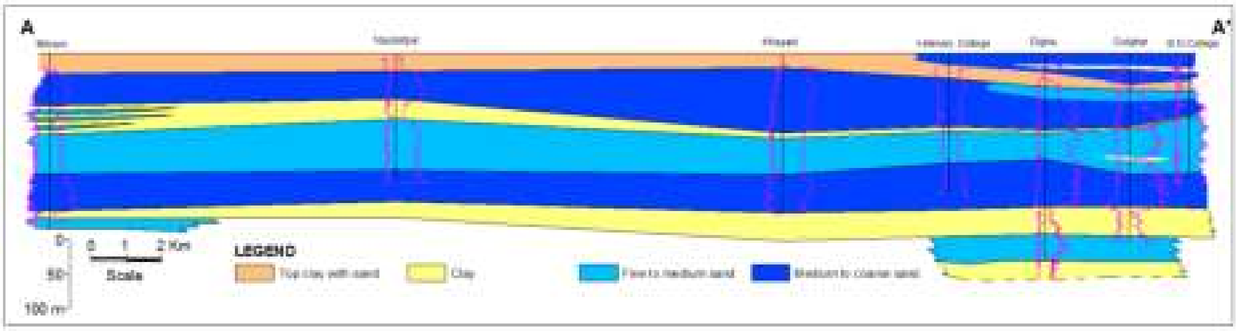


Fig. 3.5 k: Section (based on electrical log data) along SW-NE direction in aquifer mapping area

3.5.6 (b) Section BB′ (based on e-logs)

This section passes through Bikram, Naubatpur, Khagaul, Anisabad, Mithapur, Karbighaia, Congress Maidan.This section is also oriented along SW-NE direction (Fig.3.5 l). The top clay/ sandy clay layer maintains depth 20-25 m at the S western part whereas at the N eastern part at 50 metre depth with a thickness 10-12 m. The logs of Mithapur, Karbighaia and Congress Maidan show that a top sand aquifer is existing above this clay layer. Below this clay/sandy clay bed (aquitard) a medium to coarse grained sand aquifer is existing down to the depth range of 70-110mbgl. It is becoming thicker at N-E part. A clay patch is visible within this sand aquifer. Below this coarse sand bed another clay bed is present within 70- 115 mbgl in general. This bed is thick at Bikram and Naubatpur area whereas thinner in the north-eastern part. This may be termed as 1st clay boundary.Within this clay bed thin sand pockets are present in Bikram area. Below this clay layer the thick sand bed is observed down to the depth range 220-230mbgl. Depending upon the log deflection this sand bed divided into two parts i.e., i) fine to medium sand and ii) medium to coarse sand. Another clay bed is detected below the coarse sand down to the depth range 220 to 250 mbgl. It is reflected at log Bikram, Karbighaia and Congress Maidan. At Bikram it is thinner as compared to other two areas. At Bikram another sand bed occurs below the clay bed.

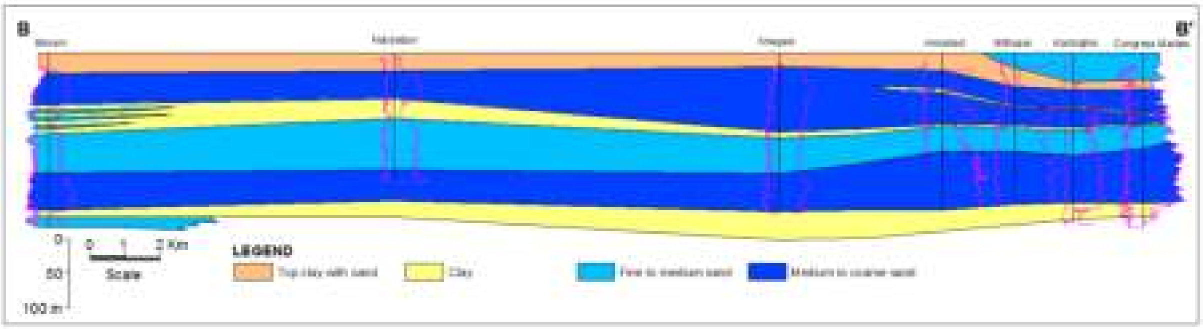


Fig. 3.5 l: Section (based on electrical log data) along SW-NE direction in aquifer mapping area

3.5.6(c) Section CC′ (based on e-logs)

This section comprised of five numbers locations namely, Bikram, Moriyama, Bihta, Simri and Maner. This section is oriented along south to north (Fig. 3.5 m). The top clay or sandy clay layer (aquitard) extends from 20 to 55mbgl depth. Below this sandy clay layer thick medium to coarse sand aquifer layer is present down to the depth range 70-90 mbgl. Below this sand layer a clay layer is present.It is found that at southern part this clay is thicker (40m approx.) and at northern part it is 9 to 10 m thick. This thicker clay includes thin sand beds in between at Bikram. Below this clay bed there is presence of fine to medium sand and medium to coarse sand bed down to the depth 210 to 220 mbgl. At Bihta, Simri a thin clay bed is found in between two types of sand beds (depth 165m). Below this sand layer another clay layer is identified down to the depth of 240 mbgl which is thicker in the northern part and thinner in the southern part. Another sand bed is present below this clay down to the depth of 250 to 280 mbgl. The last clay layer is detected down to the depth range 250 to 297 mbgl as observed at Moriyama and Simri.

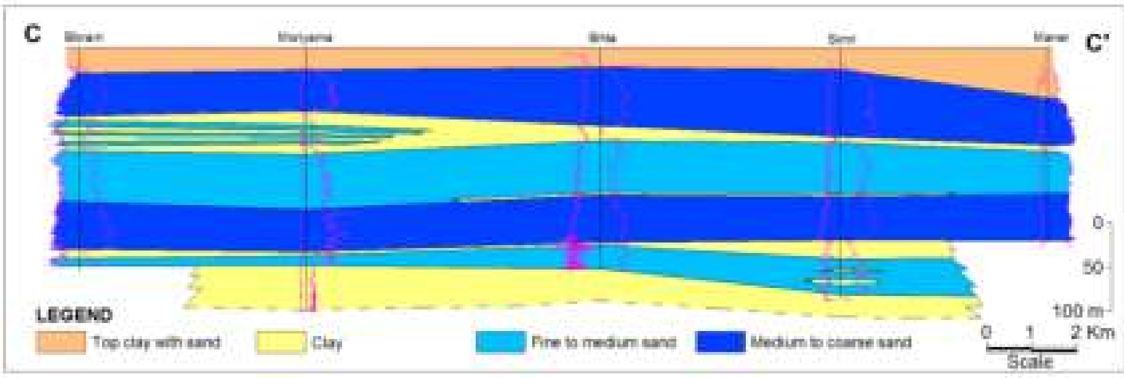


Fig. 3.5 m: Section (based on electrical log data) along SW-NW direction in aquifer mapping area

3.5.7 Comparative study between e-log and VES at Maner

The VES curve at Maner is plotted on double log graph paper and the electrical log scale is converted into double log scale from cm scale, and then projected side by side for comparison. It is observed that from top soil to coarse sand down to 220 mbgl exactly matching with log except the thin clay layer at 100 mbgl. But the deeper clay below 220 mbgl is reflected in the VES as well as in log. Fig. 3.5 n shows the comparative study between e.log (orange) and VES (pink) at Maner.

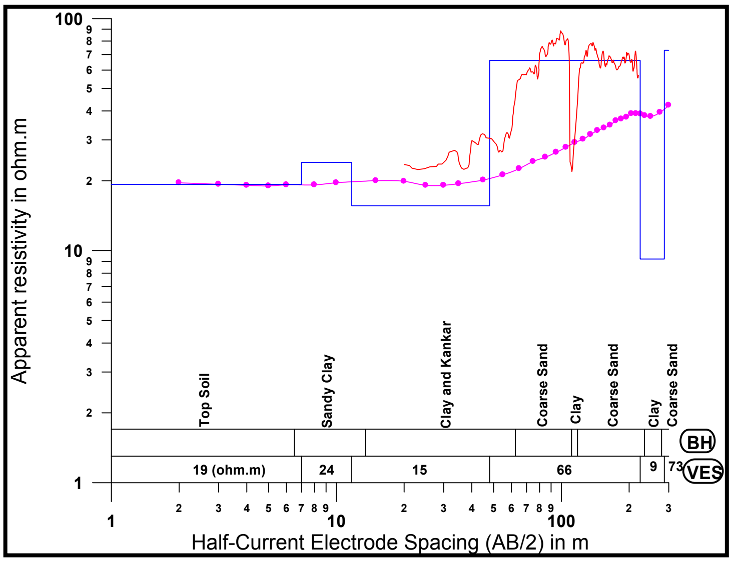


Fig.3.5 n : Comparative study between e-log (orange) and VES (pink) at Maner

3.6 Geophysics Investigation carried out by NGRI (Outsourced)

This part of the report is based on the NGRI report titled AQUIM-Final report AQBHR (2015), Patna District.

3.6.1 Introduction

The geophysical survey in the Pilot aquifer mapping area, Patna, Bihar has been outsourced to CSIR-NGRI, Hyderabad. There are several geophysical techniques which could be used for delineated aquifer geometry. Out of them, a few ground geophysical survey including data acquisition, processing and interpretation by Resistivity survey (VES, 2D Resistivity Imaging survey), Ground Electromagnetic survey, and geophysical logging of bore-holes were used in the pilot mapping area, Patna, Bihar to precisely delineate the principal aquifer zones along with its continuity both vertically and laterally up to depth of ~300m. Besides these ground geophysical survey, heliborrne geophysical survey were also carried out by NGRI in collaboration with Arhaus University, Denmark to map the aquifer up to 300m depth.

3.6 .2 Methodology

3.6.2.1 Geophysical methods/techniques

Geophysical methods/techniques applied in the pilot study are described briefly in Table 3.6(a). The interpretations of geophysical data based on the hydrogeological inputs are being used to delineate the extent of aquifer both vertically and laterally as well as quality in terms of salinity wherever it exists. The originally work, as shown in Fig. 3.6(a), was planned to carry out heliborne geophysical data acquisition just after the compilation of existing data in the area and conceptualization of the existing aquifer system. Followed by its validating by ground based measurements such as VES, TEM, ERT, drilling, borehole logs, etc., and then integration and inversion of all the data depending on their sensitivity leading into realistic aquifer models and their characteristics. However, management and time constraints forced to modify the original plan broadly in three phases i.e., pre-SKY-TEM, SKY-TEM and post-SKY-TEM. Roughly 90% of the ground based measurements and 90% of the drilling were done during the pre-SKY-TEM phase and remaining during post-SKY-TEM phase. SKY-TEM survey took place in the month of December 2013.

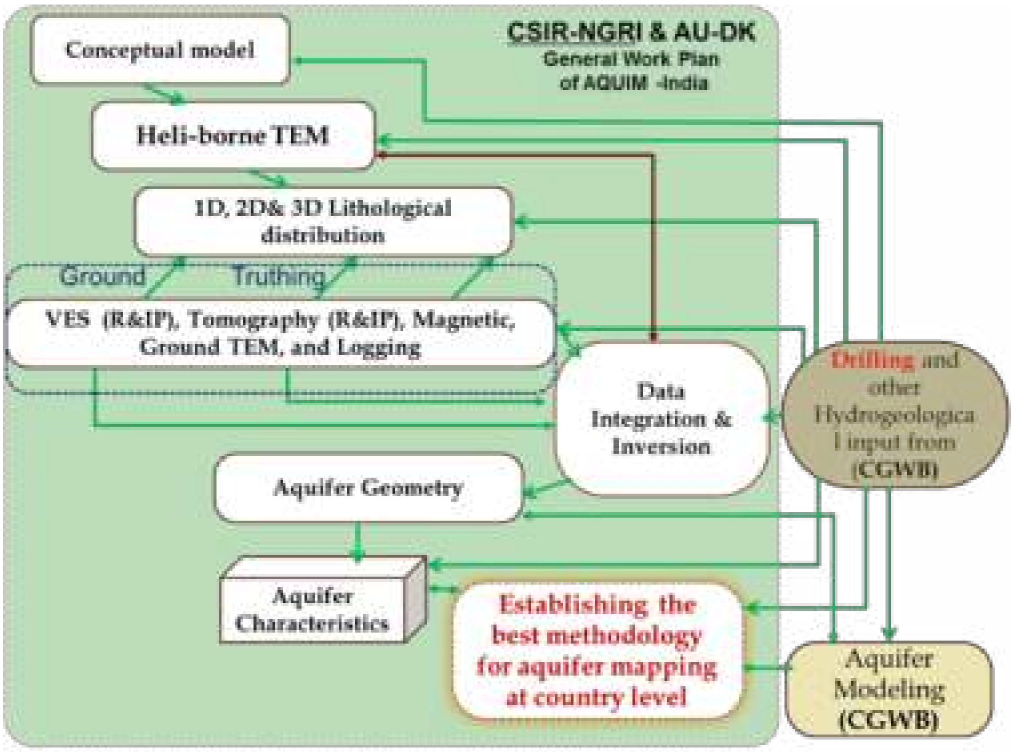


Fig. 3.6 a: Original work plan conceived at start of the project

Table 3.6 (a): Geophysical methods/Techniques applied

<table>
<tr><th colspan="3">Methods</th><th>Techniques</th><th>Geophysical parameters</th><th>Applications</th></tr>
<tr><td colspan="2">Air-borne</td><td colspan="2">Electromagnetic (Time Domain)</td><td>Layer conductivity (inverse of resistivity) and thickness</td><td>Almost continuous information on Aquifer geometry in 3-D</td></tr>
<tr><td rowspan="3">Surface</td><td rowspan="2">1-D Geophysics</td><td>Resistivity,</td><td>Vertical Electrical Soundings (VES)</td><td>Layer resistivity and thickness</td><td>Aquifer/aquitard characteristics and thickness</td></tr>
<tr><td>Transient Electromagnetic</td><td>Sounding</td><td>Layer conductivity and thickness</td><td>Aquifer/aquitard characteristics and thickness</td></tr>
<tr><td>2-D Geophysics</td><td>Resistivity</td><td>Electrical resistivity tomography (ERT)</td><td>Spatial distribution of resistivity and thickness</td><td>Aquifer geometry</td></tr>
<tr><td colspan="2">Sub-surface</td><td>Borehole Logging</td><td>Short Normal, Long Normal, Lateral, SP and natural Gamma</td><td>In-situ physical property measurements</td><td>Precise delineation of aquifer and well design</td></tr>
</table>

3.6.2.2 Ground geophysical survey

In the AQBHR pilot area, 72 Vertical Electrical Soundings, 101 TEM, 19 ERT and geophysical logging of 3 boreholes were carried out. Locations detailes of VES, TEM and ERT are given in annexure 3.6a, b & c, respectively. The status of geophysical investigation under the AQUIM project shown in Table 3.6 (b). Three geophysical loggings were carried out in the boreholes drilled by CGWB-MER, Patna at Naubatpur and Simri. It includes parameters like SP, SN&LN resistivity and natural gamma radioactivity.

In total 72 VES were observed(Fig. 3.6 b 1) in 4-phases with the aid of IRIS make Syscal R1+ Instrument, France and ABEM Terrameter LS, Sweden make.The maximum current electrodes spacing (AB) was 3000 m. At several sites large spread VES could not be observed due to standing crops.

In total 101 TEM soundings were observed (Fig. 3.6 b 2) with the aid of TEM 48 HPC, The Netherlands make instrument and TerrTEM System.

In total 19 ERT were observed with the aid of IRIS make Syscal R1+ Instrument, France(Fig. 3.6 b 3). The ERT spread varied from 320 to 480 m.

Table 3.6 (b): The total data collected by CSIR-NGRI in the AQBHR area

Name of Activity		Target	Pre- SKY-TEM	SKY-TEM	Post - SKY-TEM	Total	Remarks
1-D GEOPHYSICS	VES (no.)	150	50		22	72	Syscal R1+ Instrument was used
	TEM (no.)	25	58		43	101	TEMfast48HPC system with 50m x 50m loop size, 1 and 4 A current and TerraTEM system with 100m x 100m loop size, 8 A current were used
2-D GEOPHYSICS	ERT (LKM)	16	8.32		0	8.32	Syscal R1+ (IRIS) system was used
Borehole Logging	Wells (No.)	20	0		3	3	Short normal (16), Long normal (64), Lateral, SP and Gamma logging were done
HeliTEM	Dual moment SKY-TEM 304 (LKM)			770		770	TEM data using Line/Tie line

					spacing: 250 m/2000m
HeliMAG	Geomertics Cesium Vapor type 822A(LKM)	770		770	TEM data using Line/Tie line spacing: 250 m/2000m

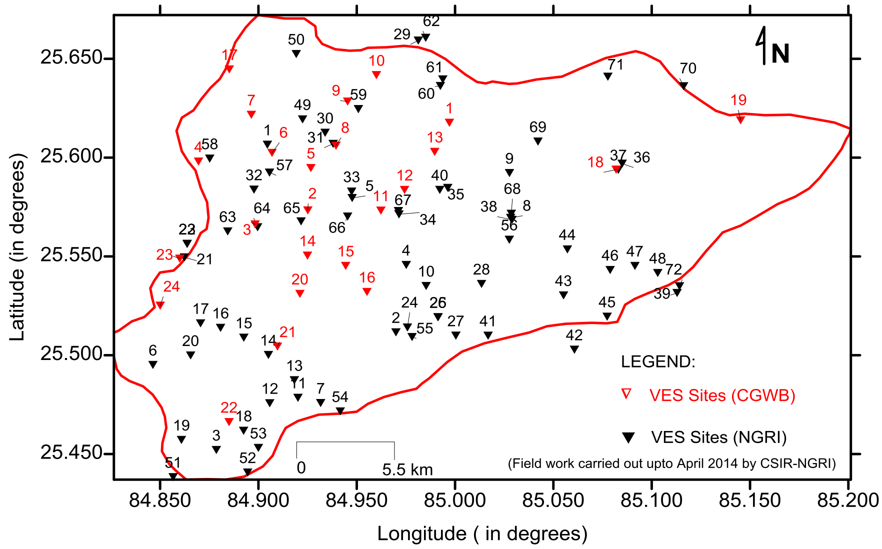


Fig. 3.6 b (1): Location map of the VES sites, AQBHR, Patna, Bihar

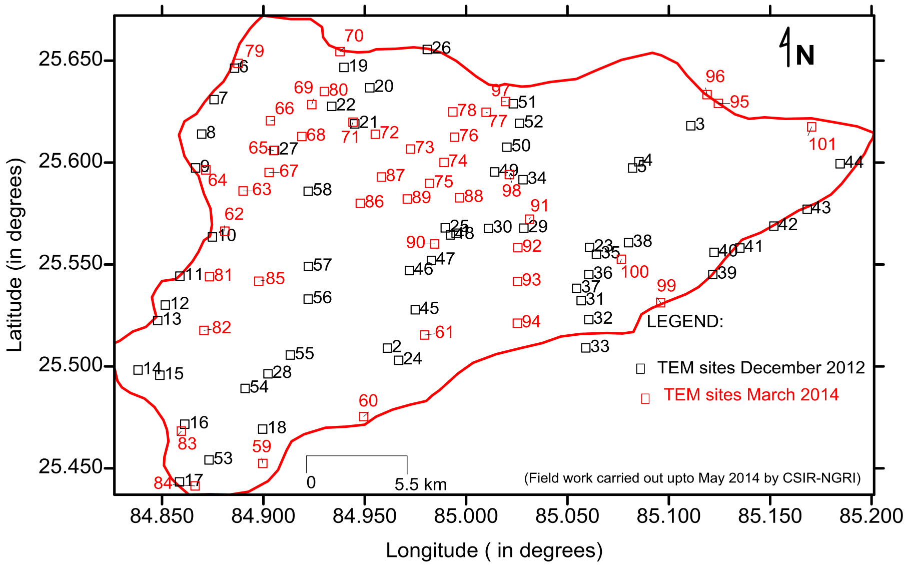


Fig. 3.6 b (2): Location map of the TEM sites, AQBHR, Patna, Bihar

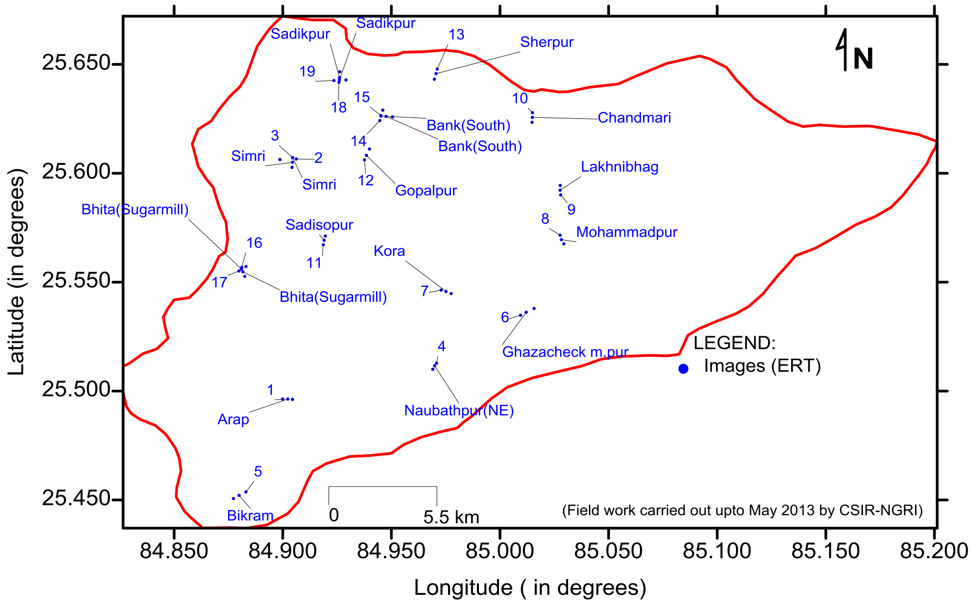


Fig. 3.6 b (3): Location map of ERTsurvey sites, AQBHR area, Patna, Bihar

3.6.2.3 The SKY-TEM survey

The state-of-the-art heliborne electromagnetic (heliTEM) survey-a major component of the AQUIM project, has been carried out in collaboration with Aarhus University, Denmark using dual moment SKY-TEM system developed at AarhusUniversity and operated and owned by SKY-TEM Survey Aps, Denmark. The dual moment ensures high-resolution information from near surface to deeper level by means of low and high magnetic moments of the transient electromagnetic field transmitting coil. Originally it was planned to carry out SKY-TEM surveys first to be followed by ground based geophysical investigations for spot subsurface character verification. But, due to time and administrative constraints the heliborne survey was carried out in December 2013 after the completing most of the ground geophysical surveys.

The entire area could not be covered by heliborne survey due to non-availability of clearances from concerned Ministries.Only a triangular patch of about 150 km^2 in the south-western part of the project area could be covered under SKY-TEM survey within which 52 km^2 of the project area lies (Fig. 3.6 c1 & 3.6 c2). The heliborne survey data was acquired with close spaced flight-lines (250 m) which extended up to SonRiver towards west. There were 50 fly-lines in west-east direction. The average flight speed of the helicopter was 22 m/s with an average flight altitude (frame height) of 30 m above the ground. The detail of the SKY-TEM survey is presented in Table 3.6 (c). Total flown line km works out to be about 765 km, but 770 line km data was acquired and also accepted for processing. Even though the survey area is influenced by man-made installations, the general quality of the acquired data is good. The gaps seen in SKY-TEM flight lines are either no flow or filtered out data due to the structures such as power lines, roads, fences, village, towns, etc.

The aim of heliborne survey in AQBHR was to map the alluvial-aquifer system in Middle Ganga Alluvial Plain. The result of this project also focuses on the applicability of heliborne survey in alluvial environment. It aims to demonstrate the efficacy of the heliborne survey as a cost effective, fast-coverage, high-resolution method for aquifer mapping. The dense data information on sub-surface through heliborne survey is expected to facilitate the future aquifer management program.

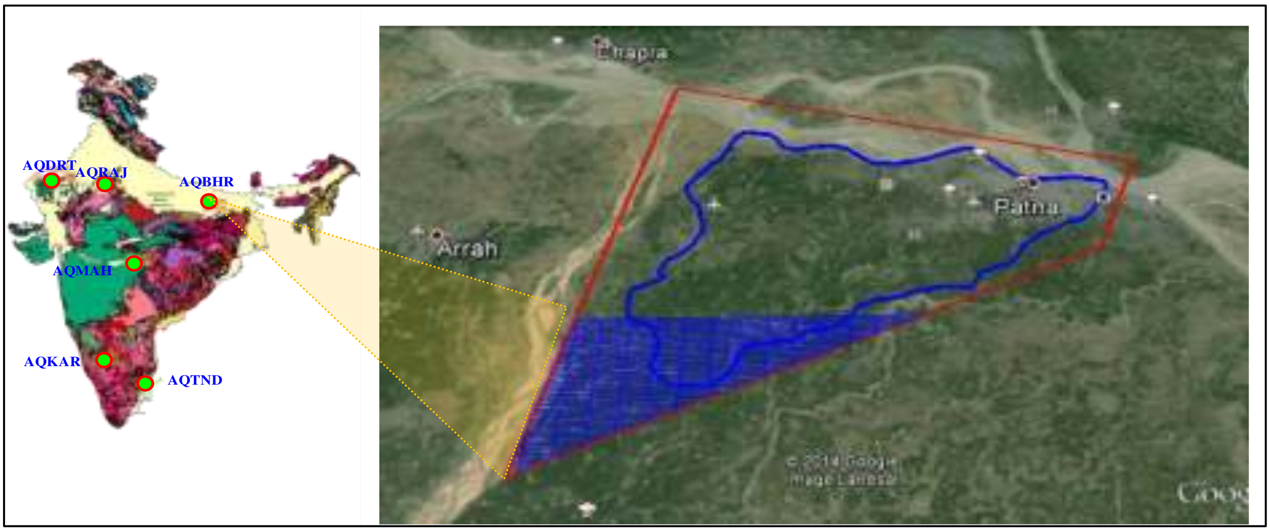


Fig. 3.6 c (1): Location map of the AQBHR pilot area showing the SKY-TEM flight lines (flight lines are shown as bluelines)

The results from the SKY-TEM survey were analyzed independently along several profiles parallel to the flight-lines (east-west) and also collated while studying them spatially. The SCI approach to analyze the data base has been used essentially for the spatial integrity of the results. The surveyed area has been studied along a few profile lines through Smoothed Inversion Mode (SIM, 1-D resistivity-depth information) of heliborne data at selected ground geophysical measurement (VES, TEM and ERT) sites and compared with the layer parameters obtained from ground geophysical surveys. The results were also correlated with borehole lithological depth sections and finally inferences were drawn on aquifer dispositions. An attempt has also been made to deduce 3-D view of the aquifer disposition in the pilot area.

Table 3.6 (c): Details of the SKY-TEM survey

SKY-TEM survey AQBHR 2013	
Locality	AQBHR, India
Field Period	December 02-09, 2013
Line km planned	765 km
Line km acquired	770 km
Flight Line separation	250 m
Tie Line separation	2000 m
Average flight speed	~22 m/s
Average flight altitude (frame height)	30 m above the ground

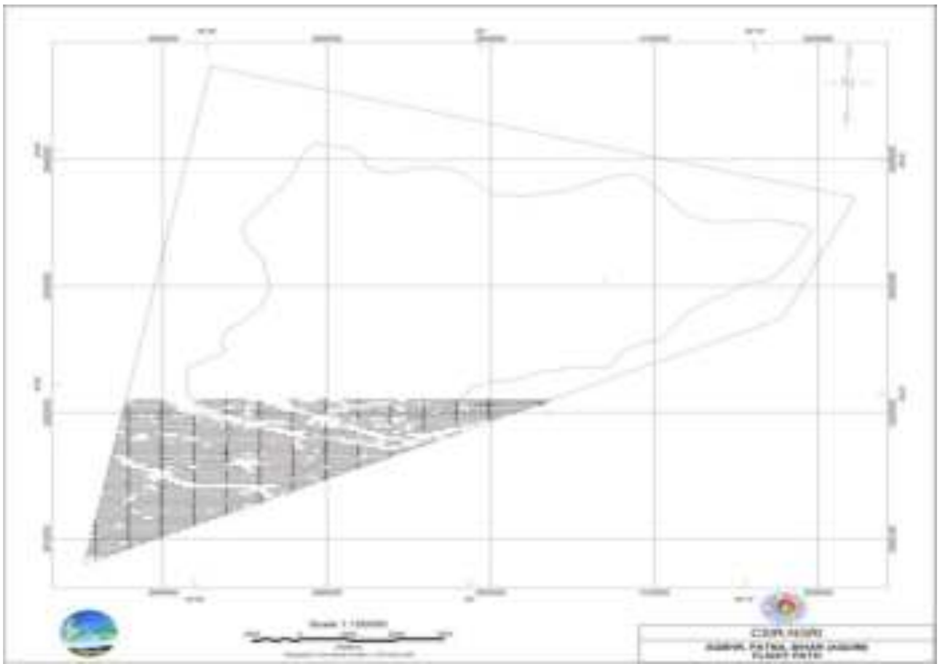


Fig. 3.6 c (2): Location map of the AQBHR pilot area showing the SKY-TEM flight lines

3.6.3 Validation, data integration and translation into hydrogeological model

In order to achieve one of the main objectives of mapping the principal aquifers, we established an approach for translating the geophysical results into the hydrogeological models through the steps as follows:

a. SKY-TEM results are calibrated against the drilling lithologs, ground and borehole geophysical results and then integrated lithological log at each borehole are prepared.
b. Equivalent litho-units of the integrated logs are converted into principal litho-units as proxy of principal aquifer and aquitard.
c. The principal lithologs are imported to the Surfer and incorporated with the individual sections prepared at each 2 km x 2 km grid line as shown in Fig. 3.6 j(9).
d. The principal litho-facies are interpolated and extrapolated along the SKY-TEM sections using the calibrated resistivity values.
e. Based on the hydrostratigraphy, the principal lithological units are finally attributed into principal aquifers, exploited aquifers and confining layers.

Lithological layer boundaries are prepared for all possible SCI model separated ~25 m from each other along the grid lines. This is followed by gridding using the kriging interpolation scheme. The interpolation has averaged out some of the sharp anomalies indicating smooth variation. In order to retain the small-scale variation, it is desired to do the digitization and demarcation of lithological boundaries for all the flight lines.

3.6.4 HeliTEM results

To draw the hydrogeological inferences from the SKY-TEM data inversions first the depth upto which the information could be reliably obtained is studied. The depth of confidence (DOC) obtained from the SKY-TEM data in the area varies from 40 to 400 m below ground level (Fig. 3.6 d 1).The information is obtained from depths more than 280 m in the eastern part and it is maximum upto 320 m. As per the colour code given in Fig. 3.6d (1) the blue patches show DOC less than 120 m, whereas it ranges from 140 to 160m in the areas with green patches. The yellow and red patches show DOC more than 200 and 240 m, respectively. Based on these codes it is observed that on an average the aquifers upto depths around 260 m could be delineated from the SKY-TEM data inversions.

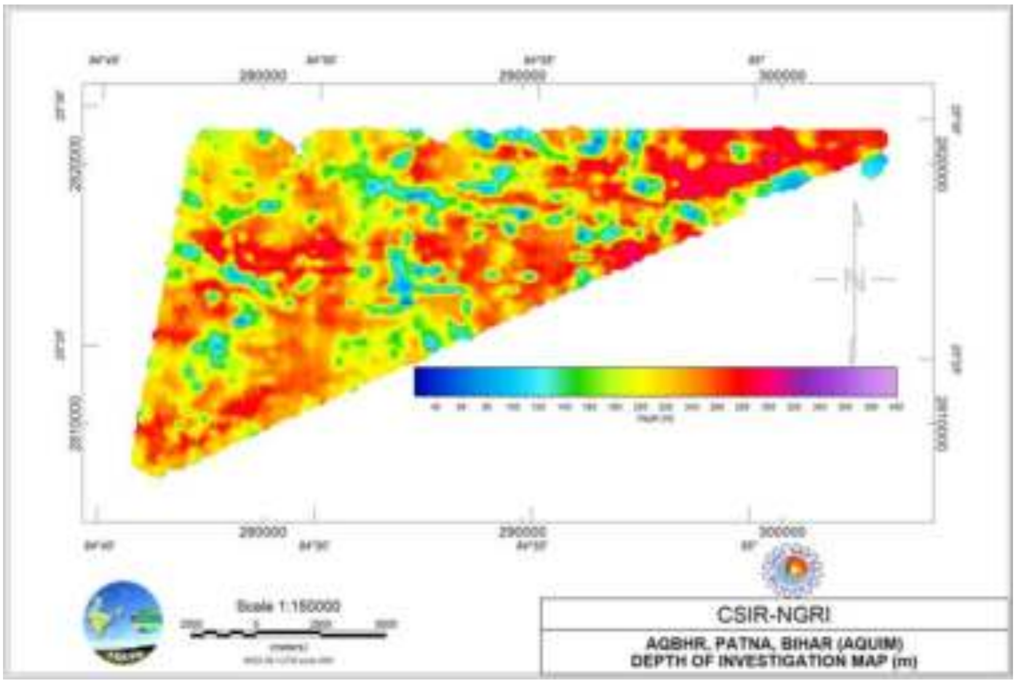
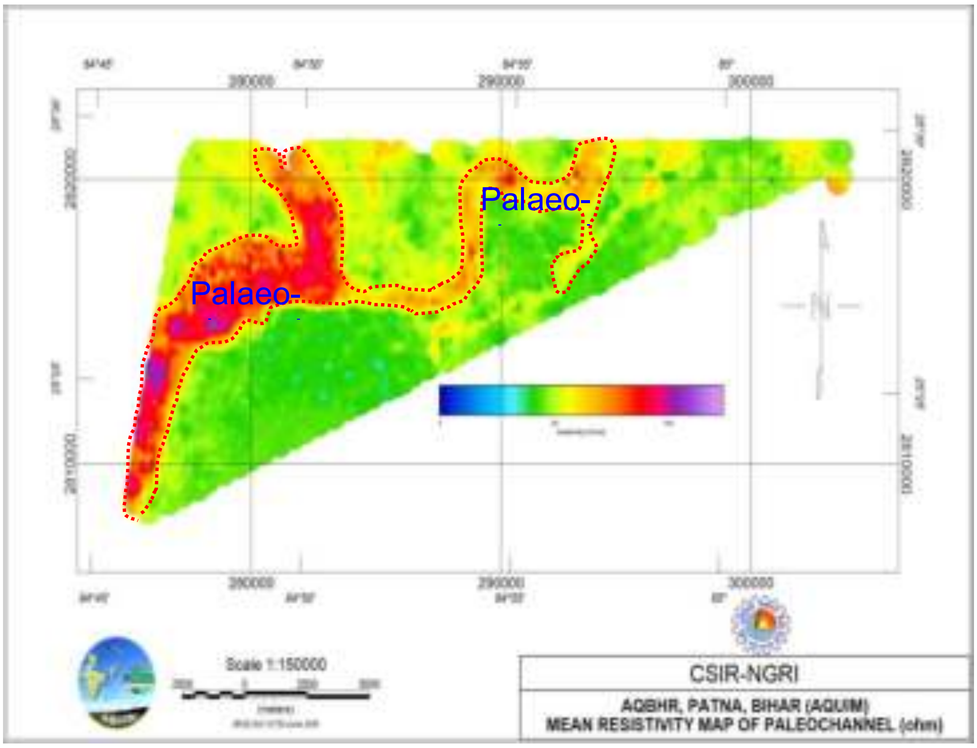


Fig. 3.6 d (1): Map showing DOC of the SKY-TEM data in the AQBHR area, Patna, Bihar

3.6.4.1 Palaeo-channels

The SKY-TEM data have been analyzed and interpreted to locate the near-surface palaeo-channels. The palaeo-channels hold material of relatively higher granularity and relatively associated with higher resistivity compared to the surrounding, if the granular materials of palaeo-channels are saturated with fresh water. These palaeo-channels are confined within 20-30 m depth from the ground surface. To demarcate the palaeo-channels characterized with higher mean resistivity, the resistivity distribution obtained from SKY-TEM are sliced at depth ranging from 5 to 35 m below ground surface. The selective mean resistivity depth slices are shown in Figs. 3.6(d 2) & 3.6 (d 3). Palaeo-channels are manifested in the western part of the project area (Fig. 3.6 d 2) at a depth around 20 m. It is oriented in NE-SW to E-W directions in the central part. Its influence diminishes with depth and extensions are limited in the central western part of the study area as seen in Fig. 3.6 d (3).



3.6d (2): Spatio- occurrences of palaeo-channels at depth of 20 m, bgl in the AQBHR area, Patna, Bihar

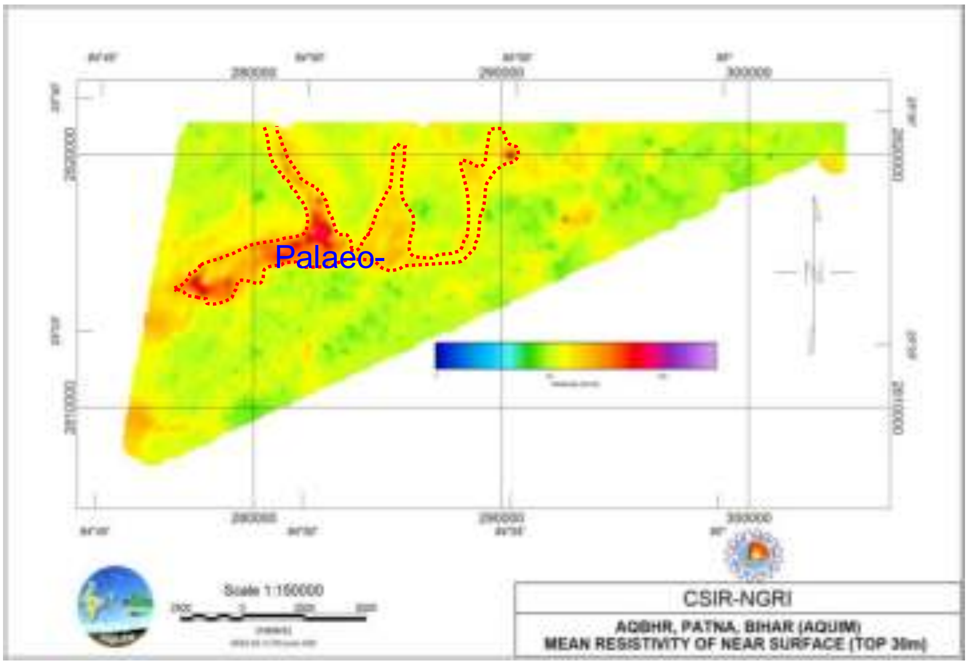


Fig. 3.6 d (3): Spatio- occurrences of palaeo-channels at depth of 30 m, bgl in the AQBHR area, Patna, Bihar

3.6.4.3 Aquifer systems

The aquifers underlying the palaeo-channels are shown through two typical SCI resistivity cross-sections shown in Fig. 3.6 e (1). The profile AB taken in the extreme northern part of the flown area shows multi-aquifer systems over a stretch of 25 km from west to east of the study area up to explored depth of 250 m. There is a continuous black line imposed in the section represents the DOC depth variation. The electrical resistivity distributions beyond the DOC line are not considered for any hydrogeological interpretation. The resistivity variations are shown through different colour codes. The near-surface red colour section indicates the occurrence of electrically resistive (30-60 Ω-m) palaeo-channels. These palaeo-channels are impregnated in a relatively less resistive (7-15 Ω-m) near-continuous strip shown through yellow colour. Underling it, the continuous red coloured strip across the profile length represents the resistive first principal aquifer. It is further underlain by a laterally discontinuous thin strip of green and yellow colour associated with resistivities around 7-15 Ω-m attributed to the presence of a clay layer. As observed, the clay layer is not continuous laterally. The discontinuity in clay layers are shown by arrows at a1 and a2 in AB section and a3 in CD section. The advantage of SKY-TEM over ground geophysical survey is aptly illustrated here. Resolving such discontinuities in clay layer is very difficult through ground based geophysical measurements, and even if it is attempted, the ground survey close coverage would take enormous time. It is possible only from the dense data which could be acquisitioned through SKY-TEM in such a short time. Underlying the clay layer the second principal aquifer is encountered at depths in both the sections. The resistivity of the aquifers varies from 20 Ω-m to 120 Ω-m. The higher resistivity of aquifer indicates higher granularity and hence higher water yielding capacity.

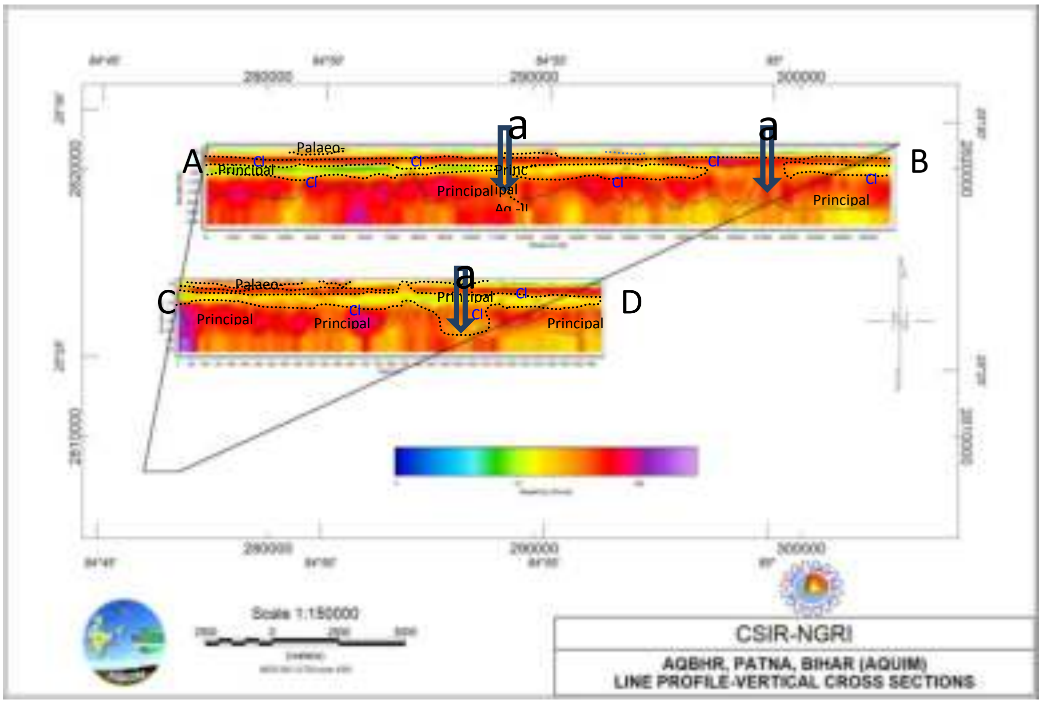


Fig.3.6e (1): Electrical section along line profile-vertical cross-section in the AQBHR area, Patna, Bihar

Fig.3.6 e (2) shows the mean resistivity of the first principal aquifer. It is controlled with an average resistivity around 60-70 Ω-m. The potentiality being associated with granularity and hence the resistivity, the first principal aquifer is better developed in the south-eastern and northern parts part of the flown area. However, in the south-western part the resistivity is less than 20 Ω-m, indicating mixing of clays with sand in the aquifer in this area. The deeper second principal aquifer is extensive (Fig. 3.6 e 3). It is delineated throughout the flown area. However, there are variations in resistivity of the deeper second principal aquifer. The resistivity is relatively high in the western part and low in the south eastern part (Fig. 3.6 e 3). These analyses reveal that while the first principal aquifer is developed prominently in the eastern and northern part towards the present day course of River Ganga located more than 20 km far way, the second principal aquifer is more predominant in the western part near the present day course of River Son, indicative of the palaeo-environment and the parent source of deposition of these aquifer formations.

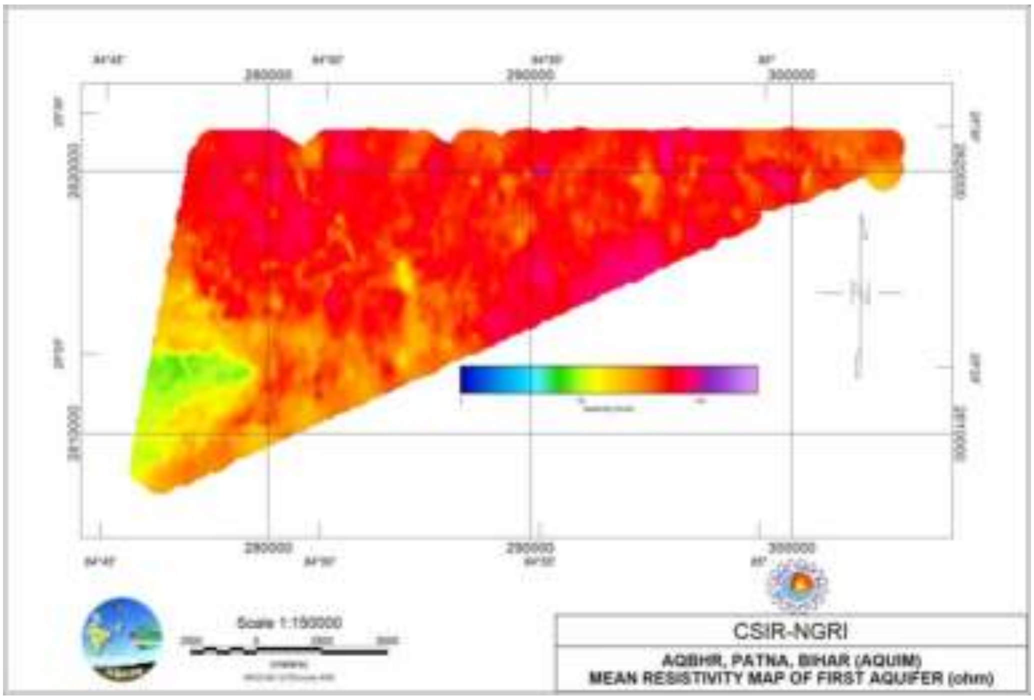


Fig. 3.6 e (2): Mean resistivity of the first principal aquifer in the AQBHR area, Patna, Bihar

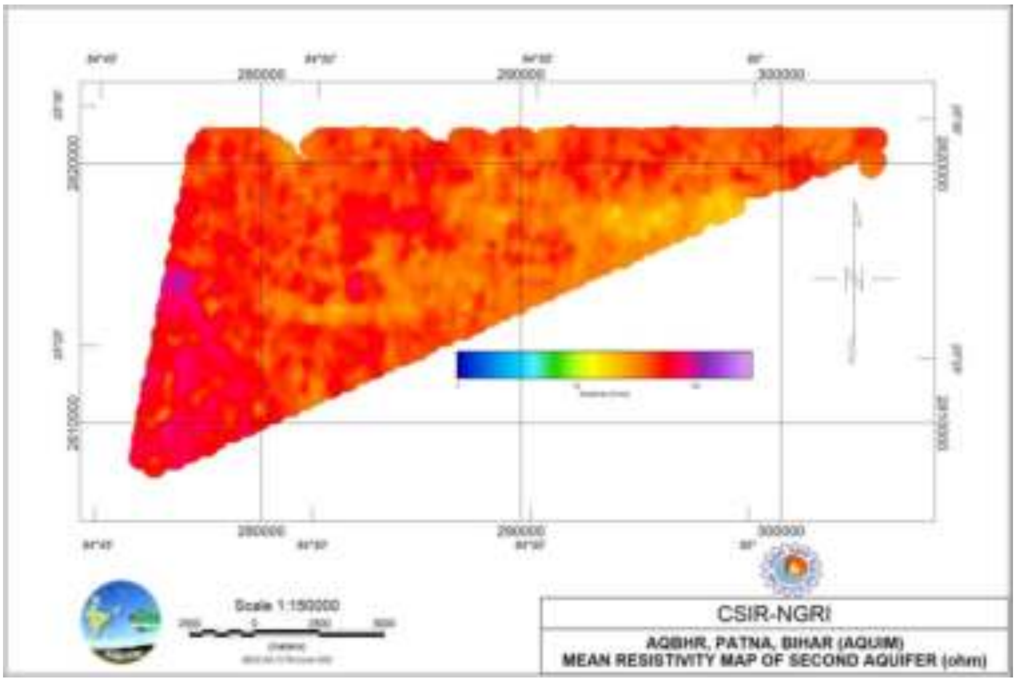


Fig. 3.6 e (3): Mean resistivity of the second principal aquifer in the AQBHR area, Patna, Bihar

3.6.5 HeliMag results

HeliMag survey was carried out along with the HeliTEM using Geometrix Caesium vapour type having sensitivity 0.1 nT. Magnetic sensor was synchronized with TEM measurements. The position of the magnetometer sensor is located at the front panel as shown in Fig. 3.6 f (1).

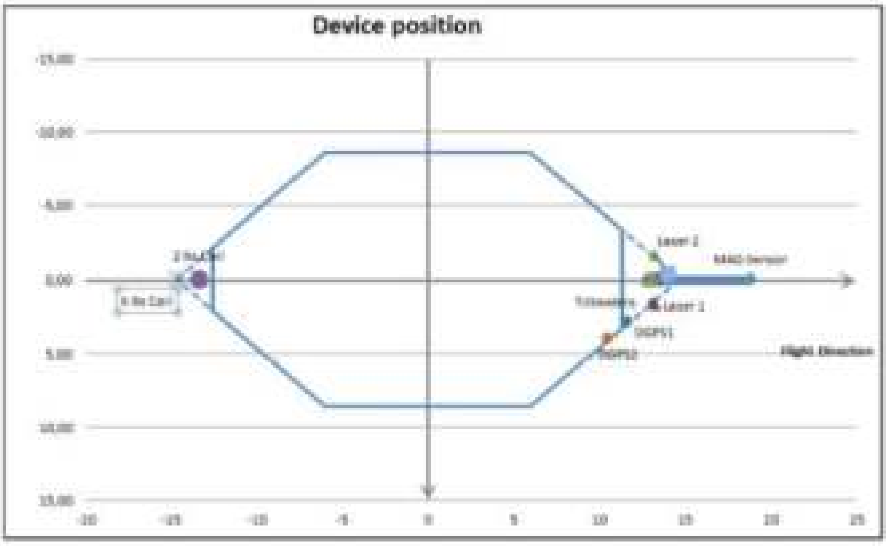


Fig. 3.6 f (1): Sketch showing the frame and the position of the basic instruments including the GPS position

A base station was used for continuous magnetic measurement to record the temporal changes, which is applied for correcting the magnetic data recorded by the by main magnetometer attached with HeliTEM transmitter. Final processing of the magnetic data involved an application of traditional corrections to compensate for diurnal variation and heading effects prior to gridding. Advanced full processing of magnetic data was implemented in Geosoft's Oasis Montaj software as follows:

- Processing of static magnetic data acquired on magnetic base station
- Pre-processing of airborne magnetic data
- Stacking of data to 10 Hz in SkyLab (SKY-TEM in-house software).
- Moving positions to the center of the sensor in SkyLab.
- Processing and filtering of airborne magnetic data
- Standard corrections to compensate the diurnal variation and heading
- effect
- IGRF correction

- Statistical and full levelling
- Micro levelling, and
- Gridding

Finally total magnetic field intensity map has been prepared after all correction and data levelling (Fig. 3.6 f2). The magnetic field of the flown area varies from 46790 to 46980 nT. The higher magnetic field is observed in the north-west part as well as in the middle of south-eastern part of the study area. The higher magnetic field indicates compartively the shallow basement. A linear strip of low in magnetic field is observed in the central part of the flown area which indicates a NE-SW deepening trend in the basin. The most significant finding from the heliMag map is the deepening of the pre-Tertiary basement and associated deepening of second clay bed in the southeastern part of the area.

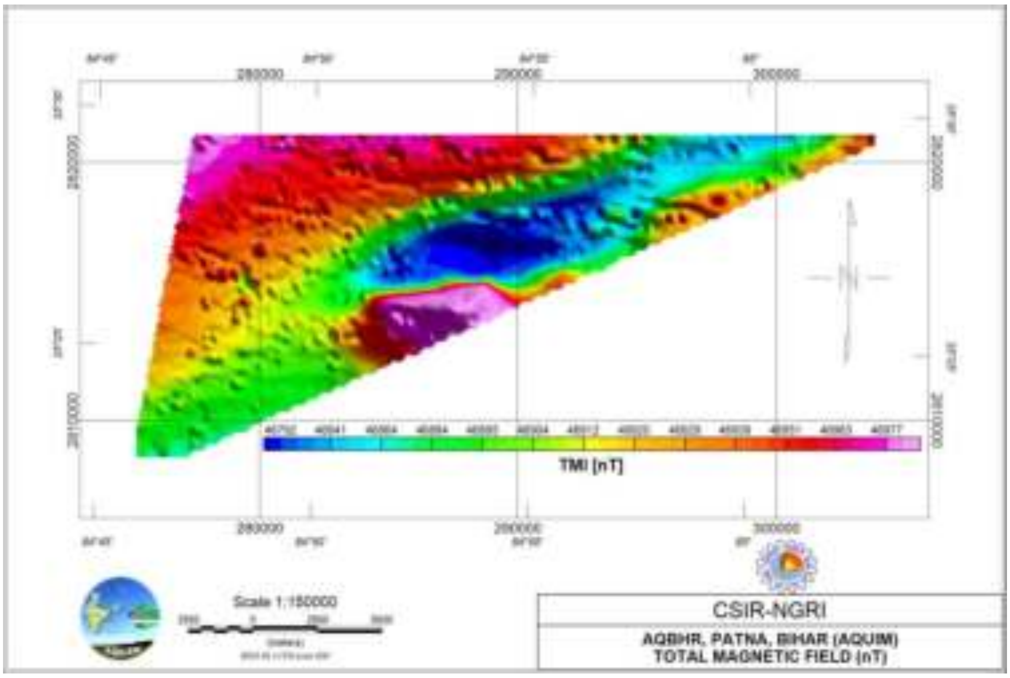


Fig. 3.6 f (2): Total magnetic field (in nT) in the AQBHR area, Patna, Bihar

3.6.6 Comparison performance of the SKY-TEM data along with ground geophysical data and value addition analysis

An attempt has been made to have comparative analysis between the SKY-TEM and ground geophysical results. The comparison has been done in three ways as: i) Sky-TEM vs.existing borehole logs and its lithologs, ii) SKY-TEM vs.1-D geophysics i.e., VES and TEM; and iii) SKY-TEM vs. ERT. Because so far the drilling was not conducted in the SKY-TEM flown area. The existing drilling results along with ground geophysical survey and the SKY-TEM data have been validated below.

3.6.6.1 Comparison of SKY-TEM results and geophysical logs of boreholes

The SKY-TEM results were compared with the geophysical logs of 2 existing boreholes drilled in the area. A profile has been drawn in South-North direction encompassing the 2 boreholes (W-1 and W-II approximately 6 km apart, Fig. 3.6 g (1)). The short-normal and long normal resistivity values correlate satisfactorily with the high resistivity zones obtained from the SKY-TEM results and vise versa. Broadly it shows multi-aquifer systems up to the explored depth of 300 m. The first principal aquifer starts at a depth around 40 m bgl and thickens towards north, but the bottom clay base of the first principal aquifer becomes shallow. The second principal aquifer may not be under complete confined condition. It could be in leaky-confined aquifer condition as the top clay layer may not be confining layer (Fig. 3.6 g (1)). The resistive zones at shallow depth inferred to be palaeo-channel could be prominently traced by SKY-TEM, which could not be picked up from logging as it starts from 20 m depth.

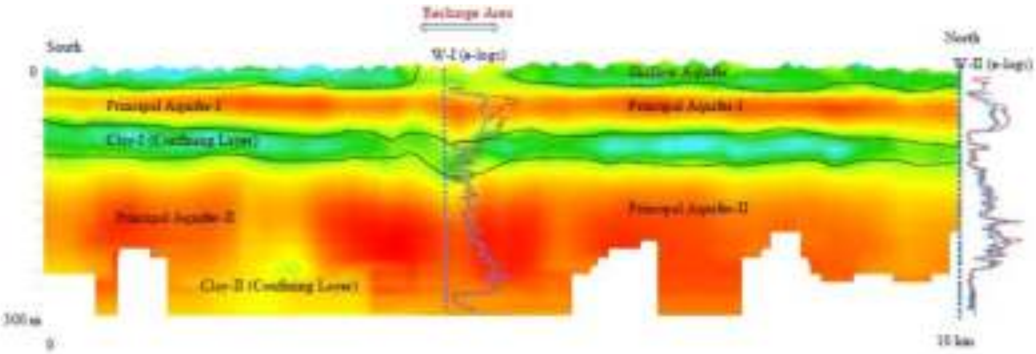


Fig. 3.6 g (1): Comparison the results of SKY-TEM with the resistivity log of boreholes.

3.6.6.2 Comparison of SKY-TEM results and borehole lithologs

The SKY-TEM section along the same profile (Fig. 3.6 g (2) has been compared with the litho logs which are available for the bore wells W-I &W-II. The clay layer at shallow depth exiting all along the profile length is nicely picked-up. Also, the clay layer at depth separating the first and second principal aquifers is picked-up as a prominent band of low resistivity. The deeper thick resistive sand zones –the second principal aquifer is delineatable. Its resistivity varies spatially. In the southern part it gets mixed with finer sediments and the resistivity gets reduced to about 20 Ω-m. The bottom of the second principal aquifer could not be resolved precisely because of DOC limited to about 200m.

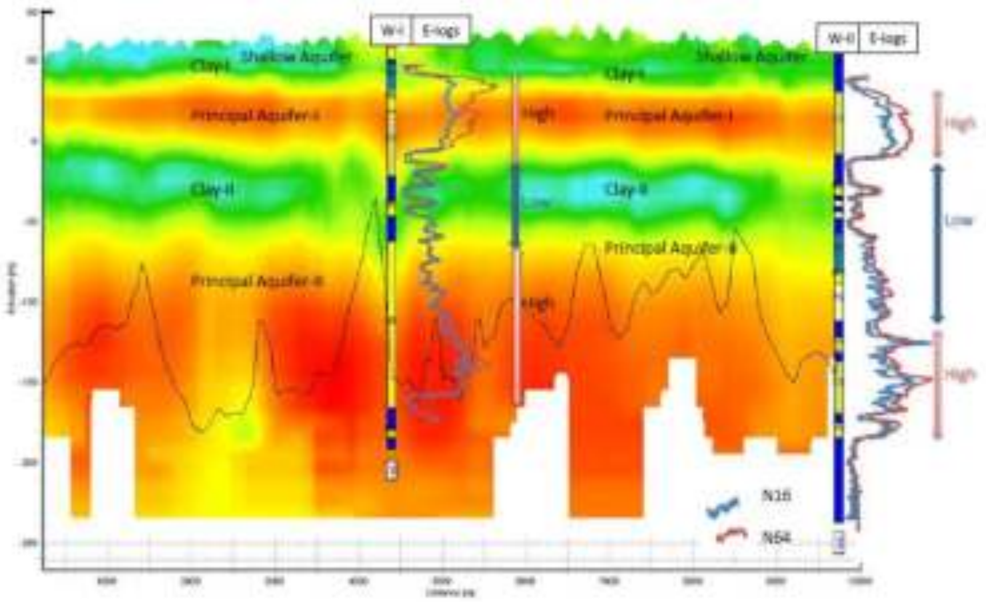


Fig. 3.6 g (2): Comparison of the results of SKY-TEM data with borehole lithologs

3.6.6 .3 Comparison of SKY-TEM and VES results

The VES 3 observed at Bikram is located towards east of Bikram bore well (W-I). The interpretation of the VES curve yielded 9 geoelectrical layers (Fig. 3.6 g3) and the depth investigated is beyond 526m. The VES reveals clay with 8 Ω-m resistivity in the depth range of 14 to 25 m bgl. The overlying layer has a higher resistivity around 27Ω-m. At this site the first principal aquifer is associated with 58 Ω-m resistivity. Its thickness is around 54 m which matches satisfactorily with the SKY-TEM resistivity section (Fig. 3.6 g 4). This layer is underlined by a conductive layers with 28Ω-m may form the confining layer and has a thickness of 54 m. This is further underlain by a layer with 51 Ω-m resistivity at a depth of 133m. It is the second principal aquifer of thickness around 96m. Significant finding at this site is the delineation of basement rock at a depth around 527 m bgl and the occurrence of a very thick (around 300 m) layer of relatively less resistivity (25 Ω-m) material in between the second aquifer and the basement. The resistivity 25 Ω-m is the average resistivity and may contain sand predominating layers, which could not be differentiated by the VES due to their deeper occurrences and relatively less thickness. The depth to the bottom of second aquifer is 230 m bgl and it also matches satisfactorily with the SKY-TEM results. Another SKY-TEM section in S-N direction was compared with the results of VES BV-19 carried out at Khoriatha village (Fig. 3.6 g 5), located around2 km away from the borehole Bikram. At this site the resistivity and thickness are 65 Ω-m and 66 m, respectively, of the first principal aquifer deduced from VES matches with the results of the SKY-TEM results. The boundary between the first aquifer and clay is also deduced from the VES and corroborated with the SKY-TEM result.

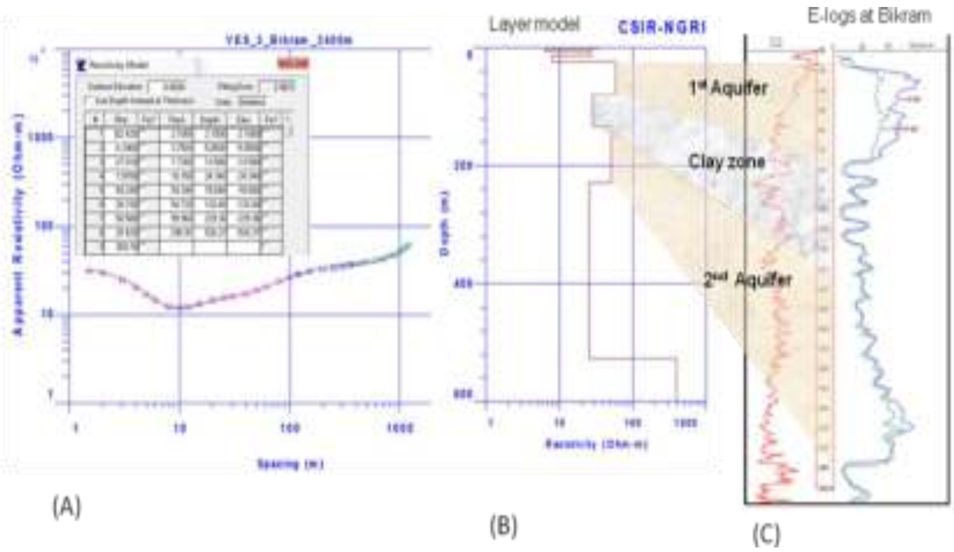


Fig.3.6 g(3): The interpreted results of VES BV-3 at Bikram; (A) observed and model VES curves, (B) layer model and (C) electrical logs of borehole at Bikram, Patna, Bihar

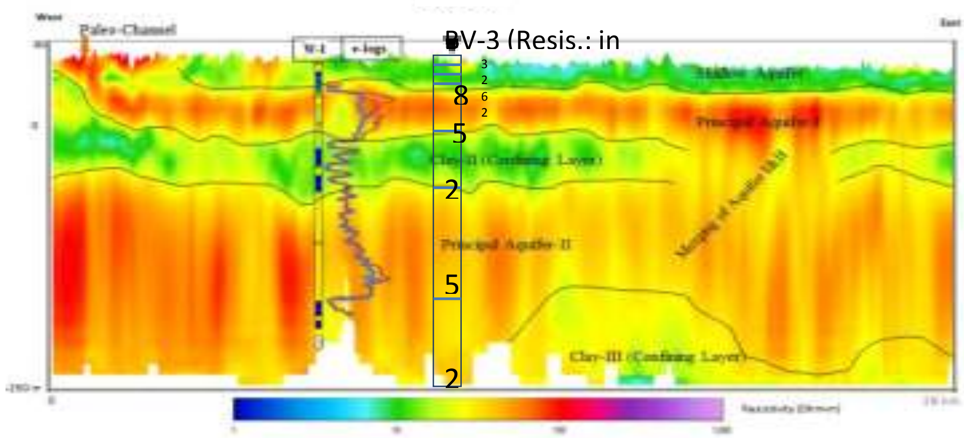


Fig. 3.6 g (4): The SKY-TEM results compared with the results of VES (BV-3), AQBHR area, Patna, Bihar

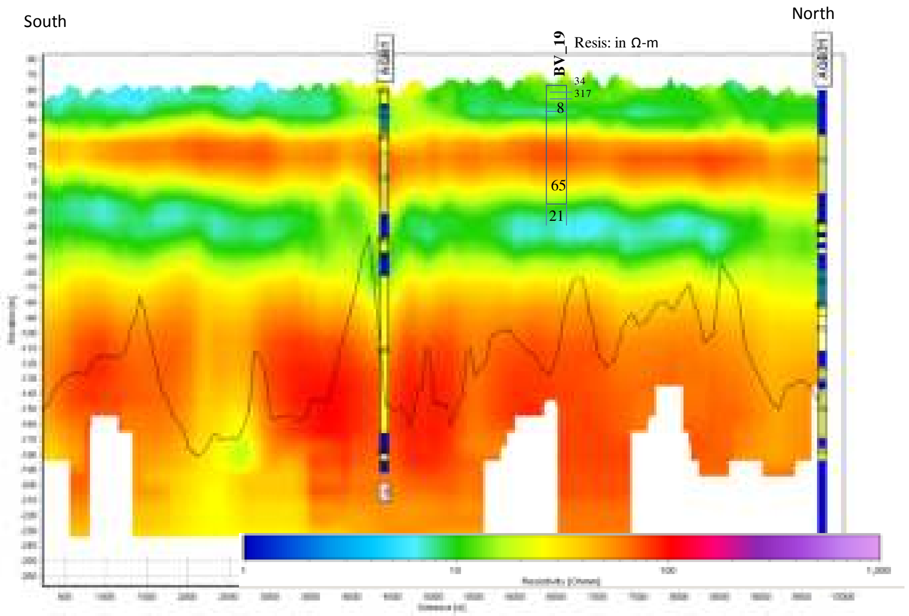


Fig.3.6 g (5): The SKY-TEM results compared with the results of VES (BV-19), AQBHR area, Patna, Bihar

A smooth layer model obtained from the SKY-TEM data was compared with the interpreted results of VES 53 (Fig. 3.6g 6). The resistivity of first principal aquifer obtained from SKY-TEM is lower while that of the second principal aquifer is little higher. Overall, the inferred lithological units for both these techniques are more or less the same.

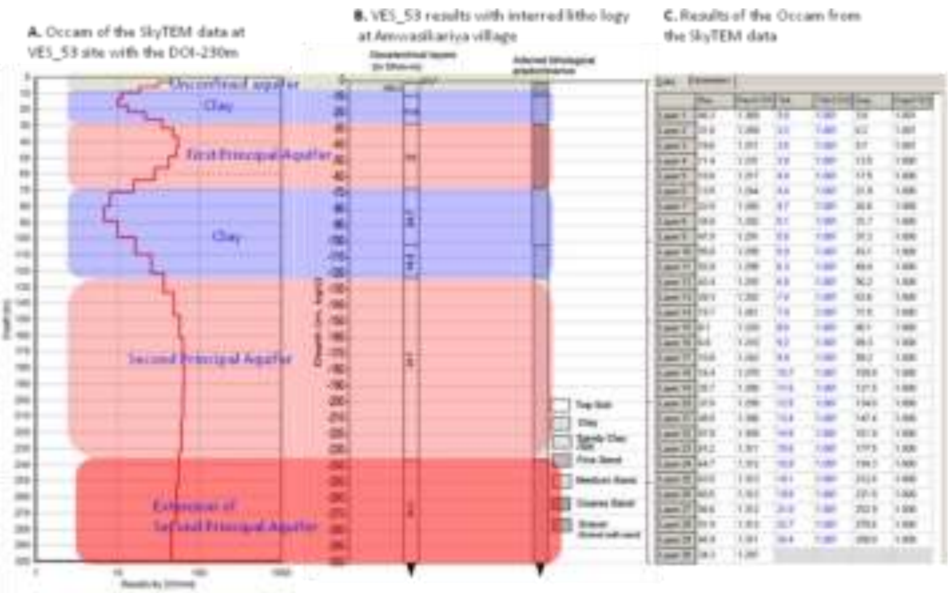


Fig. 3.6 g (6): The VES showing (A) the Smoothed Inversion Model (SIM) of the SKY-TEM data, (B) layer parameters of the VES and inferred litho-units, and (C) interpreted SIM inverted layer table at Amwasikariya village.

3.6.6.4 SKY-TEM data compared with TEM data

The ground TEM data at the site of TEM 17 (village Bikram) indicates clay (resistivity17 Ω-m) up to the depth of 28 m bgl (Fig. 3.6 h (7)). The near-surface aquifer is obtained within 9 m depth. The bottom of first principal aquifer (resistivity 58Ω-m) is at 77 m bgl. Underlying this clay layer (resistivity: 12 Ω-m) is encountered. The bottom of the first aquifer is not resolved by the ground TEM data alone due to low power transmitter of the equipment (TEM Fast 48 PC) used. The resistivity around 17 Ω-m for the clay is also obtained from SKY-TEMSIM (DOC: 230m), but the resistivity of the underlying first principal aquifer is to be lower compared to the ground TEM data. The depth to the bottom of first principal aquifer obtained from the SKY-TEM and the ground TEM data are in agreement.

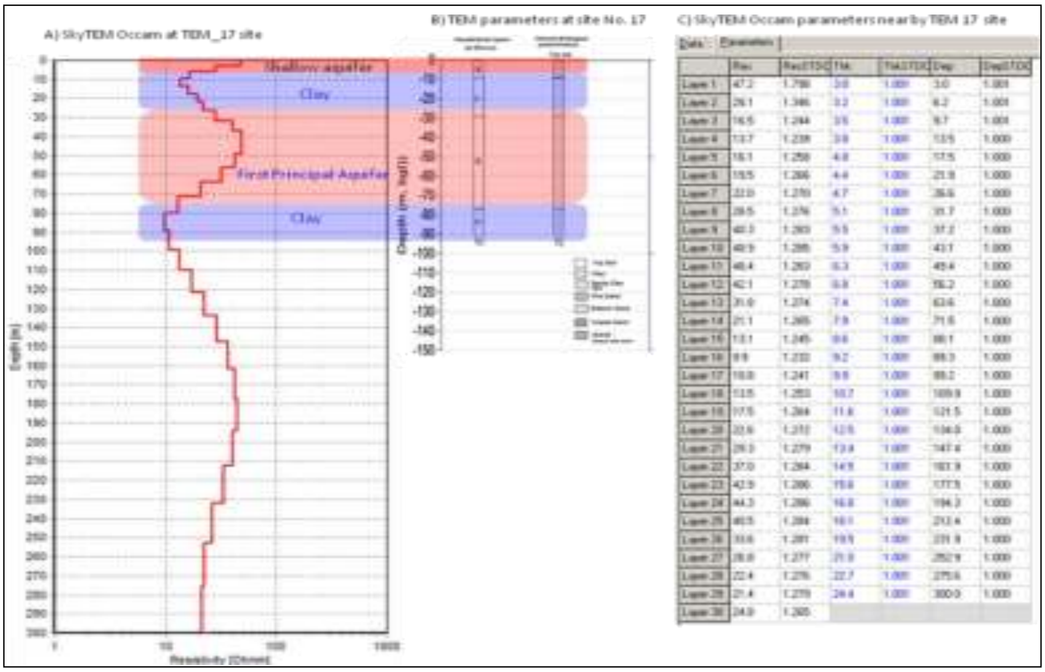


Fig.3.6 g(7): TheSIM results of SKY-TEM data at the site of ground TEM 17; A) SIM of SKY-TEM sounding, B) Layer parameters of the Ground TEM and inferred lithounits, and C) interpreted SKY-TEMSIM parameters at TEM 17.

3.6.6.5 Comparison of the SKY-TEM and ERT data

A total 19 ERTs were collected using IRISmakes Syscal R1+ Instrument, France during December 2012 and interpreted with the help of RES2DINV ver 3.71 Geotomo software. The ERT (No. 5, Fig. 3.6 g(8 A) at Bikram village is located in the SKY-TEM flown area. It revealed a clay layer up to an average depth of 26 m bgl and thereafter a sand layer - the first principal aquifer continuing to the explored depth of 60 m along this profile. It was confirmed through the SKY-TEM data shown in

Fig. 3.6 g(8 B). The SKY-TEM sounding Occam inversion result at the centre of the ERT profile indicates first principal aquifer occurring at a depth of 26 m bgl and continuing up to 60 mbgl. Its resistivity varies from 25 to 68 Ωm. It is also observed that the resistivity of top clay layer varies from 8.6 to 15.1Ω-m with an average resistivity of 12 Ωm in the SKY-TEM Occam inversion (Fig. 3.6 g8 (C)) which is more or less same (as in the ERT results). The clay layer at the bottom of the first principal aquifer acting as a barrier between the two principal aquifers was not resolved through ERT data due to limitation of instrument and proper spreading.

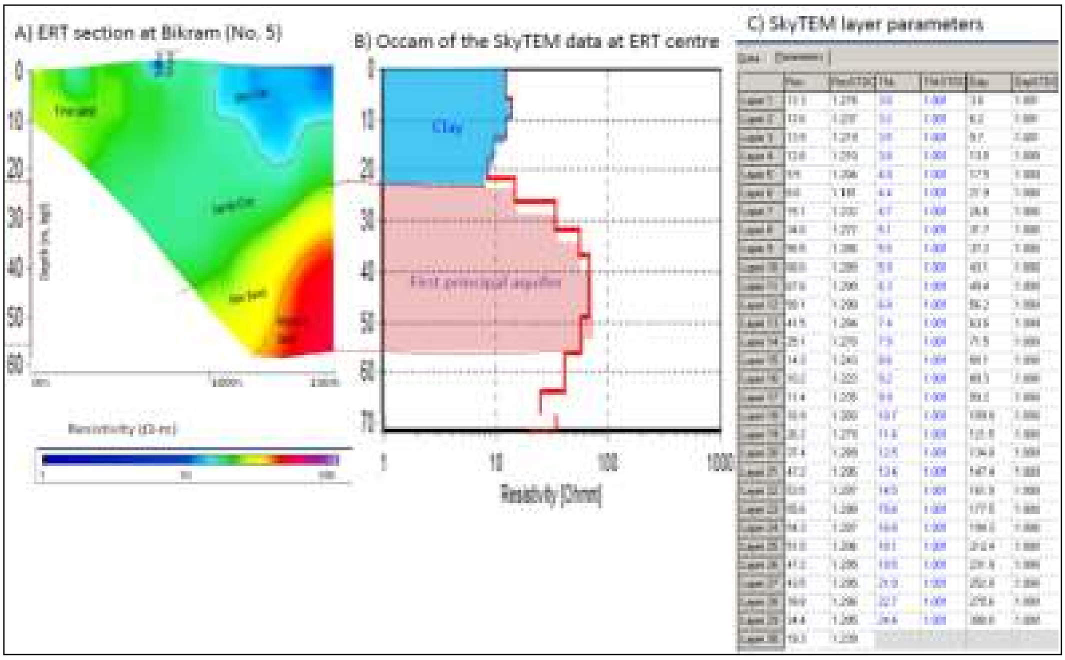


Fig.3.6 g(8): The comparison of ERT and SKY-TEM results; A) ERT section carried out at Bikram (BE-5), B) the SIM of the SKY-TEM sounding data at the center of the ERT and C) interpreted SIM parameters.

Overall, the SKY-TEM survey with dense and high quality data has added great value in mapping the subsurface that revealed several features of high significance in terms of ground water occurrence and dynamics and hence aquifer mapping.

3.6.7. Value addition and data integration

Validation of the heiloborne and surface geophysical data with the drilling log results has been done on the WellCAD platform using the evaluation version, an excellent platform for data validation and integration. Finally, all sorts of available information from heliborne, surface, borehole geophysics and drilling logs were integrated and prepared composite and integrated litholog upto 300 m depth. In addition the aquifer maps prepared from the SKY-TEM data were compared with the aquifers deduced by CGWB-MER, Patna and discussed below.

3.6.7.1 Comparison CGWB litho-section with the SKY-TEM, Ground based VES and TEM results

The litho-section of CGWB prepared based on only two available e-logs along Bikram-Moriyama have been compared with the SKY-TEM resistivity section. It indicates nearly perfect matching of litho-logical layers upto the SKY-TEMDOC. However the prominent clay layer detected in the SKY-TEM section between 75-125 m depth appears as thin discrete layers in the well e-logs section of CGWB. Similarly deeper persistence of thin clay layer appearing on the e-logs section is not detected because of limited DOC along this section (Fig. 3.6 h (1). Based on the validated litho-section (Fig. 3.6 h (1)), the continuity of the aquifer disposition upto Maner (North) has been also deciphered through the e-logs (Fig. 3.6 h (2)). Another validation of the SKY-TEMsection has been attempted with the e-log section along Bikram-Naubatpur in the flown area. Then based on the validated litho-section, the continuity of the aquifer disposition upto BN College (North-East) has been deciphered through the e-logs in the pilot area (Fig. 3.6 h (3).

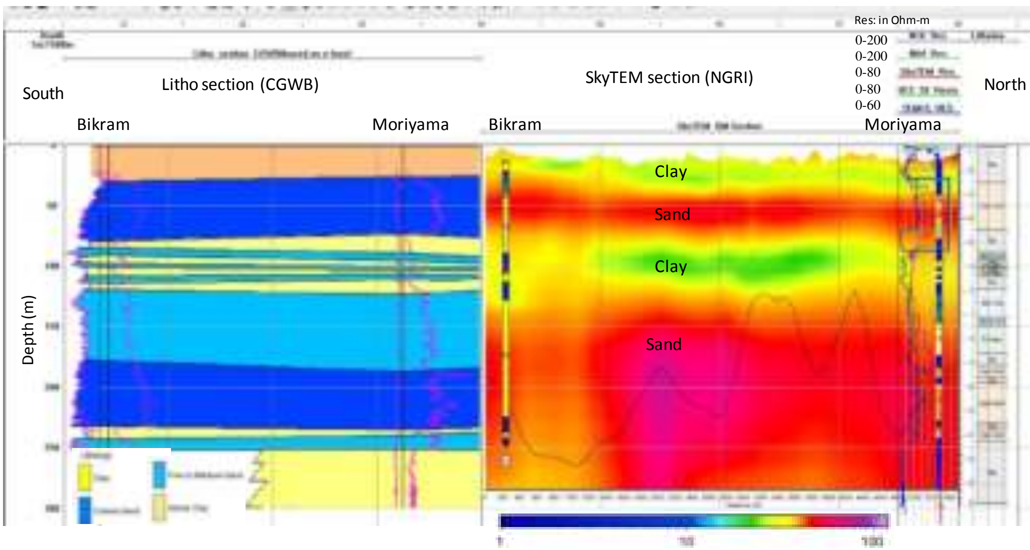


Fig. 3.6 h (1): Showing comparison of the SKY-TEM results with CGWB litho-section along Bikram-Moriyama

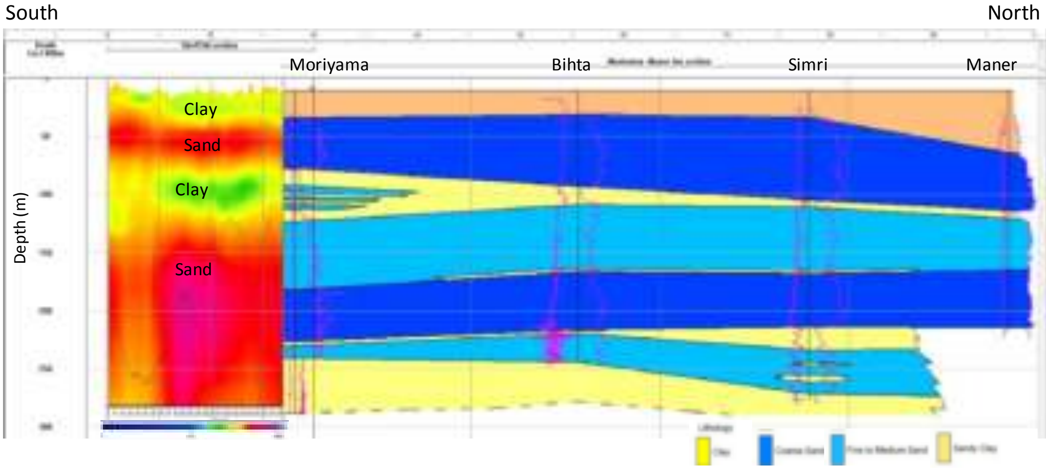


Fig. 3.6 h (2): Showing comparison of the SKY-TEM results with CGWB litho-section along Bikram-Moriyama and extended upto Maner in the AQBHR area

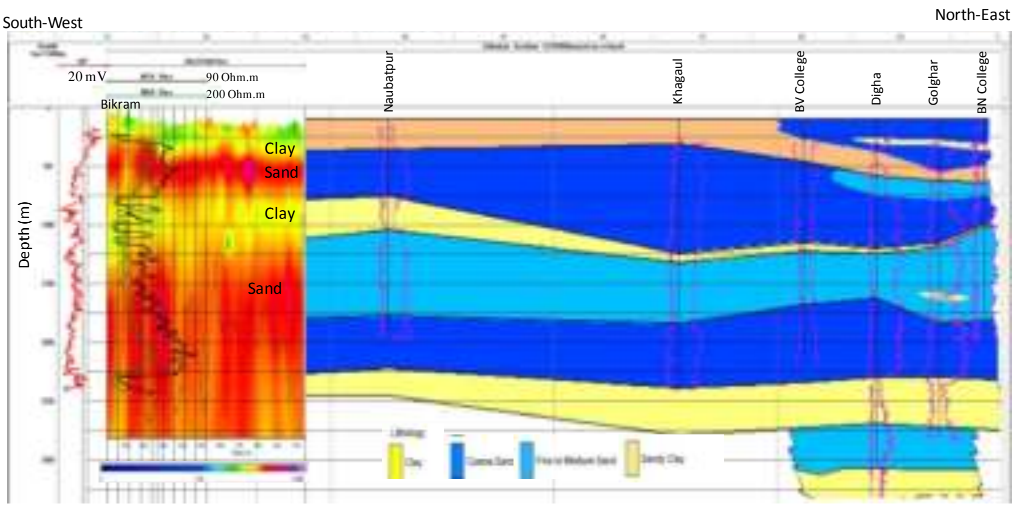


Fig. 3.6 h (3): Showing comparison of the SKY-TEM results with CGWB litho-section along Bikram-Naubatpur and using the e-logs the litho-section extending upto BN College where the SKY-TEM data not available

The SKY-TEMsection has been validated with the litho-section obtained from the results of CGWB-VES data along Bikram-Arap in the flown area. Thereafter based on the validated litho-section, the continuity of the aquifer disposition upto Bhatehari (North) has been deciphered through the interpreted results of CGWB-VES data (Fig.3.6 h (4)). Based on the validated litho-section in the Bikram-Arap area, the continuity of the aquifer disposition along Arap-Kalapur-Pandepur has been also deciphered with the help of CGWB-VES interpreted results (Fig. 3.6 h 5).

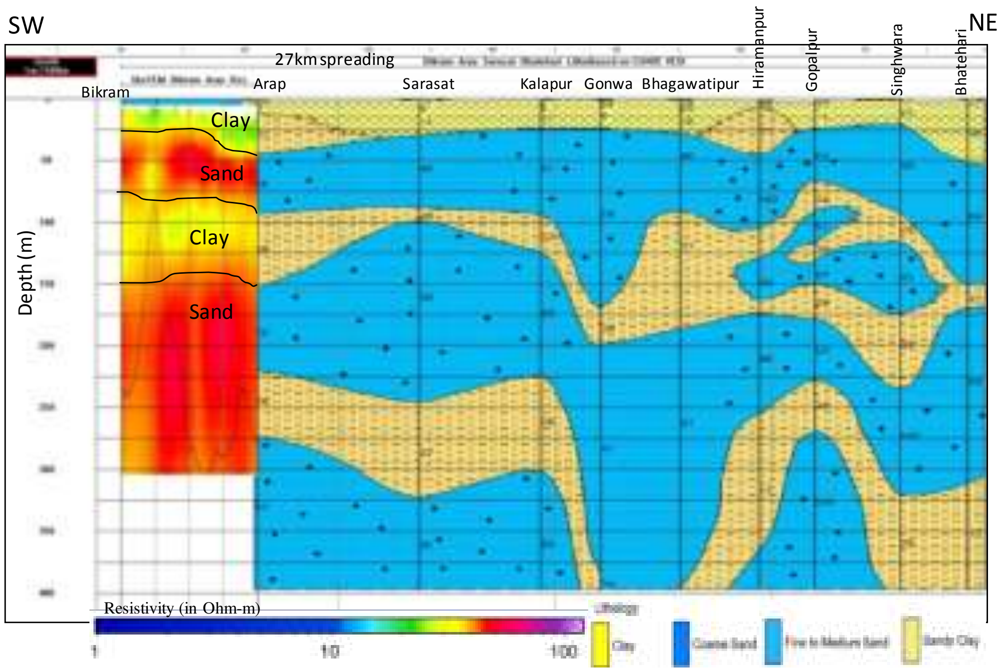


Fig. 3.6 h(4): Showing comparison of the SKY-TEM results with CGWB litho-section along Bikram-Arap prepared from the VES results and the litho-section extending upto Bhatehari where the SKY-TEM result is not available

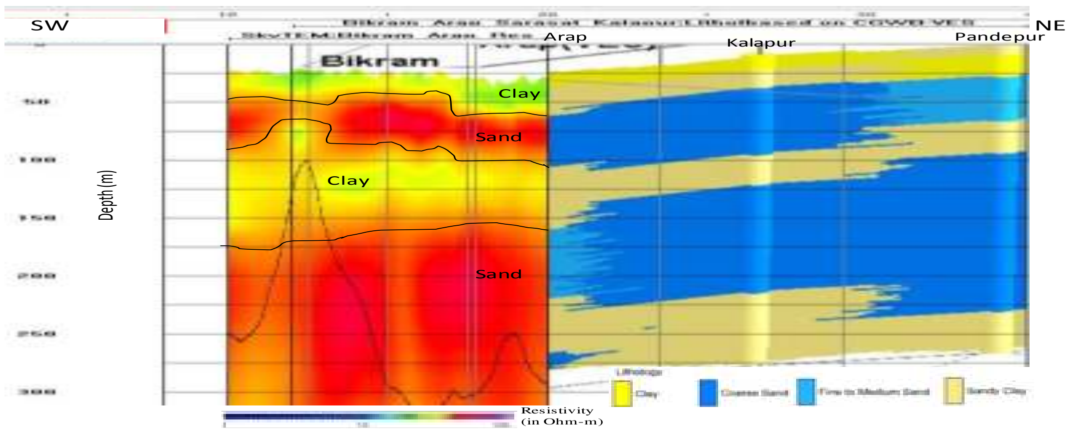


Fig. 3.6 h(5): Showing comparison of the SKY-TEM results with CGWB litho-section along Bikram-Arap prepared from the VES results and the litho-section extended upto Pandepur in the non-flown area of the AQBHR area, Patna, Bihar

3.6.8 Translation into hydrogeological model

Two dimensional perceptions on geo-electrical layer dispositions through several cross-sections (Fig. 3.6 i (1)) in South-North & West-East directions were made to understand the aquifers conditions over the study area. This attempt enabled in distinguishing litho-logical setting/discontinuity and formed an important aspect on understanding the hydrogeological condition of aquifers comparing the existing litho-logs. A typical section is discussed below and the rest were used for preparation of aquifer dispositions which are presented in annexure 3.6(d).

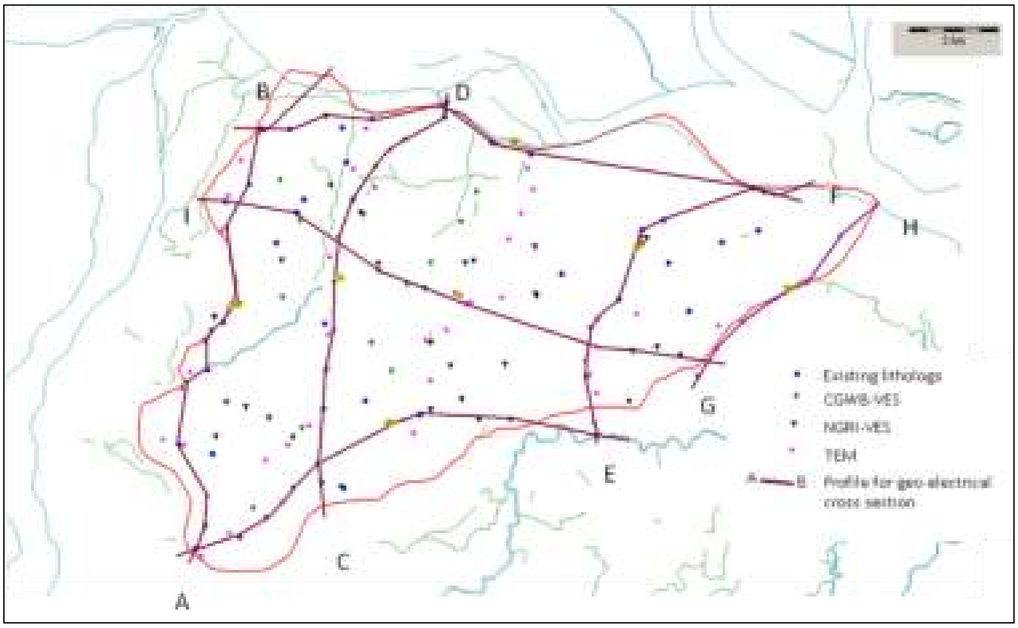


Fig. 3.6 i (1): Showing profiles (S-N & W-E orientations) considering all the interpreted VES, ERT, and TEM along with lithologs.

3.6.8.1 AB Profile (South-North direction)

Transformation of geophysical data into hydrogeological layers was attempted to evolve a 2-D perception along a traverse AB line (Fig. 3.6 i (1)) in the western boundary of the pilot area using the available lithological controls and geophysical sounding interpreted results. This attempt resulted in a more or less meaningful transformation and facilitated in mapping of sedimentary aquifers based on the interpreted resistivity values to a depth more than 300 m (Fig. 3.6 i 2) and beyond giving information deeper than the present lithological depth controls. In general it shows that the first clay layer separates shallow and first principal aquifers with the variable thickness and it also being thickening towards the Ganga River. The discontinuity of the Clay-I layer in between Sikaria and Raghpur indicates the presence of abandoned channel.

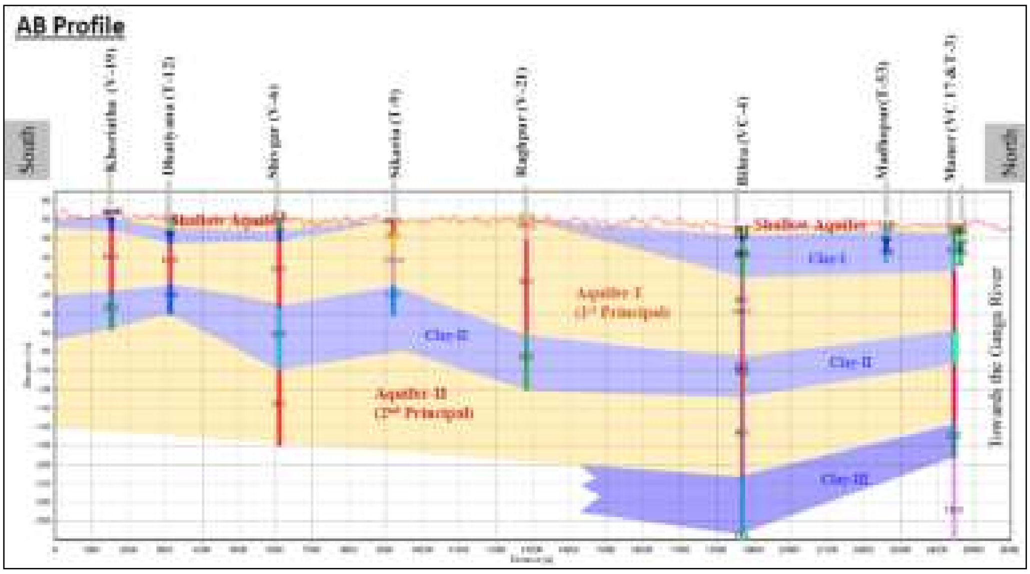


Fig. 3.6 i (2)**:** Showing aquifer deposition along the AB profile considering all the interpreted VES, ERT, TEM results

In addition, the transformation attempt from geo-electrical into hydrogeological brought out plausible litho-continuity from Bikram to Manner attributes in reasoning of clay occurrence of the area at the several stages which could be used for assigning the aquifer geometry for ground water modelling. When the continuity of the clay-II &III had been traced with the help of interpreted VES, TEM results, it had not been mapped towards Birkarm clearly.

Thus the e-logs and lithological controls through exploratory bore wells at Bikram and Maner along this section were incorporated and then it clearly demarcates the significant feature of first and second principal aquifers separated by the clay layers (Fig. 3.6 i (3)). The clay and sand facies sequences encountered in the boreholes on the southern part at shallow depth onwards were geo-electrically detected to extend beyond the depth of 287 m at Maner in the northern part. The continuity of clay layer was not demarcated in the southern part of this profile at the bottom of second aquifer due to the limitation of the shallow depth investigation through ground geophysical surveys. When this geoelectrical section was compared with e-logs and lithologs the extension of the clay layer, which acts as the bottom of the second principal aquifer, are clearly demarcated.

The hydro-geophysical transformation enabled to map principal aquifers of different stages (upto 2nd Confined aquifer) to a depth beyond 320 m (Fig. 3.6 i (4)). However, the continuity and depth of occurrences of different stages directly points out that the aquifers on the western part of the pilot area may respond and directly could be used as aquifer geometry for ground water modelling (fig 3.6 I 5).

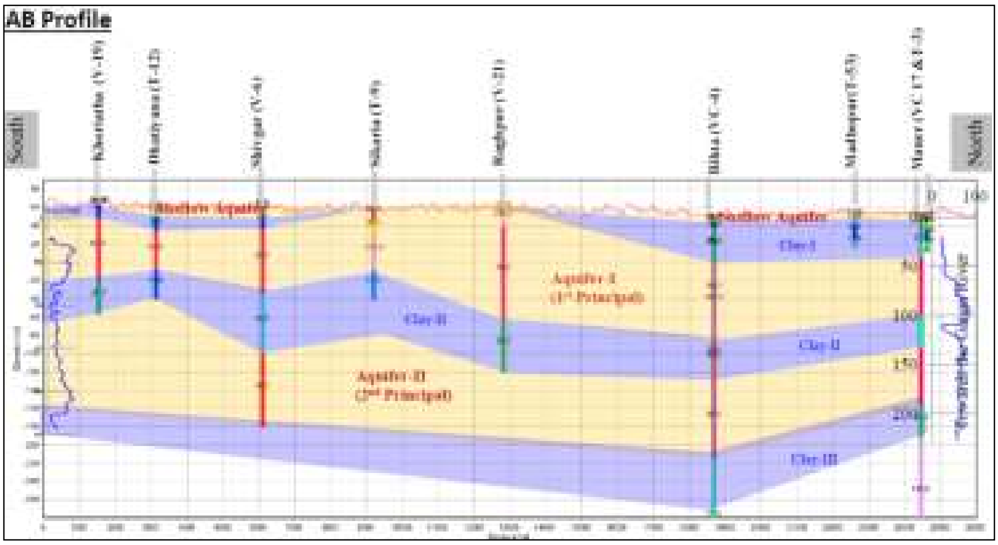


Fig. 3.6 i (3): Comparison of the e-logs (blue color trace showing long normal resistvity at bore wells) with theinferred aquifer depositions along the AB profile

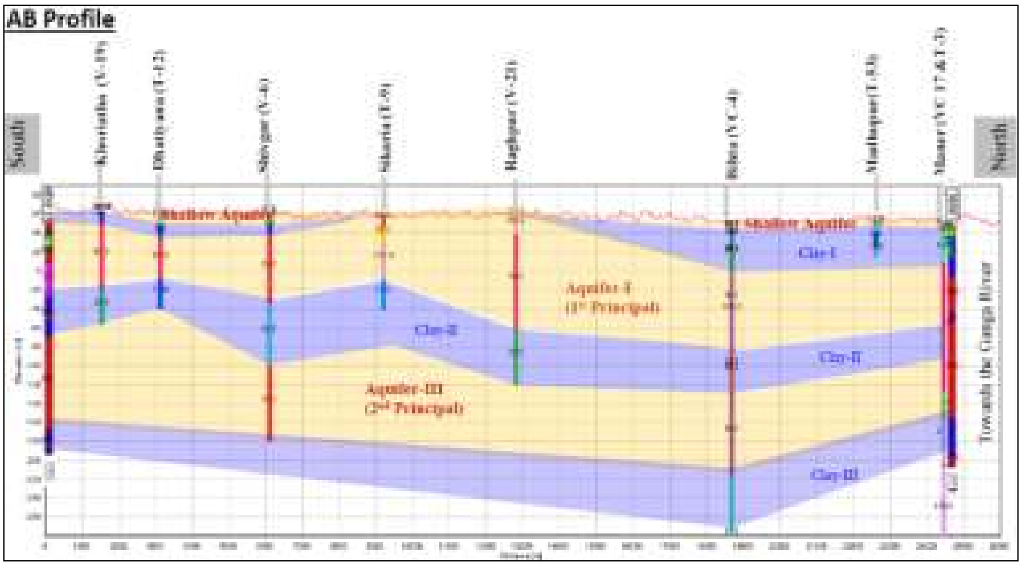


Fig. 3.6 i (4) modified theinferred aquifer depositions along the AB profile with the help of existing bore litho-logs

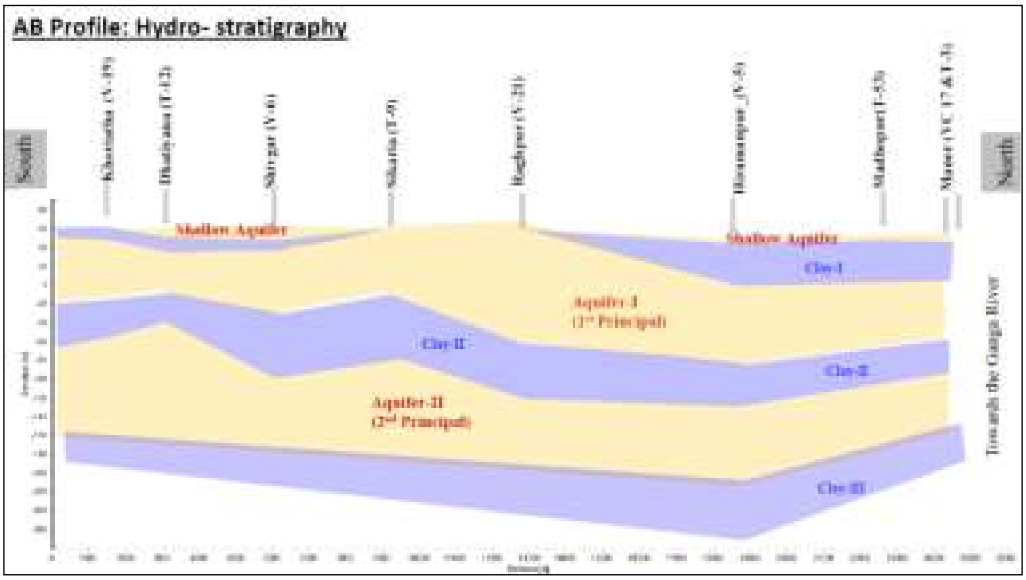


Fig. 3.6 i (5): Hydro-stratigraphy section along the AB-profile for ground water modelling, AQBHR area, Bihar.

3.6.8.2 Deducing aquifer map form the SKY-TEM results

The SKY-TEM results were compared with the geophysical logs and existing litho logy in the flown area. A typical profile has been drawn in South-North direction encompassing the 1 borehole (W-1 located at Bikram, Fig. 3.6 i (6)). The short-normal and long normal resistivity values correlate satisfactorily with the high resistivity zones obtained from the SKY-TEM results and vise versa. Broadly it shows multi-aquifer systems up to the explored depth of 300 m. The first principal aquifer starts at a depth around 40-50 m bgl and thickens towards east in this profile, but the bottom clay base of the first principal aquifer becomes shallow in the western part. The second principal aquifer may not be under complete confined condition. It could be in leaky-confined aquifer condition as the top clay layer may not be confining layer which has been shown in the eastern part of the profile (Fig. 3.6 i (6)). The resistive zones at shallow depth inferred to be palaeo-channel could be prominently traced by the SKY-TEM preferable a dense data, which could not be picked up from logging as it starts from 20 m depth as well as scatter ground geophysical data.

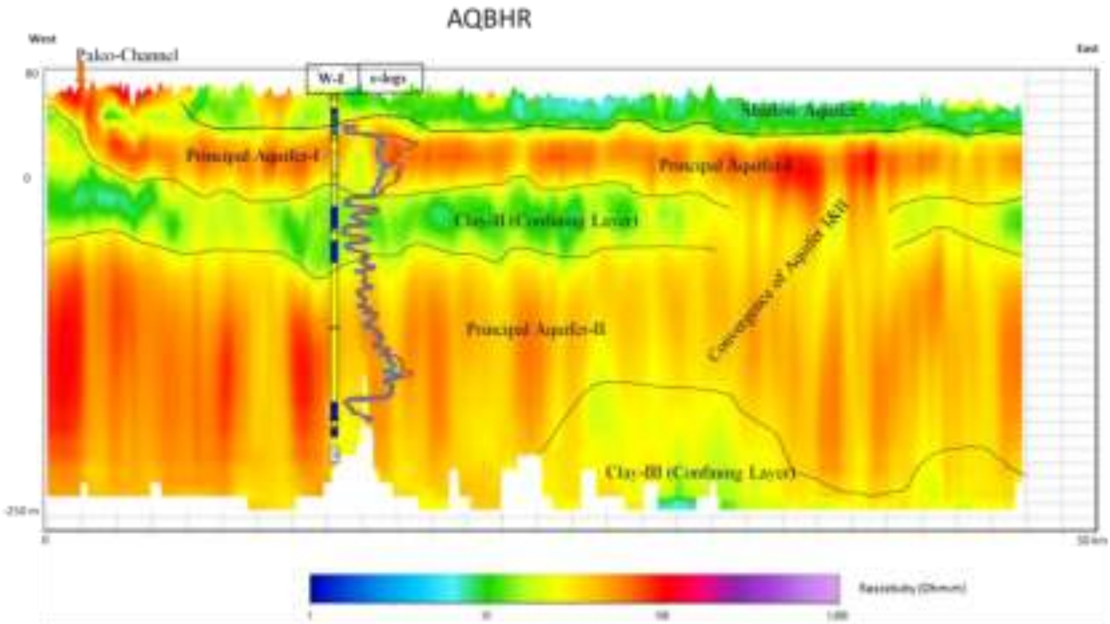


Fig. 3.6 i (6): Comparison the results of SKY-TEM with the resistivity log of boreholes.

3.6.9 Aquifer maps

Using the above logic and methodology of translating the geophysical data into hydrogeological model, aquifer maps are prepared into two stages. In the first stage the aquifer maps were prepared only in the SKY-TEM flown area, and 2) the entire pilot area has been divided into 15 rows and 21 columns with 2 km ×2km grid pattern in the second stage. In each node hydrogeological information was deduced and represented in tabular form which shows only the principal aquifers up to explored depth about 300m with the inferred hydrogeological information.

3.6.9.1 Aquifer disposition in the flown area

3.6.9.1(a) Dispositions of clay beds

The analysis of near-surface clay layer reveals that it is almost present throughout the area with minor gaps in the western and northern part (Fig. 3.6 j (1)). The bottom of this clay layer goes upto about 40 m. As observed, in general the bottom lies beyond 25 m depth in the western, northwestern and central parts. It is less in the southern and eastern parts. It reveals that while the near surface clay is thick in the western along with central parts and it is relatively thin in the eastern part. Besides, a general NE-SW trend in the clay bed bottom is observed in the southern part. The shallow occurrence of clay bottom in the southern part is obvious as the depositional basin deepens towards north. The NE-SW trend of the clay bottom in central and north-western parts most probably reflects the depositional trend in the recent past. The thickness of the near-surface clay bed does not increase towards north, instead a strip with thickening of clay bed oriented in NE-SW is seen (Fig. 3.6 j(2).). However, in the extreme eastern part of the flown area the trend becomes NW-SE.

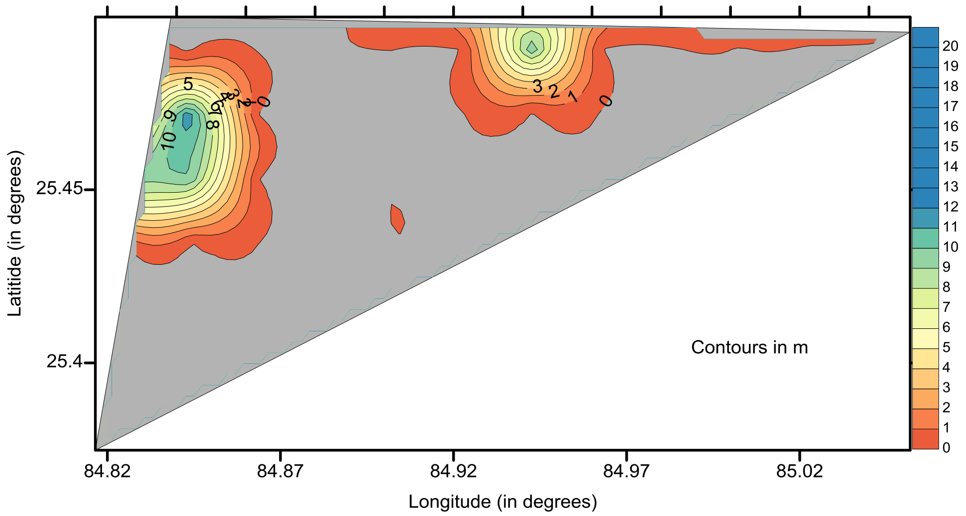


Fig. 3.6 j (1): Depth to the near surface clay (m bgl) in the AQBHR area, Patna,

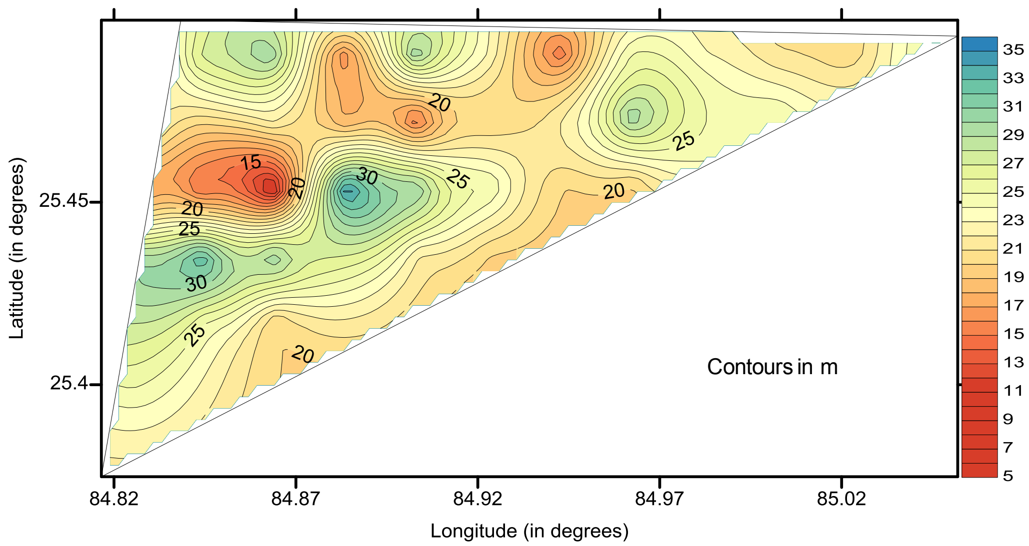


Fig. 3.6 j (2): Thickness of the near surface clay (m) in the AQBHR area, Patna, India

The analysis of the disposition of 'second clay bed' separating the first principal aquifer from the underlying second principal aquifer is quite significant. Though the trend of the first clay bottom and the second clay top is similar, the depth to the second clay bed top is not coherent with variation in the depth to the bottom of first clay bed top. It varies in general from 44 to 90 m (Fig.3.6 j (3)). The deepening of the second clay bed top is observed at several places indicating localized thinning and thickening of the first principal aquifer. The depth to the bottom of the second clay bed varies from 71 to about 135 m. These reveal the variation in thickness of the second clay bed (Fig. 3.6j (4)). The thickness varies from 25 to 60 m with an average of 40 m.

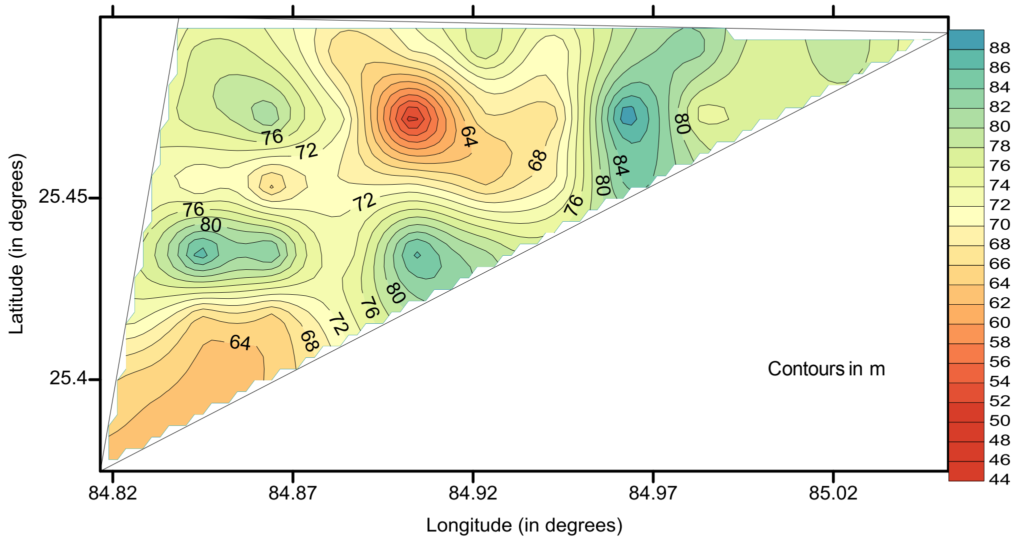


Fig. 3.6 j(3)**:** Showing depth to the top of second clay (m, bgl) separating first and second principal aquifersin the AQBHR area, Patna, India

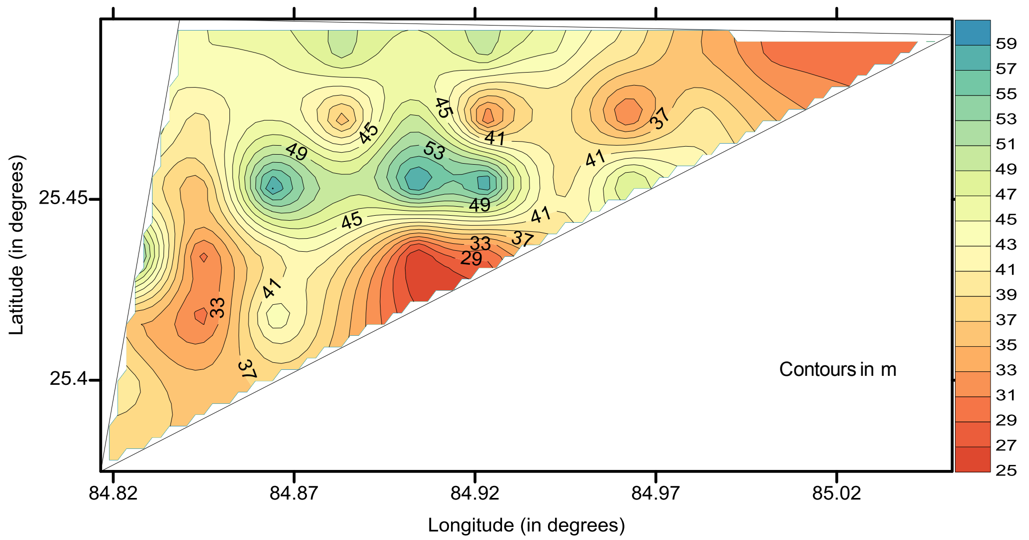


Fig. 3.6 j (4)**:** Showing thickness of second clay (m) separating first and second pricipal aquifers in the AQBHR area, Patna, India

3.6.9.1(b) Disposition of aquifers

The thickness of the first principal aquifer varies from 24 to 65 m (Fig. 3.6 j 5). Significant is its thickning towards south-central and north-western parts of the flown area. There is a thinning upto 30m observed in the central part. The trend in variations in aquifer thickness in the western part is almost N-S that could be correlated with the present day course of River Son.The second principal aquifer which commences from about 71m in the south part to 135 m in the northern and north-eastern parts is quite thick.

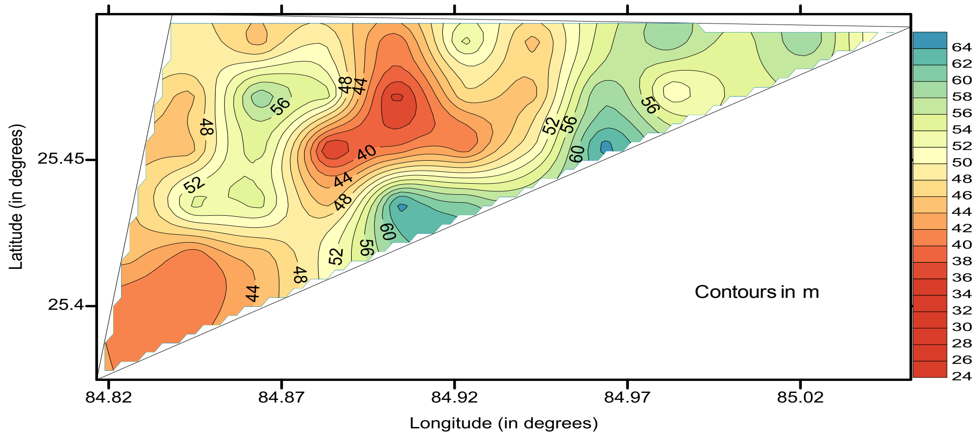


Fig. 3.6 j (5)**:** Thickness of the first principal aquifer (m) in the AQBHR area, Patna, India

3.6.9.1 (c) Three-dimensional resistivity section

The 3-D multi-aquifer system model was prepared along the existing bore well (Fig. 3.6 j 6). The sections show palaeo-channels in the western part near SonRiver. The clay layer at the top of the first principal aquifer dips in northeast, i.e., towards Ganga river. The first and second principal aquifers merge in the eastern part. The reduction in resistivity of the second aquifer in south-western part needs further understanding.

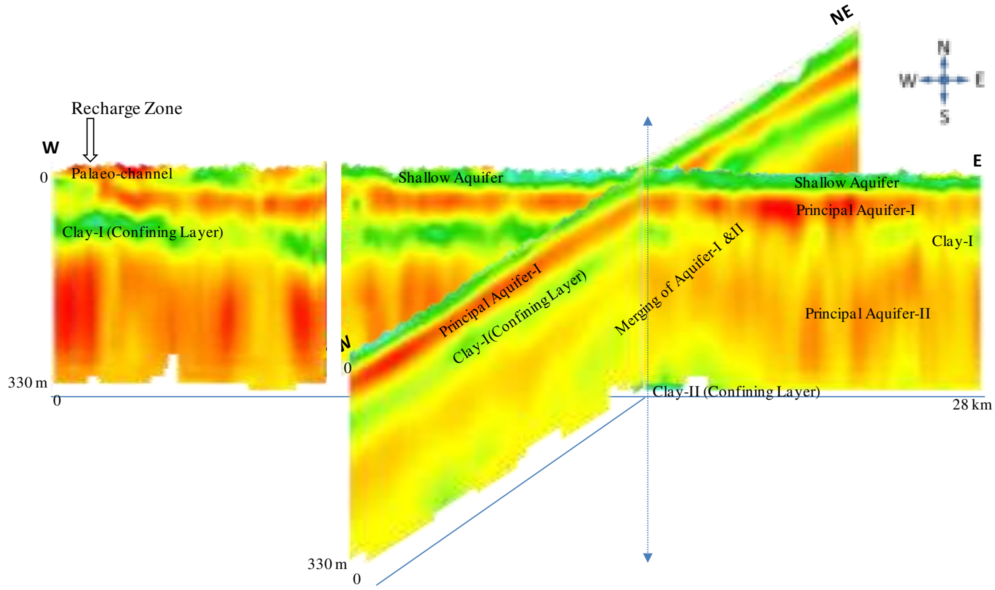


Fig. 3.6j (6): The 3-D view of aquifer disposition in the southern SKY-TEM flown part of AQBHR area, Patna, Bihar

3.6.9.1 (d) Depth section of aquifers

Resistivity depth sections were prepared from the SKY-TEM data for the depths of 50 to 60m, 10 to 20m, -20 to - 30m and -120m - to -130m amsl (Fig. 3.6 j (7)). The top section at the depth of 50-60m reveals the presence of shallow aquifers in palaeo-channels. The palaeo-channels are oriented NE-SW in the western part of the flown area whereas in the middle they are oriented in NE-SW direction. The first principal aquifer is picked up in the depth section of 10-20 m amsl. The red-colour zone in this section indicates better granularity of aquifer. In extreme south western part clay layer is present. Further deep, at the depth of -20 m to -30m amsl, a clay layer is observed acting as the confining layer between first and second principal aquifers in most part of the area. At the depth range of -120m to -130m amsl the second principal aquifer is observed. Its granularity is better near River Son.

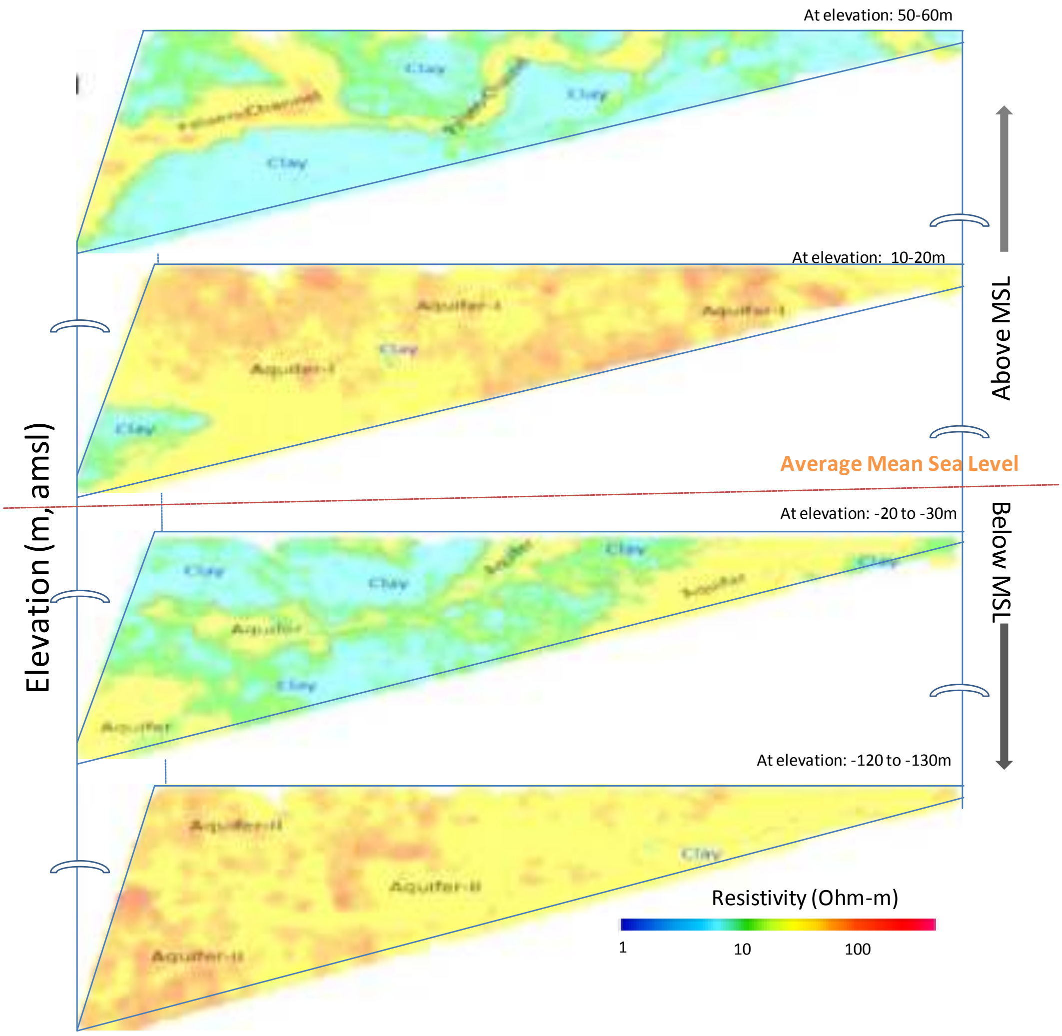


Fig. 3.6 j (7)**:** Depth section of the aquifers in the SKY-TEM flown part of AQBHR area, Patna, Bihar

3.6.9.1 (e) Three dimensional view of aquifer

A 3-D view of the aquifers with boundaries (Fig. 3.6 j8) along the boundary of the flown area was prepared. It indicates merging of aquifers at a distance of 20 km on the profile A-C. The near-surface clay is predominant along B-C profile. The clay layer at the bottom of the first principal aquifer is also predominant in the northern part compared to the southern part of the SKY-TEM flown area. The occurrence of clay layer in the western part of the area up to the top of second principal aquifer is prominent.

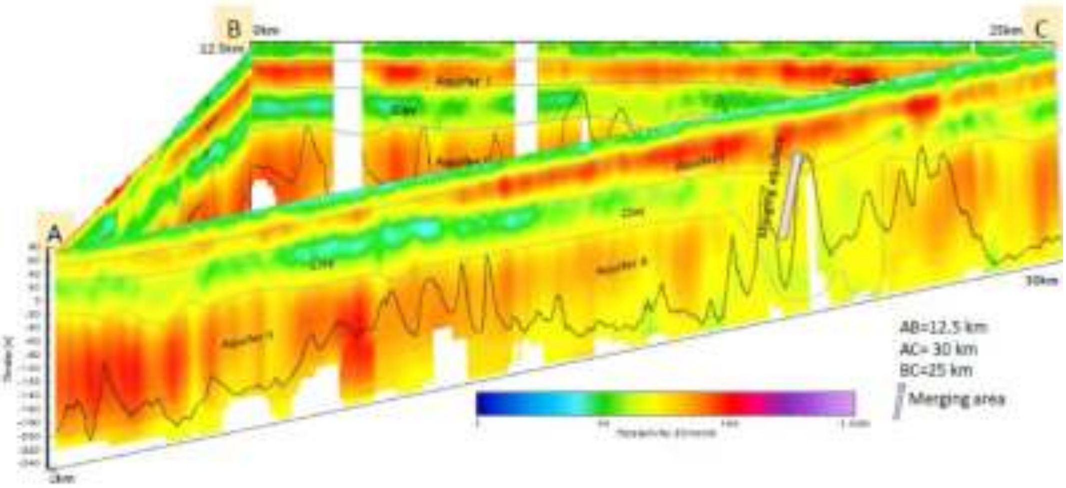


Fig. 3.6 j (8)**:**3-D cross-section of the multi-aquifer systems in the flown area in AQBHR area, Patna, Bihar

3.6.9.2 Aquifer disposition in the AQUIFER GRID (2×2 km)

The entire pilot area has been divided into 15 rows and 21 columns with 2 km ×2km grid pattern (Fig. 3.6 j 9). In each node hydrogeological information was deduced and represented in annexure 3.6 (d). It shows only the principal aquifers up to explored depth about 300m with the inferred hydrogeological information.

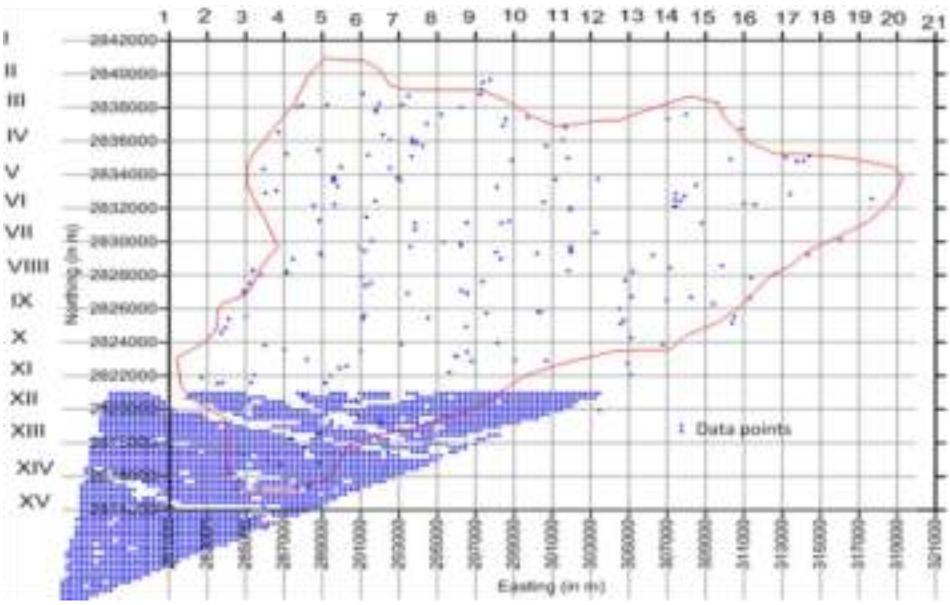


Fig. 3.6 j (9)**:** AquiferGrid of 2 km by 2km for deducing aquifer disposition in the AQBHR area

3.6.10. Concluding remarks

The SKY-TEM data are of good quality. The collected data were carefully processed to remove couplings and noise before inversion. The inversion was done initially with a smooth model using the laterally constrained inversion (LCI) approach and then spatially constrained inversion (SCI) approach.

The SKY-TEM data gave a new and comprehensive three-dimensional picture of the subsurface. The low moment data ensured high resolution near surface mapping and high moment data for the deeper level. Thus the dual moment provided high resolution mapping of subsurface from top to ~ 300 m depths.

The CSIR-NGRI conducted the SKY-TEM Heliborne survey in the AQBHR pilot area, Patna, Bihar during December 2013 for delineating different aquifers up to the depth of 300 m and beyond. It envisaged to map these aquifers through heliborne geophysics in conjunction with hydrogeological controls of exploratory bore hole lithologs. The result of the SKY-TEM data clearly manifested the disposition of aquifers concurring with the geophysical logs of bore holes drilled. The SKY-TEM results satisfactorily match with the borehole lithologs as well VES, ground TEM and ERT results from the flown area.

The ERT and TEM results clearly manifested the two-aquifer system of shallow and first principal aquifer up to explored depth around 100 m which are also agreeable with the results of the SKY-TEM data. All the ERTs, VES and ground TEM sounding model data including bore well informations are also interpreted as layered earth with the aid of Aarhus Work Bench. It helped to prepare 3-D aquifer models for the SKY-TEM flown area as well as non-flown area. It revealed a clear contrast between the ranges of resistivity of clay (up to 15 Ω-m) and sand predominating aquifers (15-120 Ω-m). The upper limit of the aquifer resistivity indicates mixing of coarse sand/gravel. The first resistive layer at depths around 40 m bgl forming the first principal aquifer is clearly mapped. The second principal aquifer which lies around 100-120m depth in this area is also demarcated.

3.7 Sub surface information

Dense data on Sub –surface information in project area was generated through drilling and ground geophysical survey carried out by CGWB, MER.Ground geophysical survey (VES, TEM and ERT) and SKY-TEM survey has been carried out by NGRI, Hyderabad to decipher the sub-surface information.

3.7 .1 Drilling under pilot aquifer mapping project

Sixteen wells were constructed at six locations (fig 3.7a) by departmental rigs in the pilot aquifer mapping area. All the wells were electrically logged upto the drilled depth and at two locations (Naubatpur and Simri) Gamma logging were also carried out.

The location details where bore wells were drilled and wells constructed tapping different aquifers are given in table 3.7 (a).

Table 3.7 a: The location details of exploration under Pilot Aquifer Mapping Project

Sl. No.	Name	Long	Lat
1	A.N.College Campus,Patna	85.1100	25.6170
2	Minor Irrigation Campus,Bihta	84.8680	25.5540
3	NaubatpurRefferalHospital Campus,Naubatpur	84.9612	25.5033
4	ViswakarmaHigh School Campus, Simri	84.9050	25.6065
5	DhanusdhariHigh School Campus,Moriyawan	84.8638	25.4916
6	Goriyaasthan(Jibrakhan Tola)	84.9332	25.6430

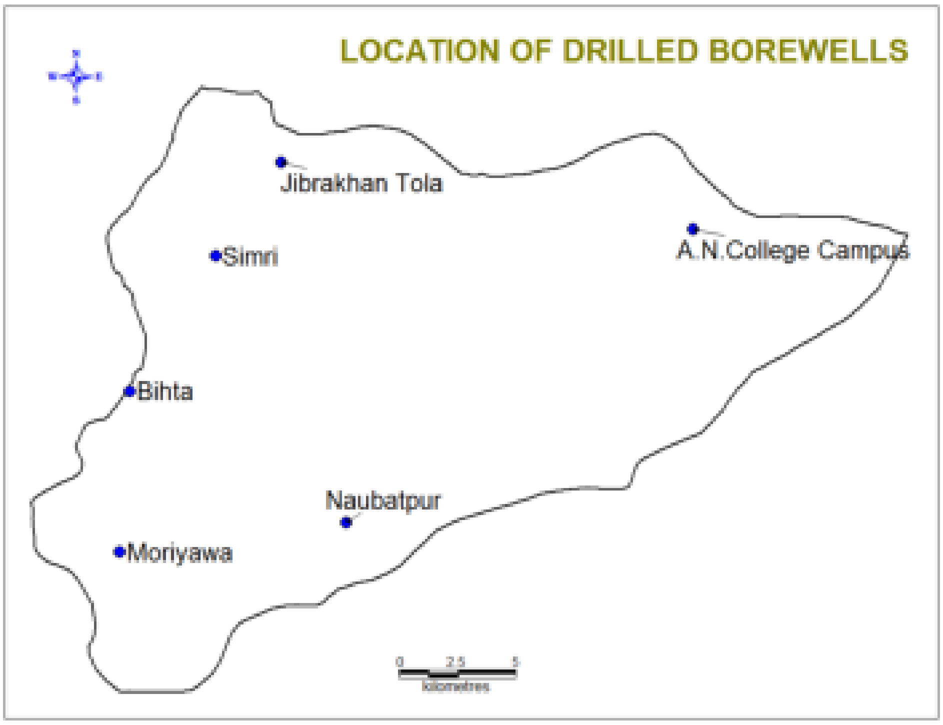


Fig 3.7 (a): Location of drilling under Pilot Aquifer mapping Project

Table 3.7b: Summarized salient characteristic of the wells drilled in the Pilot Aquifer Mapping Area

S.No.+	Location	Block	Types of Well	Drilling depth (m ,bgl)	Constructed depth (m ,bgl)	Zone Tapped(m, bgl)	Discharge (lps)	WL (m,bgl)	Dia	T m^2/day	S
1	A.N.College Campus	Patna Sadar	MW	174.56	169	151 – 166	14	---	12"/6"	--	--
			OW	180.36	167	152-164	16	6.64	4"		
			MW	78.14	77	66-75			10"/6"		
			SOW	72.82	71.5	63 - 69	10	7.14	6"		
2	Bihta Irrigation Compound	Bihta	MW	252.5	202	181-199	---	4.12	12"/6"	--	--
			OW	252.5	211	190 – 208	6	5.18	4"		
3	NaubatpurHospital Compound, Naubatpur	Naubatpur	MW	185	181	160 – 178	20	6.16	12"/6"	9047	1.48×10^{-5}
			OW-1	187	181	172 – 178	10	7.42	6"		
			OW-2	128.75	58	42 – 48	5	5.2	4"		
4	ViswakarmaHigh School Compound, Simri	Bihta	MW	291.25	281	256 – 262 266 – 278	20	7	12"/6"	6323	1.28×10^{-2}
			DOW	300	278	257-260 269-275	30	6.27	6"		
			SOW	190	190	142 – 148 181 -187	8	5.88	4"	--	--
			SEW	201.75	196	181-193	10	6.88	12"/6"		
5	DanushDhariHigh School, Moriyama	Bikram	OW	299.8	227	212- 224	21	5.65	6"	10135	4.98×10^{-4}
			EW	300	227	200.00-224.00	40	7.05	12"/6"		
6	Middle School Jibrakhan Tola ,Goriyaasthan	Maner	OW	281.75	235	220- 232	28	7.42	6"		

MW-main well, OW-observation well, SOW-shallow observation well

Table 3.7 (b) shows the summarized salient characteristic of the wells drilled during the Pilot Aquifer Mapping project. The wells drilled are electrically logged. The lithologs and e-logs of the wells drilled in the area are given annexure 3.5a & c. NGRI, Hyderabad has carried out logging at Naubatpur and Simri and rest of the wells are logged by CGWB. At Naubatpur and Simri, NGRI has carried out gamma logging also (annexure 3.5c). Few field photographs of exploration activities in Pilot Aquifer Mapping area is shown in fig 3.7 (b).

		
Start of drilling operation by Regional Director in A.N.College campus, Patna	**Rig Machine deployed at Naubatpur refferal hospital campus**	**Driiling operation at Viswakarma high school campus, Simri**
		
Collected litholog samples during drilling		
Fig 3.7 b : Field photographs of exploration activities carried out in Pilot Aquifer Mapping area		

3.7.2 Geophysical survey

Data pertaining to sub –surface information to fill the data gap was generated through following Geophysical survey:

(a) 26 numbers of Vertical Electrical Sounding with maximum current electrode separation (AB) of 1000 (Fig. 3. 5 a) by CGWB, Patna.

(b) Grounds geophysical investigations carried out by NGRI Hyderabad are given in table 3.6 c. Details of these are given in section 3.6. Besides, ground geophysical survey, the state-of-art heliborne electromagnetic (heliTEM) survey has been carried out by NGRI in collaboration with Aarhus University, Denmarkin 52 sq.km. Withinthe project area to get continuous sub-surface information.

3.8 Ground water level

3.8.1 Ground water occurrences and ground water levelbehavior

Groundwater in the area occurs under unconfined condition in the top aquitard and under semi-confined to confined condition in the deeper aquifers. The major source of recharge is through rainfall. Factors like return seepage from irrigation and subsurface inflow also contribute in recharging the ground water in the area. The area is characterized by occurrence of various grades of sand admixed with kankars in alluvial sediments forming fairly prolific aquifers.

Table 3.8a: Number of observation wells tapping different aquifers (for measurement of Ground water level)

Type of structure	Number
Open Dug Wells tapping Aquitard layer	50
Piezometer tapping Aquifer -1	19
Piezometer tapping Aquifer -2	7

A total 76 wells were established for monthly monitoring in the project area, of which, fifty are the open dug wells tapping the aquitard layer, 19 piezometers tapping the first aquifer and 7 piezometers tapping the second aquifer. The location details of the different monitoring wells first aquifer and second aquifer are given in annexure 3.8 a. b & c, respectively. Piezometres for groundwater level monitoring in first, second and third aquifers were established upon completion of well construction during the different time period in the study. The monitoring wells are distributed evenly throughout the area. Map showing location of dug wells and piezometers being monitored are given in fig. 3.8 a, b & c, respectively.

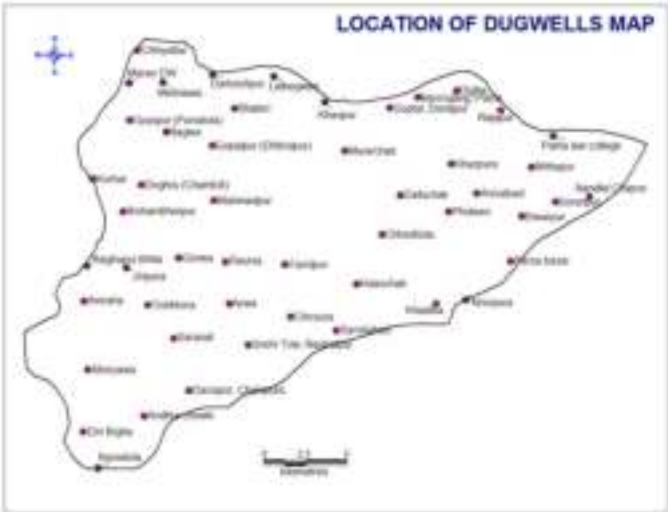


Fig 3.8 (a): Map showing locations of monitoring dug wells

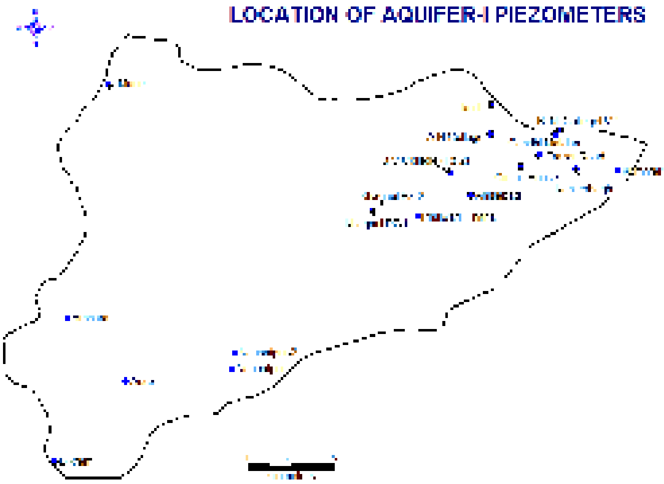


Fig 3.8 (b): Map showing location of monitoring Piezometer (tapping first aquifer)

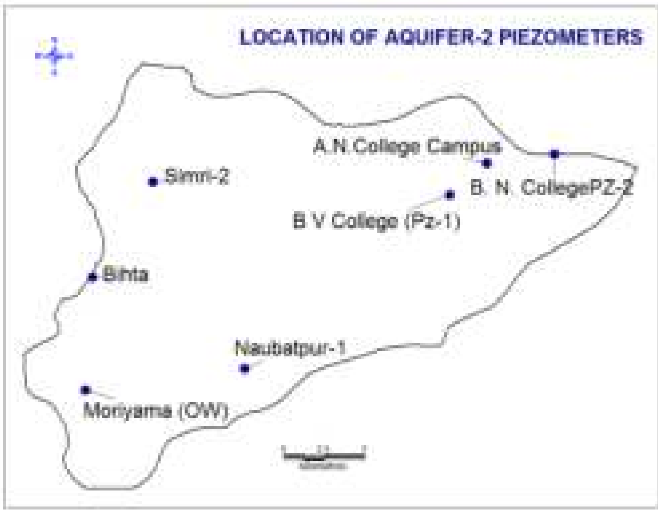


Fig 3.8 (c): Map showing location of monitoring Piezometer (tapping second aquifer)

Field photograph showing groundwater level being measured in the study area is given in the fig: 3.8 d.

Fig 3.8 d: Field photograph showing (i) Groundwater level measurement in Dug well and (ii) Groundwater level measurement in piezometer.

3.8.1 Depth to Ground water level in dug wells tapping Aquitard zone

Groundwater level in the dug wells tapping aquitard zone (unconfined condition) was systematically measured from February 2012 from 50 wells evenly spread throughout the area. The depth to groundwater level of dug well zone has been found ranging between 1.36 and 9.39 m bgl during pre-monsoon (May 2013) and between 1.22 and 9.04 m bgl during pre-monsoon (May 2014). Month–wise groundwater level records and maps are given in annexure 3.8(d). Month-wise depth to groundwater level contour map were prepared from February 2012 to June 2014 for the top aquitard layer and are given in are given in annexure 3.8(g). The depth to groundwater level of pre-monsoon and post monsoon are shown in Fig. 3.8e and fig. 3.8 f**.** The depth to groundwater level has categorised under different zones of below 0-2m, 2-5m, and 5-10 m for aquitard layer / unconfined aquifer.

Depth to groundwater level in the aquitard zone mostly remains within 5m bgl. Groundwater level beyond 5 m bgl has been observed only in small area along northern and eastern boundary of the area.

During post-monsoon (November), the depth to groundwater level remain within 2 m, bgl in major part of the area. Only in small patches along the eastern, western and northern boundry and central part, the depth to groundwater level remains between 2 and 5 mbgl.

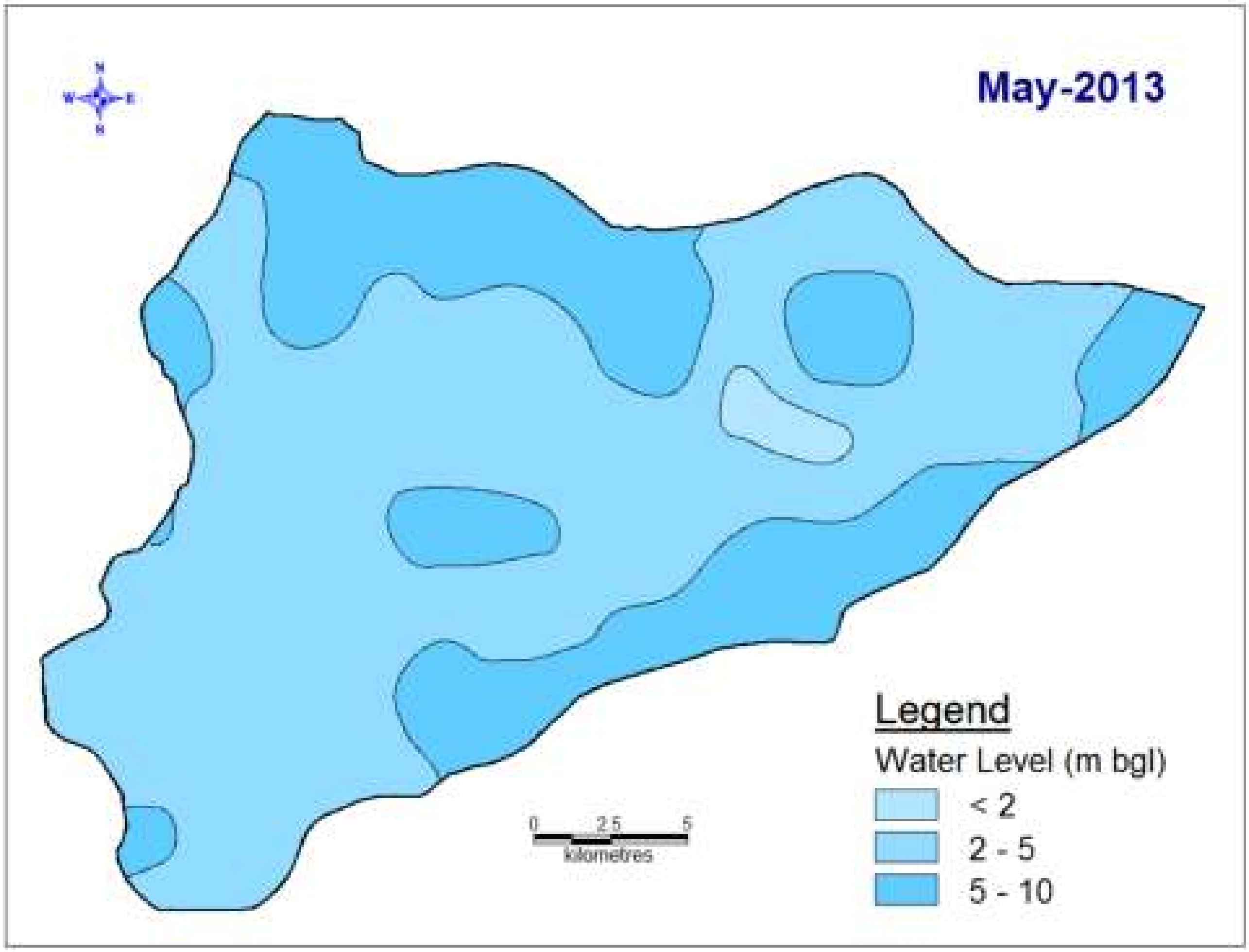


Fig. 3.8 e: Pre-monsoon depth to water level map (aquitard layer), 2013

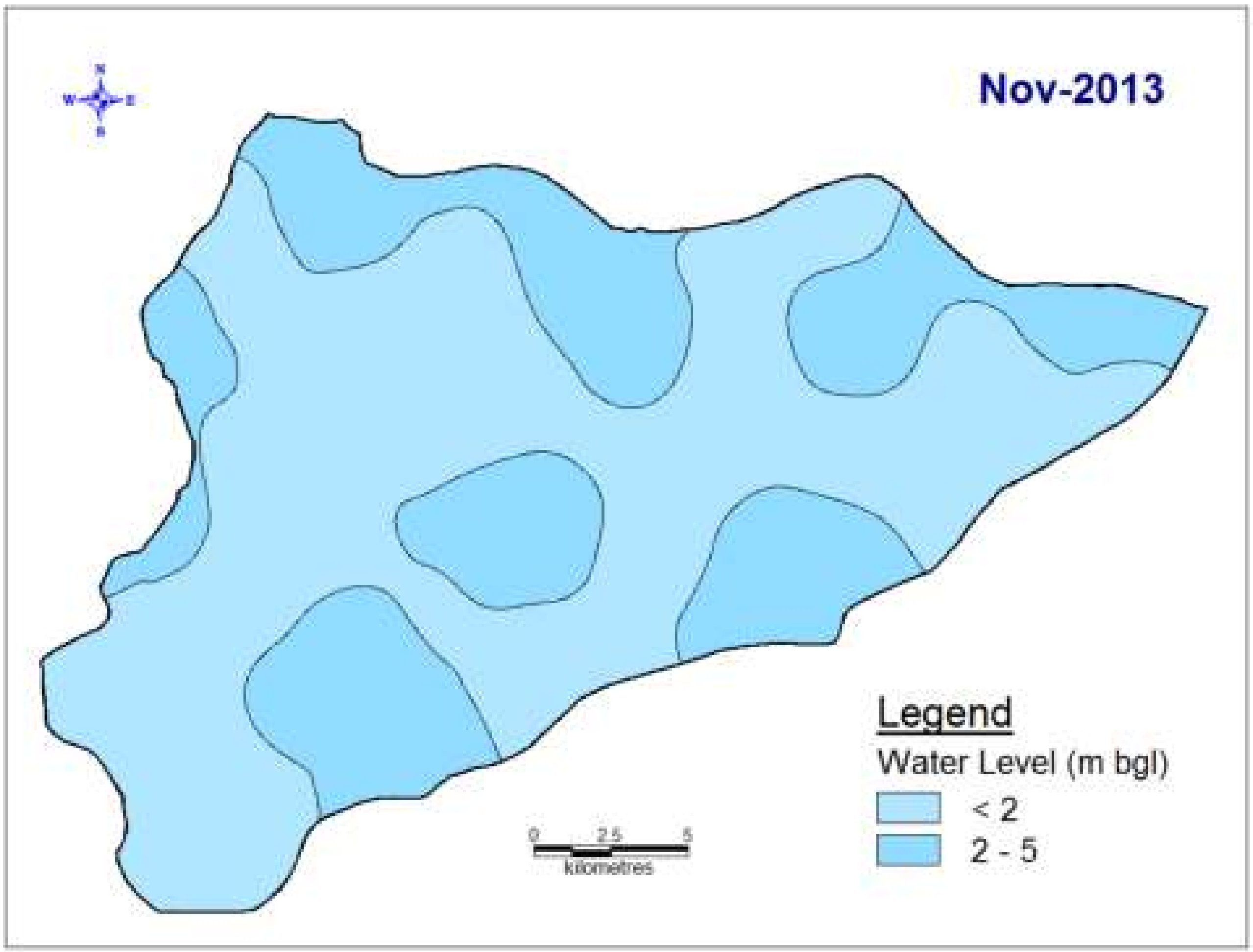


Fig. 3.8f: Post -monsoon depth to water level map (aquitard layer), 2013

The minimum, maximum and mean value of depth to groundwater level in dug wells tapping aquitard zone (unconfined aquifer) for two years (2012-2014) is given in table 3.8b.

Table 3.8 b: Three years minimum, maximum and mean value of depth to groundwater level in dug wells tapping aquitard zone /unconfined aquifer for the period 2012-2014.

Year	Depth to groundwater level (m, bgl)					
	Pre- monsoon			Post- monsoon		
	Min	Max	Average	Min	Max	Average
2012	1.32	9.69	4.8	0.61	4.96	2.1
2013	1.36	9.39	4.7	0.48	4.84	2
2014	1.22	9.04	4.34	-	-	-

3.8.2 Depth to Piezometric level in the first aquifer

The depth to piezometric level of first aquifer has been found 5.73 m and 13.16 m bgl during pre-monsoon (May 2013) and between 1.49 and 10.08 m bgl during post-monsoon (November 2014). Month–wise piezometric level records of first aquifer are given in annexure 3.8f. A variation of 4 m has been observed ruing the pre- and post-monsoon seasons.

Month-wise Depth to Ground water level contour map was prepared from February 2012 to June 2014 for the first principal aquifer and are given in annexure .3.8 i. The Pre-monsoon and post-monsoon water table map of 2013 are given in fig. 3.8 g (i) and 3.8 g (ii) respectively.The depth to Ground water level has been categorised in different zones of 2-4m, 4-6m, 6-8 m,8-10m, 10-12m and 12-14 m for first aquifer.

Pre-monsoon depth to piezometric level contour map of first principalaquifer shows that the piezometric level in most part of the area remains between 8 and 10 m bgl. Only in small patches in north-eastern part of boundary of the area, where Patna urban area is located, piezometric level was found between 12 and 14 m bgl. It was within 8 m bgl in extreme southern part and between 8 and 10 m, bgl in central part forming a track from eastern to north-western boundary.

During post-monsoon (November), the depth to piezometric level remain within 6 m bgl in major part of the area. Only in north-eastern part within Patna urban area and in small patches along the eastern boundary in southern part of the area, it was found between 10 and 8 m bgl.

Three year minimum and maximum value of depth to piezometric level in first aquifer is given in table 3.8 i.

Table 3.8 (c): Three years minimum, maximum and mean value of depth to piezometric level in first aquifer for the period 2012-14.

Year	Depth to Piezometric level (m, bgl)					
	Pre- monsoon			Post- monsoon		
	Min	Max	Average	Min	Max	Average
2012	5.83	13.24	10.49	1.77	9.74	6.22
2013	5.73	13.16	10.10	1.49	10.08	6.81
2014	4.15	13.68	10.05	-	-	-

Month-wise piezometric head maps were prepared to have an idea of ground water flow in the first aquifers of the area. The pre-monsoon water table maps of the three year indicate that the water table elevation varies from 54 m above mean sea level in the SW part of the area near Bikram to 36-38 m in the NE part with anaverage hydraulic gradient of 0.0009. The piezometric head map of first aquifer indicates that in general ground water flow direction is also from south-west towards north-east and north, as in that of the overlying phreatic aquifer. The month-wise piezometrichead maps from February 2012 to June 2014 are shown in annexure 3.8 (j) Pre and post – monsoon (2013) piezometric head map of first aquifer are shown in fig **h (i & ii)**.

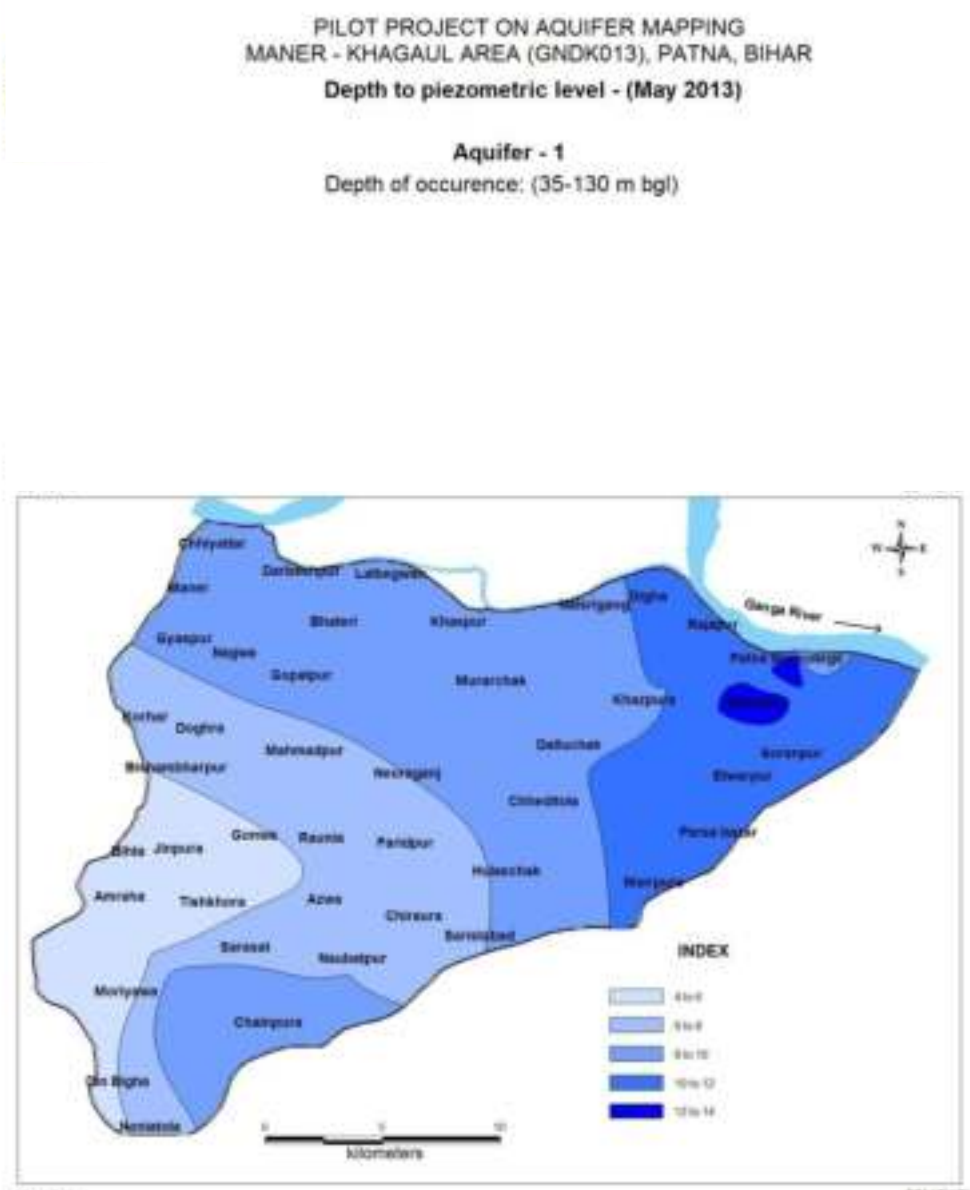


Fig 3.8 g (i): Pre-monsoon (2013) depth to piezometric level maps (aquifer-1)

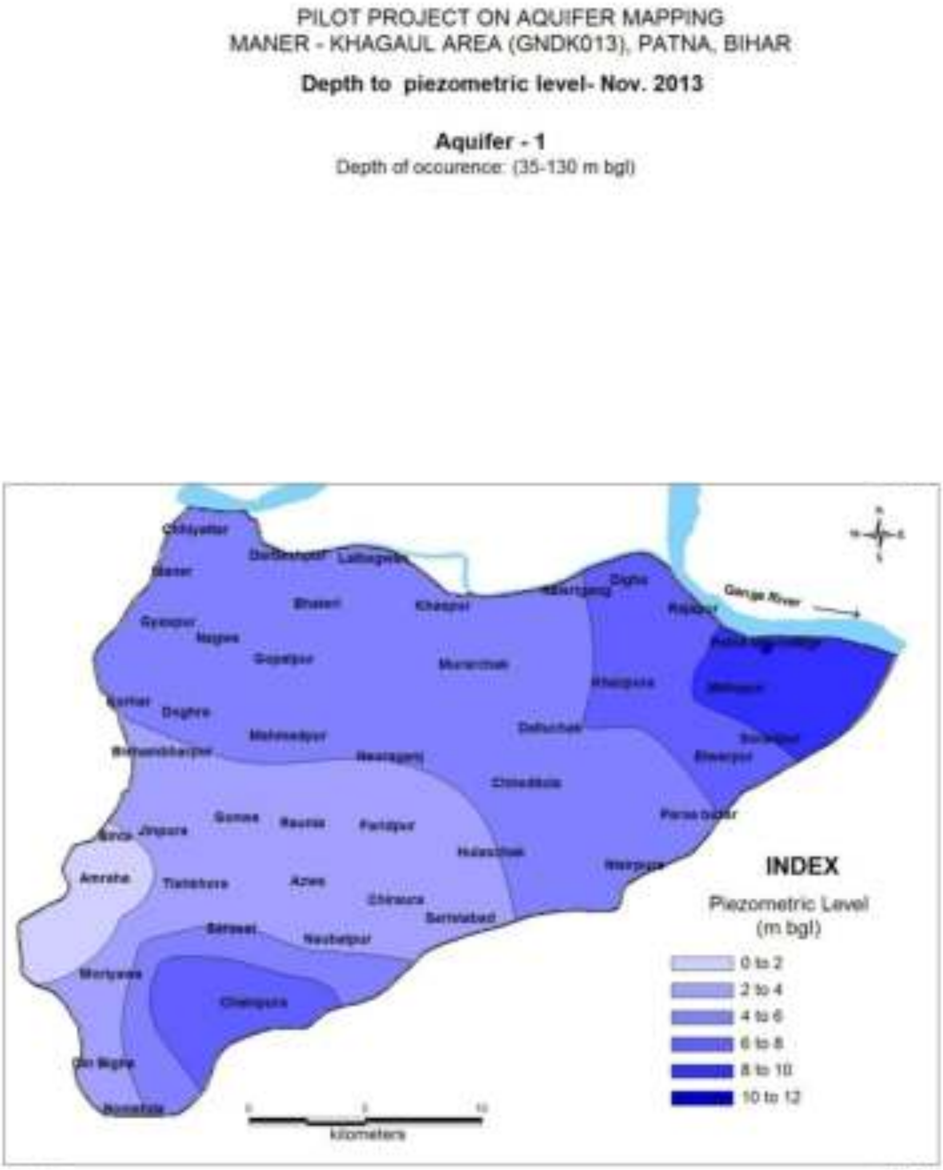


Fig 3.8 g (ii): Post-monsoon (2013) depth to piezometric level maps (aquifer-1)

PILOT PROJECT ON AQUIFER MAPPING
MANER - KHAGAUL AREA (GNDK013), PATNA, BIHAR

Piezometric Head (May - 2013)

Aquifer - 1
Depth of occurence: (35-130 m bgl)

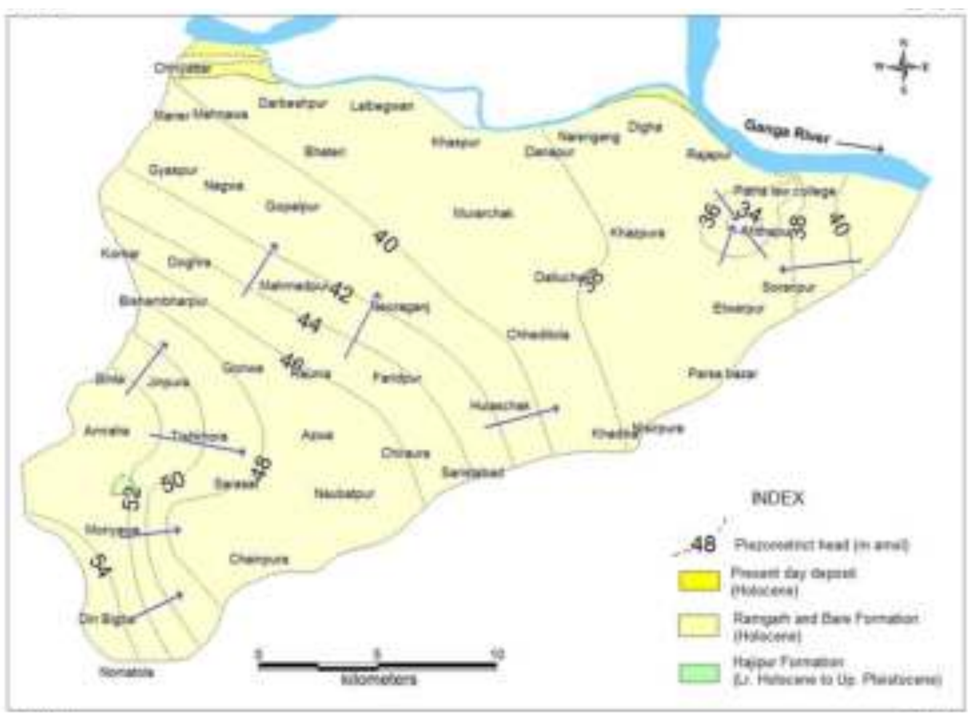


Fig 3.8 h (i): Pre-monsoon (2013) depth to piezometric head maps (aquifer-1)

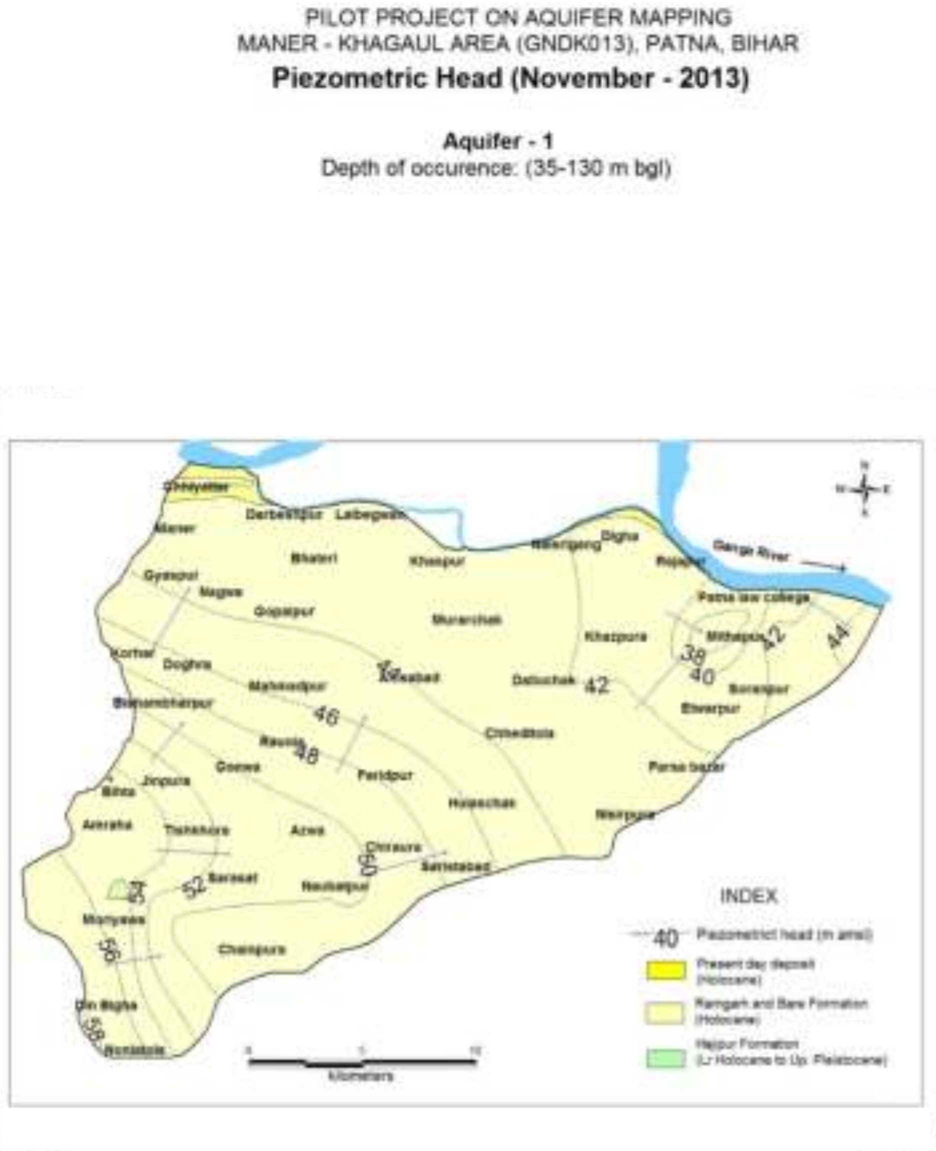


Fig 3.8 h (ii): Post-monsoon (2013) depthto piezometric head maps (aquifer-1)

3.8.3 Depth to Piezometric level in the second aquifer

Month-wise depth to groundwater level contour maps of pre and post monsoon prepared for the second aquifer based on data from February 2012 to June 2014are given in annexure 3.8 (i& j). Premonsoon and postmonsoon depth to piezometric head is shown in fig. 3.8(i &ii). The depth to groundwater level has been categorised in different zones of 2-4m, 4-6m, 6-8 m,8-10m, 10-12m and 12-14 m for aquifer.

Pre-monsoon depth to piezometric level contour map shows that the piezometric level in second aquifer in majority of the area remains within 10 m bgl. Only in small patches north- eastern boundary of the area where Patna urban area is located, the piezometric level was found between 10 and 14 m bgl.

During post-monsoon (November), the depth to piezometric level in majority of the area remain within 6 m bgl except for a small portion in the north-eastern part in within Patna urban area where rests between 6 and 10 m bgl.

The minimum, maximum and mean value of depth to piezometric level in second aquifer is given in table 3.8 d.

Table 3.8 d: Three years minimum and maximum value of depth to piezometric level in second aquifer

Year	Depth to piezometric level (m, bgl)					
	Pre- monsoon			Post- monsoon		
	Min	Max	Average	Min	Max	Average
2012	11.15	11.65	11.65	7.43	7.43	7.43
2013	6.64	12.84	9.7	3.56	10.04	6.3
2014	6.84	13.33	9.8	-	-	-

Month-wise piezometric head maps prepared and are shown in annexure 3.8 (l) to have an idea of ground water flow in the second aquifers of the area. The pre-monsoon piezometric head maps (fig. 3.8 j(i) of the second aquifer indicate that the water table elevation ranges from 54m in the SW part of the area near Bikram to 36m amsl in the NE part with a average hydraulic gradient of 0.0008. The piezometric head map of first aquifer indicates that in general groundwater flow direction is from south-west towards north-east and north as in the phreatic & the first aquifer.The post-monsoon piezometric head map of second aquifer is shown in (fig. 3.8 j (ii).

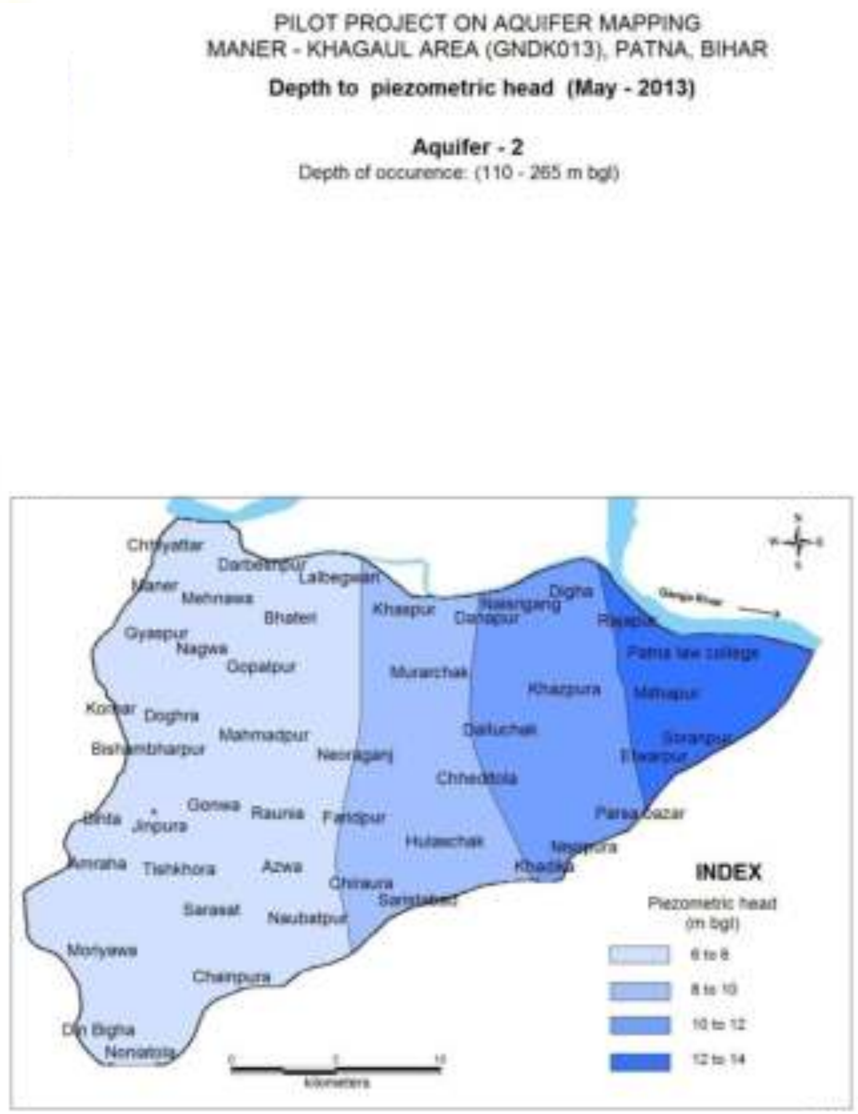


Fig 3.8 i (i): Pre-monsoon (2013) depth to piezometric level map (aquifer-2)

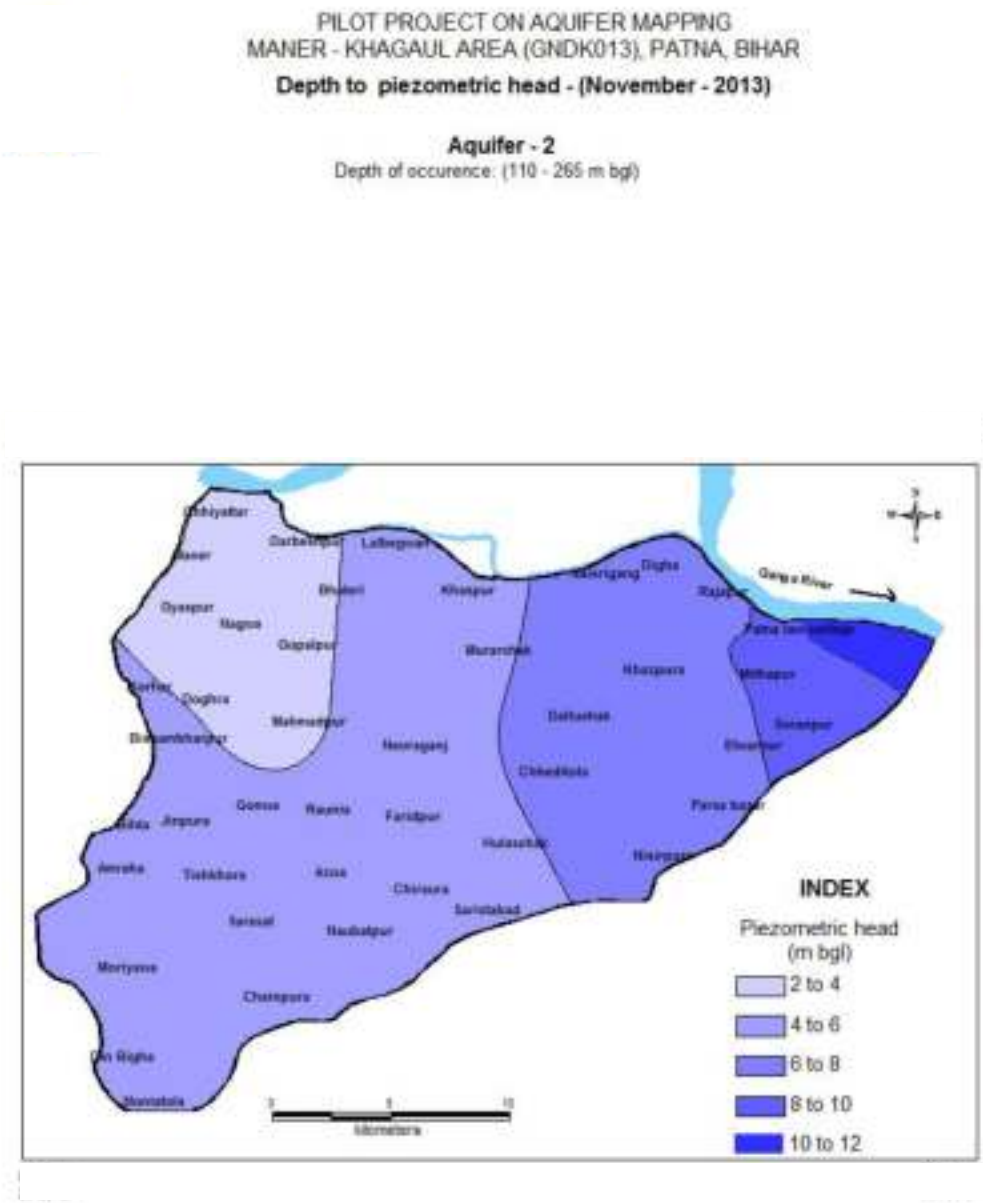


Fig 3.8 i (ii): Post-monsoon (2013) depth to piezometric level map (aquifer-2)

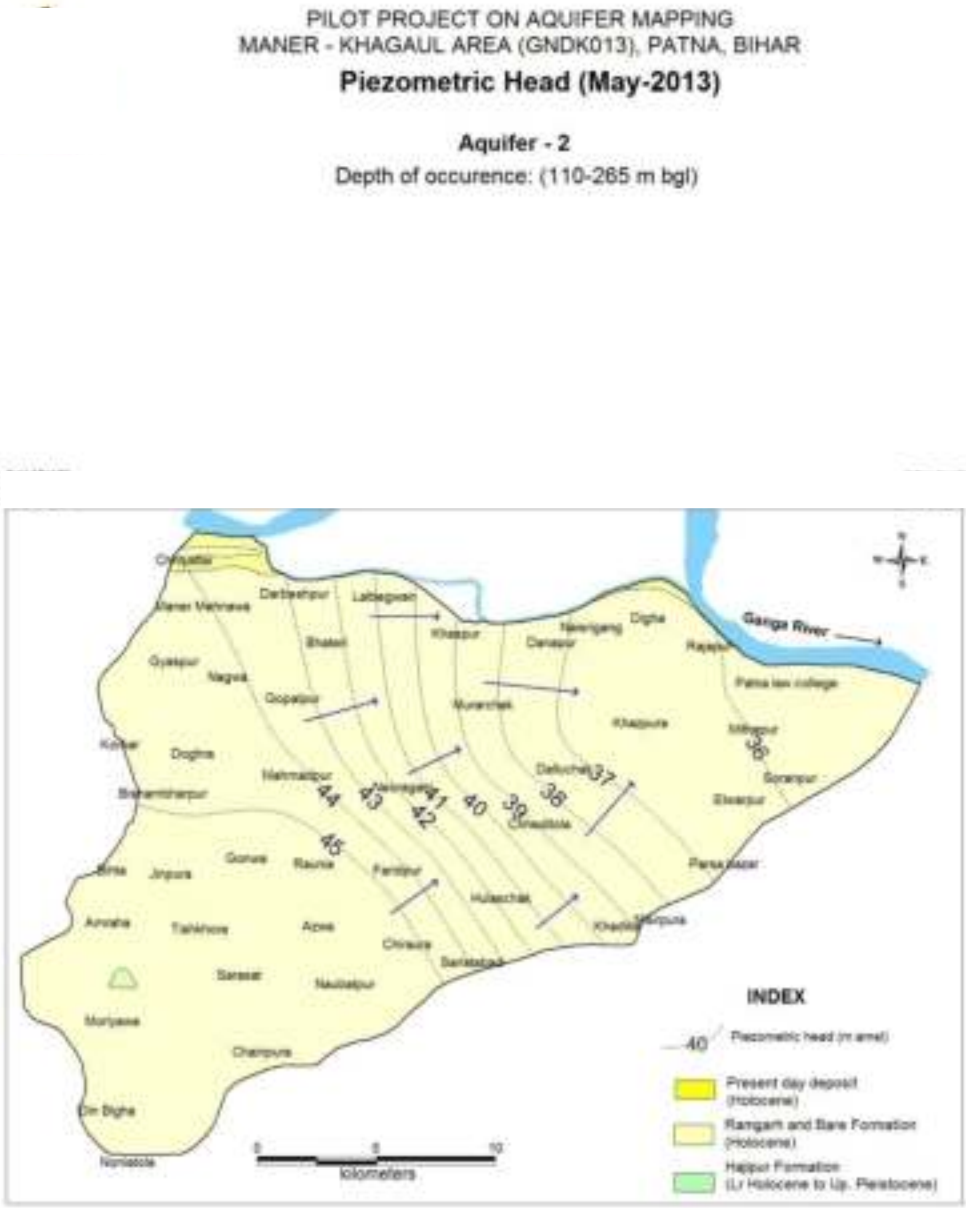


Fig 3.8 j (i): Pre-monsoon (2013) depth to piezometric level maps (aquifer-2)

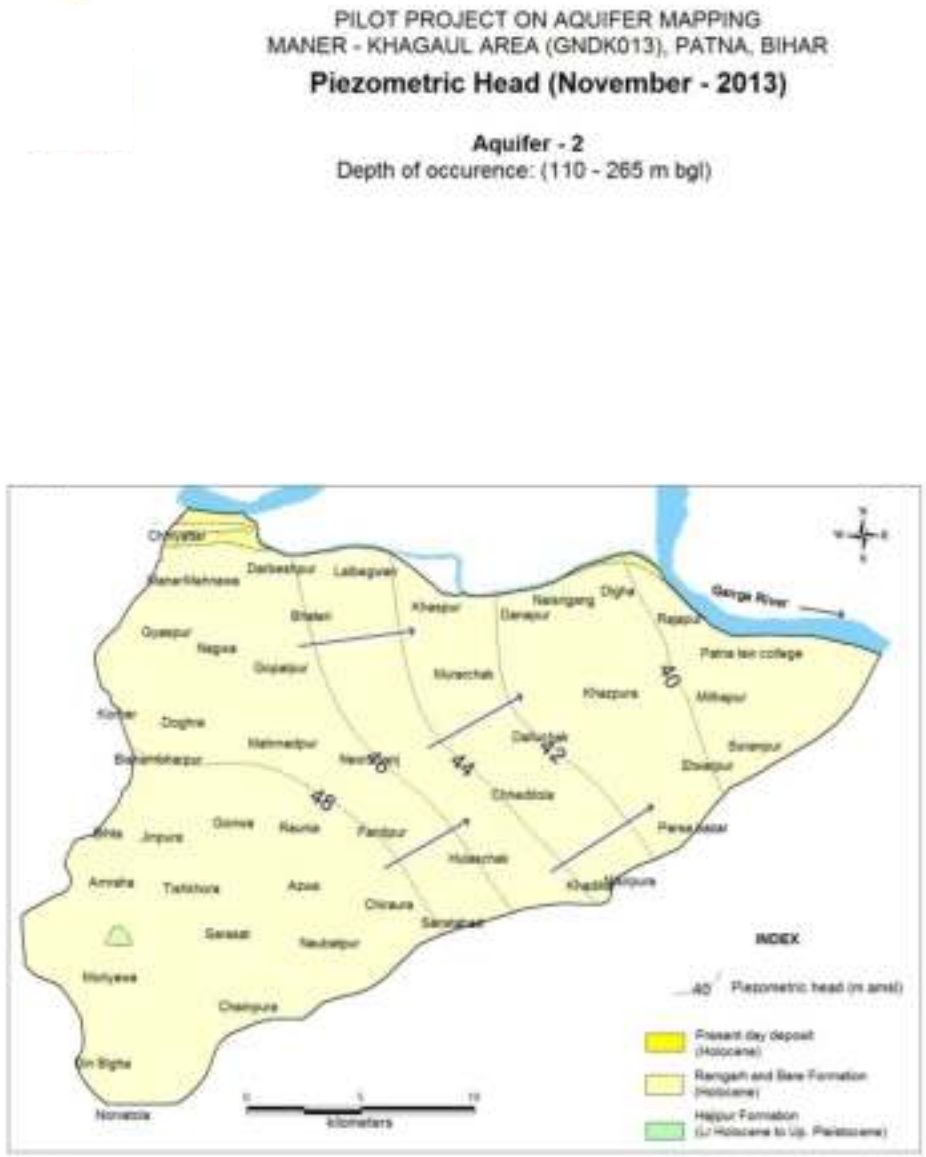


Fig 3.8 j (ii): Post--monsoon (2013) depth to piezometriclevel maps (aquifer – 2)

3.8.4 Comparison of ground water levels/ piezometric level

The groundwater levels representing the top aquitard zone as well as the deeper aquifer zone (first and second) follows the seasons, i.e. shallowest during August and deepest in May. The difference between the hydraulic heads of the aquitard and the deeper aquifer zone is apparent round the year (Table 3.8 e).

Table 3.8 (e) shows comparison of heads representing different aquifer zones at six locations. It reveals a head difference among the aquitard zone and different aquifer zones indicating existence of two principal aquifer below the the top aquitard zone.

Table 3.8 e: Groundwater levels/ piezometric heads of different aquifer zones

Sl. No.	Place	Aquifer Zone	May-2013	Nov-2013
1	Khazpura	DW	7.2	3.25
	B V College (Pz-2)	Aquf.-1	9.82	7.31
	B V College (Pz-1)	Aquf.-2	11.33	6.88
2	Maner DW	DW	4.93	1.81
	Maner	Aquf.-1	8.6	5.48
	Simri-2	Aquf.-2	6.64	3.56
3	Snehi Tola, Naubatpur	DW	6.08	2.4
	Naubatpur-2	Aquf.-1	6.79	3.54
	Naubatpur-1	Aquf.-2	7.88	4.78
4	Raghopur,Bihta	DW	5.55	6.05
	Amhara	Aquf.-1	1.77	4.15
	Bihta	Aquf.-2	-	9.11
5	Moriyawa	DW	4.21	1.88
	Arap	Aquf.-1	9.76	7.12
6	B.N.CollegePZ-1	Aquf.-1	11.23	11.36
	B.N.CollegePZ-2	Aquf.-2	12.84	10.04

3.8.5 Ground water level fluctuation

Long term trend of the shallow aquifer as well as piezometric level of the deeper aquifer could not be studied due to paucity of data. However, the time series data of groundwater level of of selected measuring stations of top aquitard layer 1st

aquifer and 2nd aquifer is shown in figures 3.8 k (i) to 3.8 k (vi) and for first aquifer in figures 3.8 l(i) to 3.8 l(iii) and in 3.8 m (i) to 3.8 m (iii) respectively. These time series figure do not show any significant trend. Annual groundwater level & piezometric level fluctuation map of May 2012 - May 2013 of top aquitard layer and first aquifer are shown in figure 3.8(N) and figure 3.8(O) respectively. Figure 3.8 (P) shows the annual pre-monsoon piezometric level fluctuation map of second aquifer. These indicate very insignificant decline in groundwater level during this period (<2m) in few patches and even there is rise of < 2m in many parts of the area.

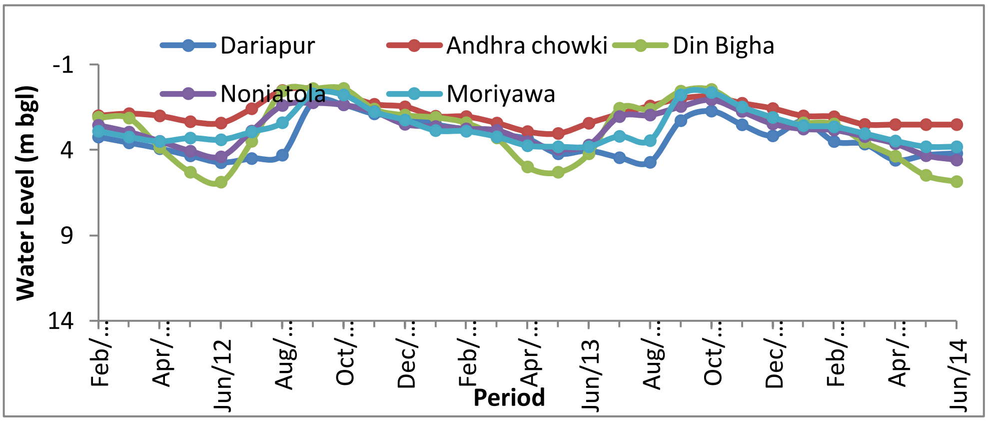


Fig 3.8 k (i): Time series data of groundwater level at Dariapur, Andhra chowki, Din Bigha, Nonia Tola and Moriyama (Dug well)

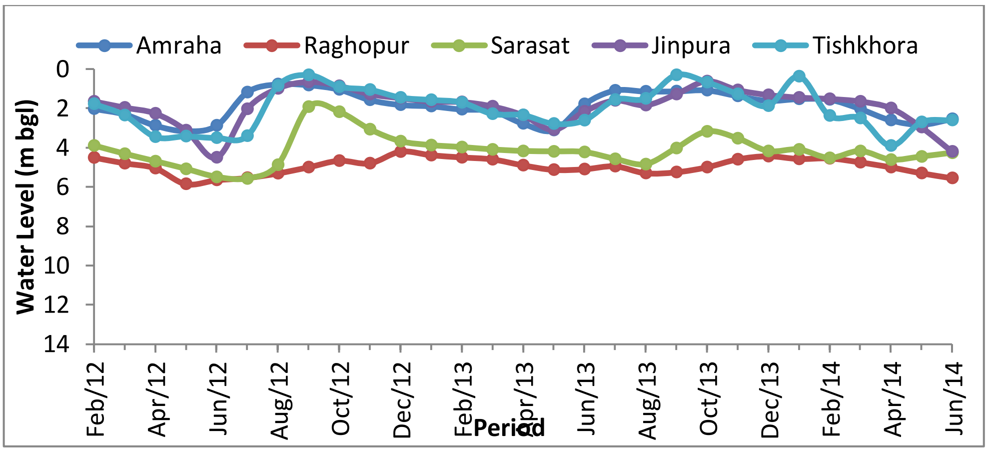


Fig 3.8 k (ii): Time series data of groundwater level at Amraha, Raghopur, Sarasat, Jinpura and Tiskhora (Dug well)

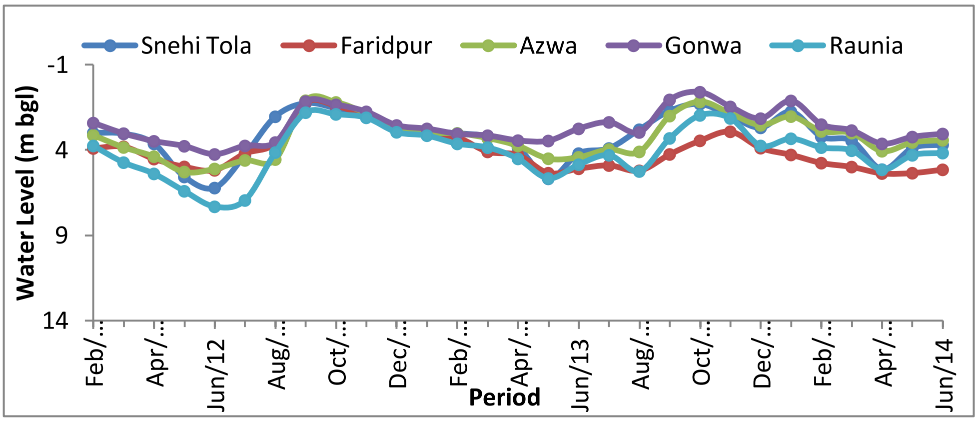


Fig 3.8 k (iii): Time series data of groundwater level at Snehi Tola, Faridpur, Azwa, Gonwa and Raunia (Dug well)

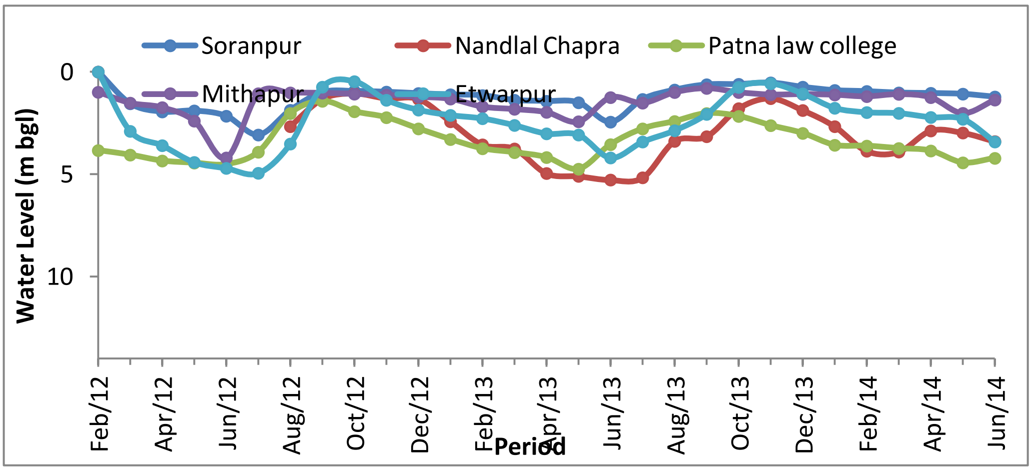


Fig 3.8 k (iv): Time series data of groundwater level at Soranpur, Nandlal Chapra, Patna Law college, Mithapur and Etwarpur (Dug well)

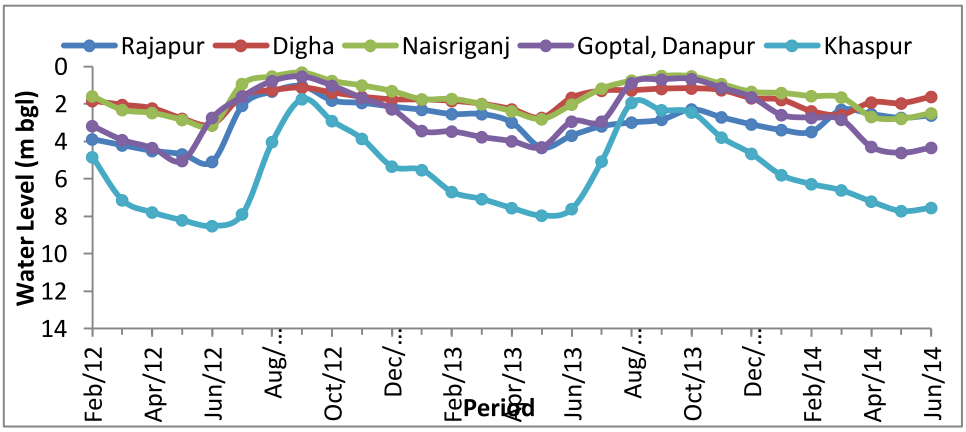


Fig 3.8 k (v): Time series data of Ground water level at Rajapur, Digha, Nasariganj, Goptal, and Khaspur (Dug well)

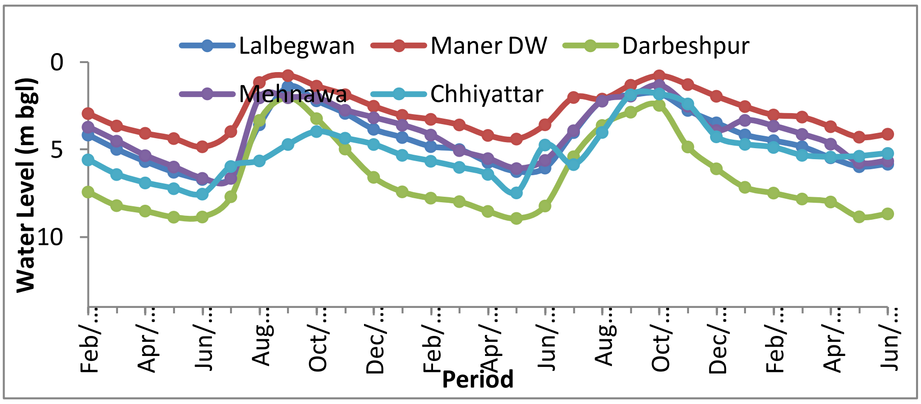


Fig 3.8 k (vi): Time series data of groundwater level at Lalbegwan, Maner, Darbeshpur, Mehnawa, and Chiyattar (Dug well)

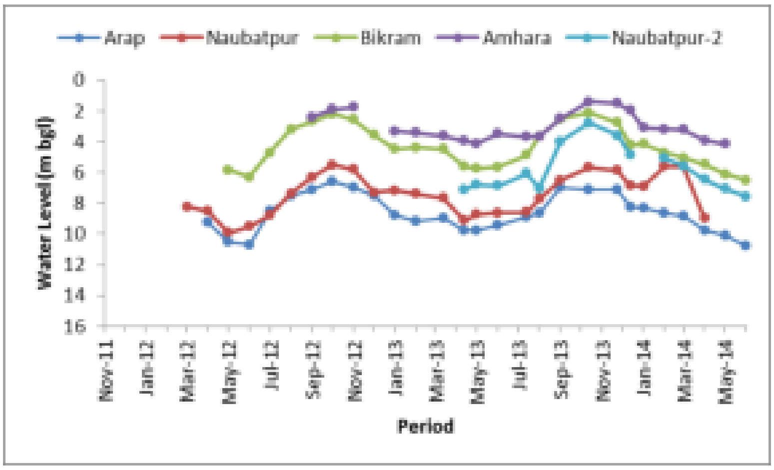


Fig 3.8 l(i): Time series data of Arap,Naubatpur, Bikram, Amraha, and Naubatpur -2 (first aquifer)

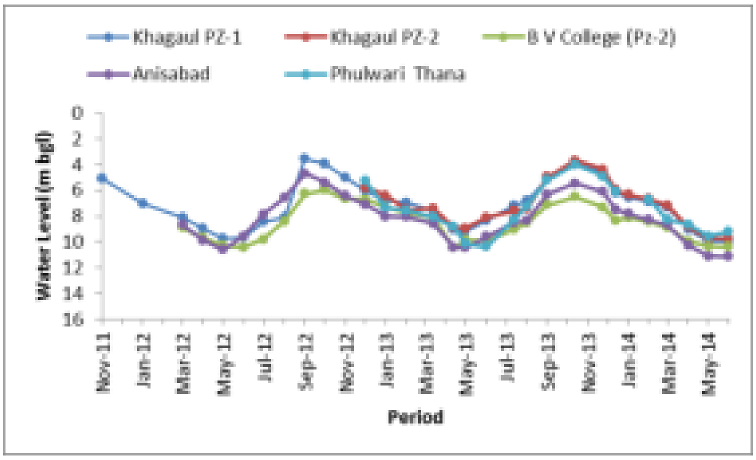


Fig 3.8 l(ii): Time series data of Khagaul, B.V.College, Anisabad, and Phulwari (first aquifer)

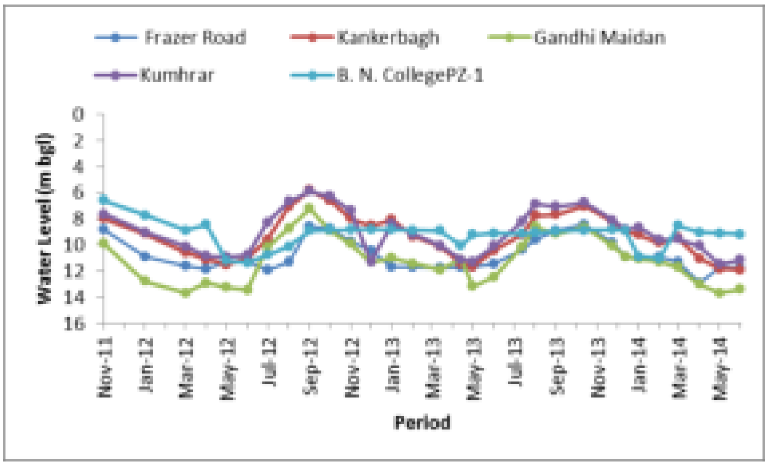


Fig 3.8 l (iii): Time series data of Frazer road, kankarbagh, Gandhi maidan Kumhrar and B.N.College (first aquifer)

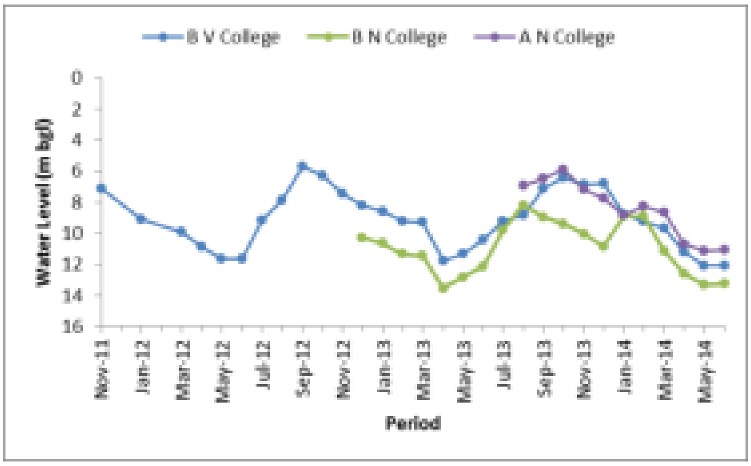


Fig 3.8 m (i): Time series data of B.V.College, B.N.College and A.N.College (second aquifer)

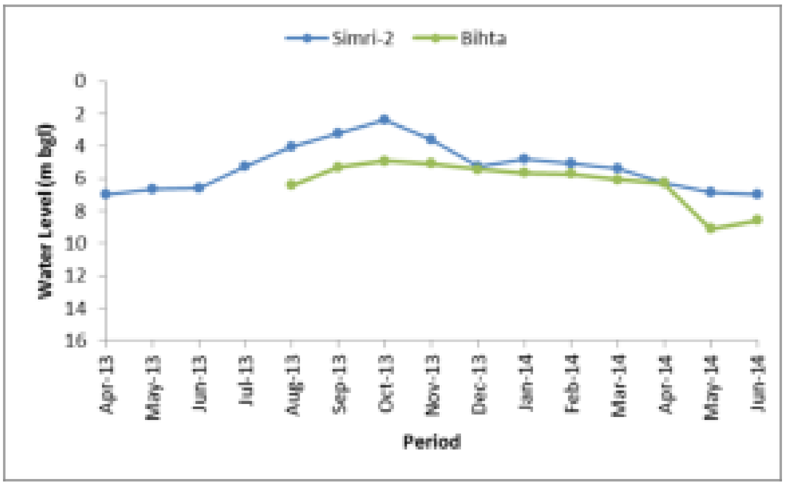


Fig 3.8 m(ii): Time series data of Simri and Bihta (second aquifer)

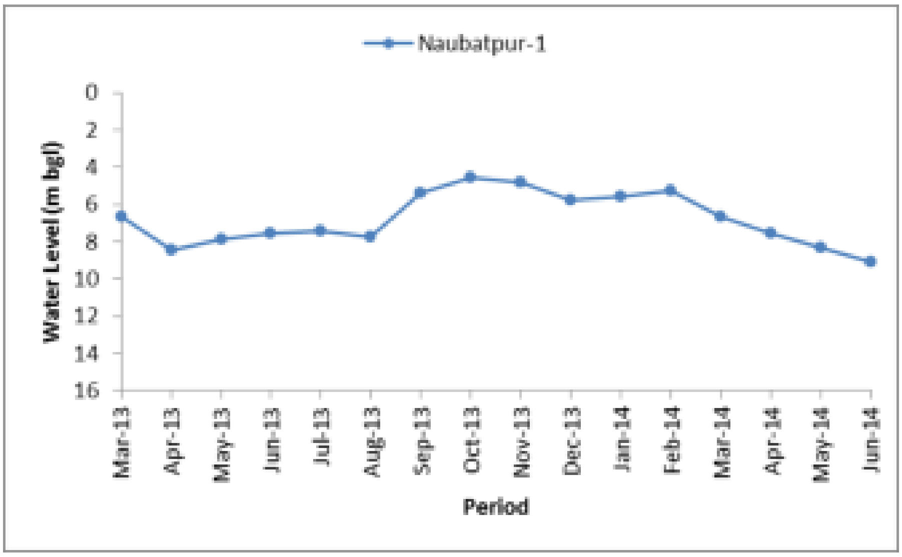
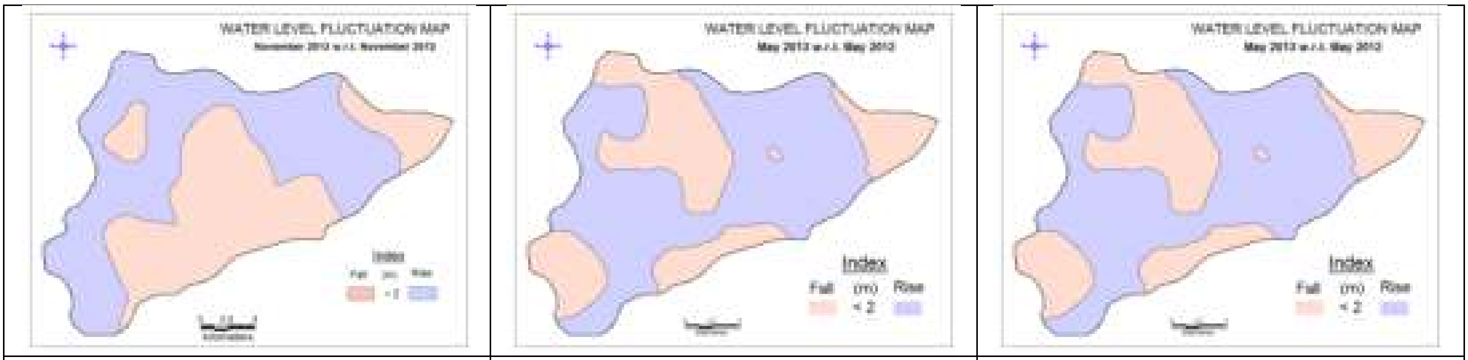
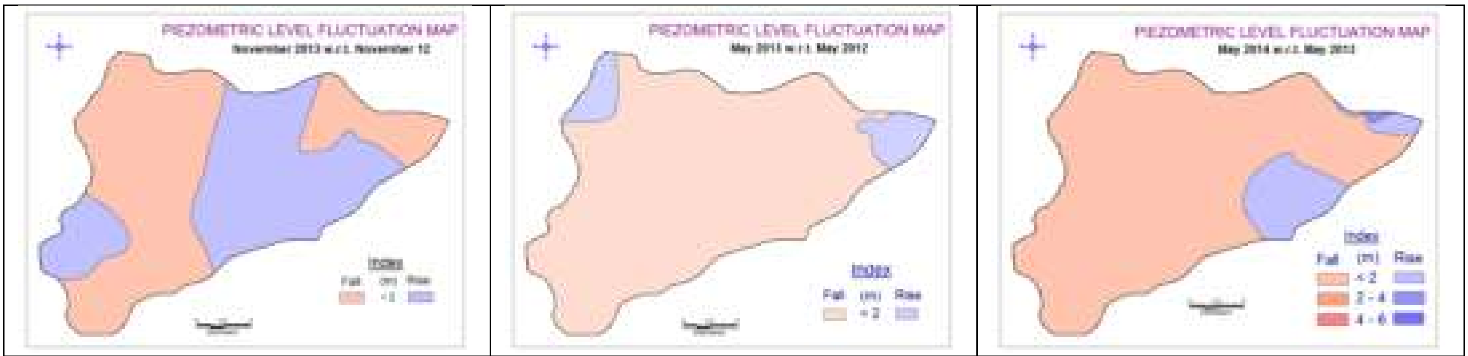


Fig 3.8 m (iii): Time series data of Naubatpur (second aquifer)



(a) (b) (c)

Fig 3.8 n: Annual groundwater level fluctuation map (aquitard) (i) Nov-12 to Nov.13 (ii) May-12 to May-13 (iii) May-13 to May-14



A B c

Fig 3.8 o: Annual Piezometric level fluctuation map (first aquifer) (i) Nov-12 to Nov.13 (ii) May-12 to May-13 (iii) May-13 to May-14

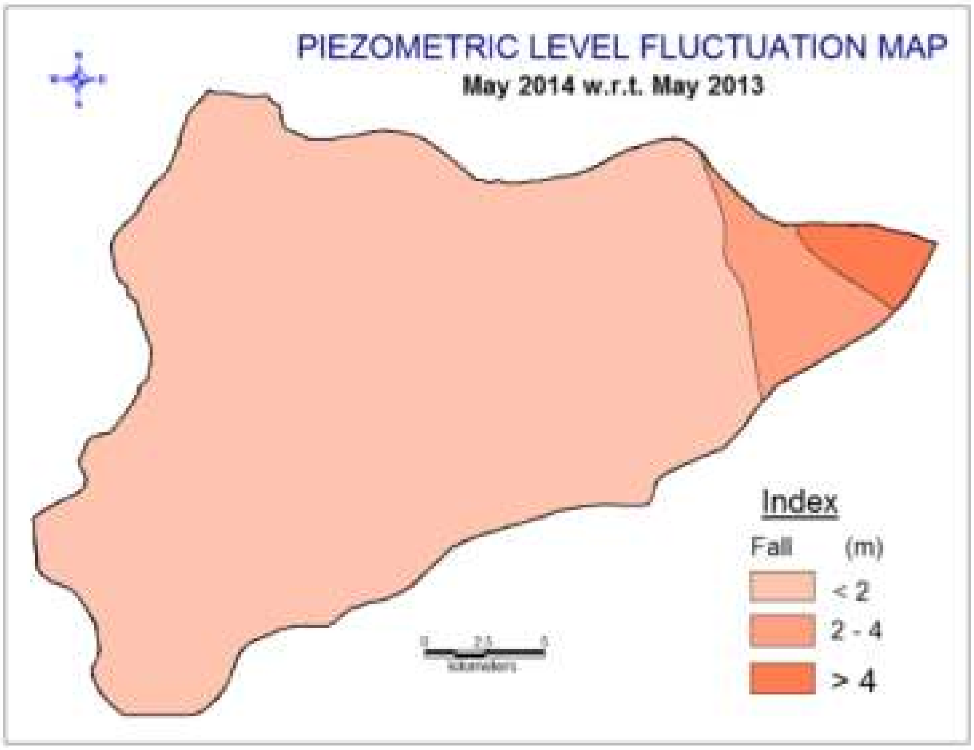
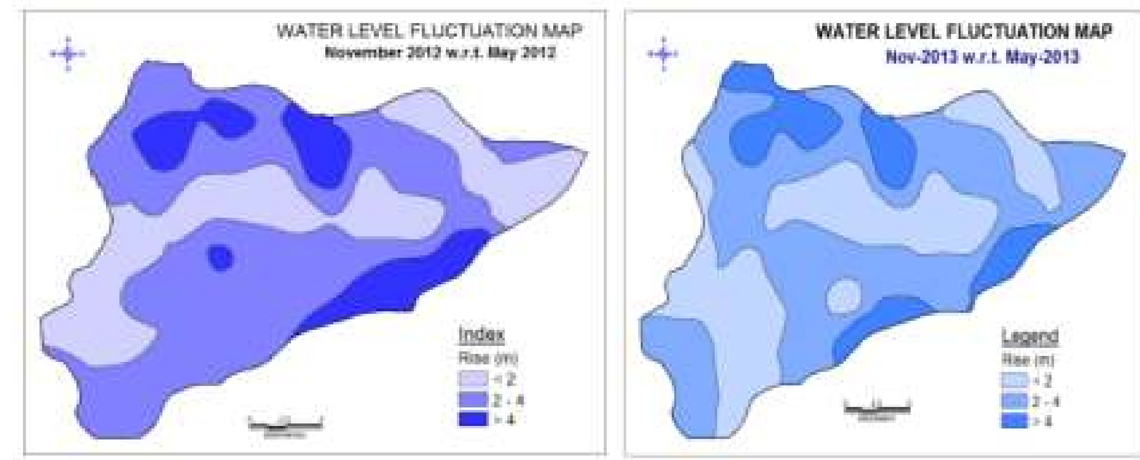


Fig 3.8 p: Annual pre-monsoon (May-13 to May-14) piezometric level fluctuation map (second aquifer)

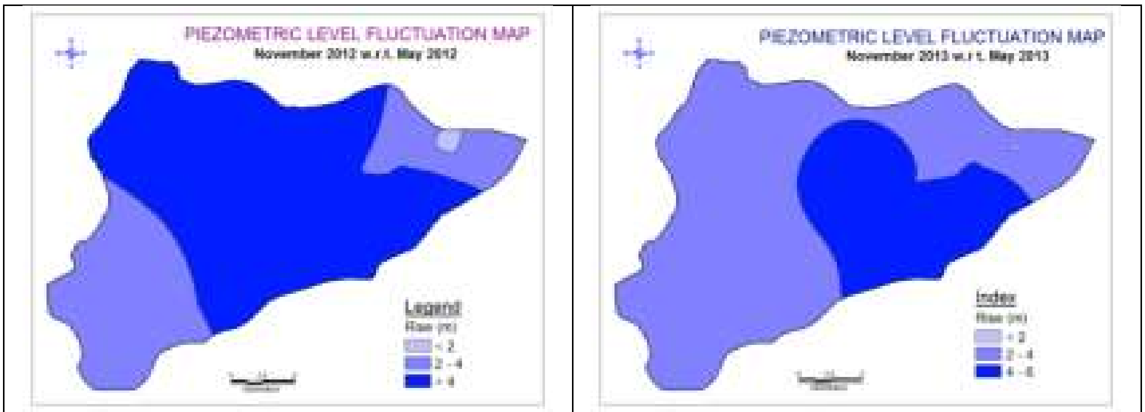
Figure 3.8 (Q) and Figure 3.8 (R) shows seasonal (Pre to post monsoon) water/ piezometric level Fluctuation map for the year 2012 and 2013 of Aquitard (dug well) and first aquifer respectively. Figure 3.8 (S) shows seasonal (Pre to post monsoon) piezometric level fluctuation map for the year 2013 of second aquifer. These indicate that rainfall has bearing on the groundwater level. The groundwater level of the dugwell tapping aquitard zone in most of the area rises up to the tune of 2 to 4 m during postmonsoon. In small pockets in eastern and northern part, there is a rise of more than 4m in groundwater level.

In the first aquifer also, the pre to post- monsoon piezometric head rise in most part of the area is in the tune of 2 to 4 m, bgl. Only in central eastern part, it is in the tune of 4- 6m, bgl. In the majority of the area piezometric head rise from pre to post-monsoon in the second aquifer also, in most part of the area is in the tune of 2 to 4 m, bgl. In the central part, in small patches, fluctuation from pre-monsoon to post-monsoon was found more than 4 m.



a	b

Fig 3.8 q: Seasonal (Pre to post monsoon) water level fluctuation map of Aquitard (dug well) (i) Year 2012 (ii) Year 2013



Fluctuation-2012 (Pre to post monsoon) –(Aquifer 1)	Fluctuation-2013 (Pre to post monsoon) –(Aquifer 1)

Fig 3.8 r: Seasonal (Pre to post monsoon) piezometric level fluctuation map of first aquifer (i) year 2012 (ii) year 2013

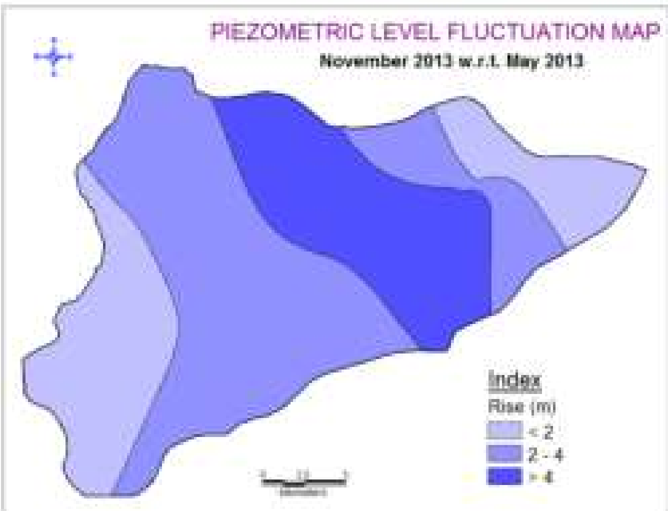


Fig 3.8 s: Seasonal (Pre to post monsoon) piezometric level fluctuation map of second aquifer for year 2013

3.9 Ground water quality

3.9.1 General

Groundwater is the most important and essential natural resource for domestic, industrial and agricultural needs. Water quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities. Understanding the quality of groundwater is particularly important as it determines the factors governing the suitability of water for drinking, domestic, agricultural and industrial purposes (Subramanian et al. 2005).

Quality of groundwater is as much demanding as its quantity. Suitability of groundwater for drinking and irrigational purpose is important for its safe and effective use. The state of Bihar is mainly dependent on groundwater for the domestic and irrigation demand .The pressure on groundwater is considerable also in the Pilot aquifer mapping area to meet urban and rural water requirements as well as the irrigation requirements in the semi-urban and rural areas. Chemically, the groundwater is an aqueous solution in the sub-surface geological formation. The concentration of the major ions and other dissolved ions in groundwater are functions of the availability of the constituents in the aquifer matrices and their solubility. Rocks, through which water circulate, are composed of minerals and amorphous solids, which in turn are composed of chemical elements that greatly affect the groundwater quality.

This chapter is an overview of the chemical quality of groundwater as determined by analyzing water samples collected from different locations spreaded over the entire Pilot aquifer mapping area, taping different aquifer zone and interpreting the acquired data with respect to its use in various spheres of life.

3.9.2 Methodology

To study the groundwater chemistry of different aquifers present in the area, a total number of 81 groundwater samples were collected from different aquifers during different time periods for analysis of major parameters. The water samples were collected and stored in 1 liter capacity clean plastic bottles. Before collection of samples, the bottles were properly washed. Prior to collecting the samples, the containers were rinsed by the water to be sampled. The wells were duly pumped before collecting groundwater sample so that the stagnant water, if any, is completely removed from storage within the well assembly

A total number of 81 groundwater samples (Figure-3.9a.) were collected from deep tube wells and open dug wells tapping aquitard layer and different aquifer across the study area for chemical analysis of major parameters during the month of June-2012; September 2012; February-2013 and March-2013. Out of 81 samples, 25 samples were collected from Dug wells (depth varying from 4.35 to14 m) and 42 numbers from the wells (HP/TW) tapping aquifer -1 (depth varying from 20 to 79m) and 14 samples collected from the wells tapping aquifer- 2 (depth ranging from 110 to 240m). Details of sample location are given in annexure- 3.9a, 3.9b & 3.9c. Salient statistical result of analysis of groundwater from aquitard, aquifer-1 & aquifer-2 samples are given in table 3.9a.

128 groundwater samples were collected for arsenic and iron analysis during different time period. Out of 128 ground water sample, 12 samples, 108 samples and 8 samples were collected from Dug well, Aquifer-1 & Aquifer-2, respectively. Figure 3.9b, shows the location from where groundwater sample was collected for As & Fe analysis.

Groundwater sample were also collected and analyzed for heavy metals like Cr, Zn, Mn and Hg besides Fe & As. Cr analysis were also carried out for groundwater samples collected from aquitard layer (dug well) at 25 locations and from aquifer-1 at 29 locations. Hg, Zn & Mn analysis were carried out for groundwater samples collected from aquitard layer (dug wells) at 9 locations and from aquifer-1 at 11 locations.

These water samples were analysed in chemical laboratory of CGWB MER-Patna, Chemical Lab, PHED, Govt. of Bihar & CMRI Dhanbad for different parameter. Besides these, available historical data of chemical analysis of groundwater were also studied to have an understanding of groundwater chemistry of the area. Analytical results of groundwater samples are given in the annexure 3.9 (d to m).

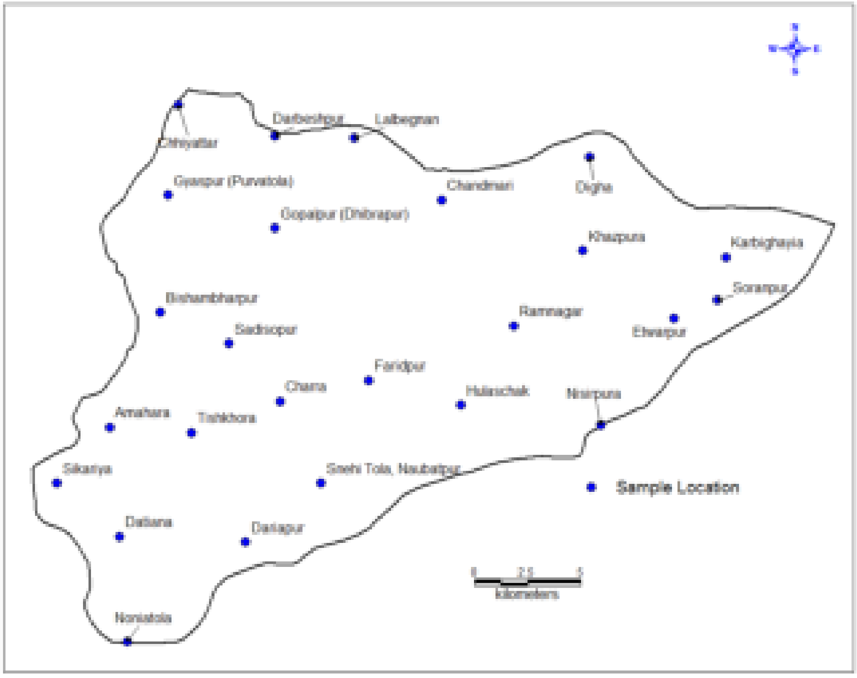


Fig. 3.9(a) Location of samples collected for chemical analysis from aquitard (Dug well)

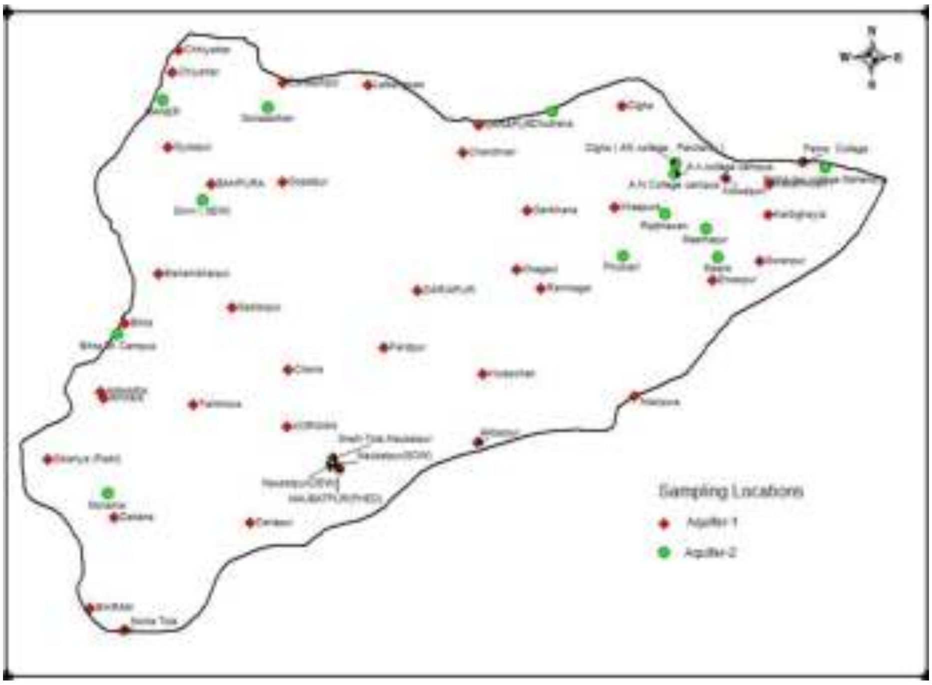


Fig. 3.9 (b) Location of samples collected for chemical analysis from Aquifer-1 & Aquifer-2.

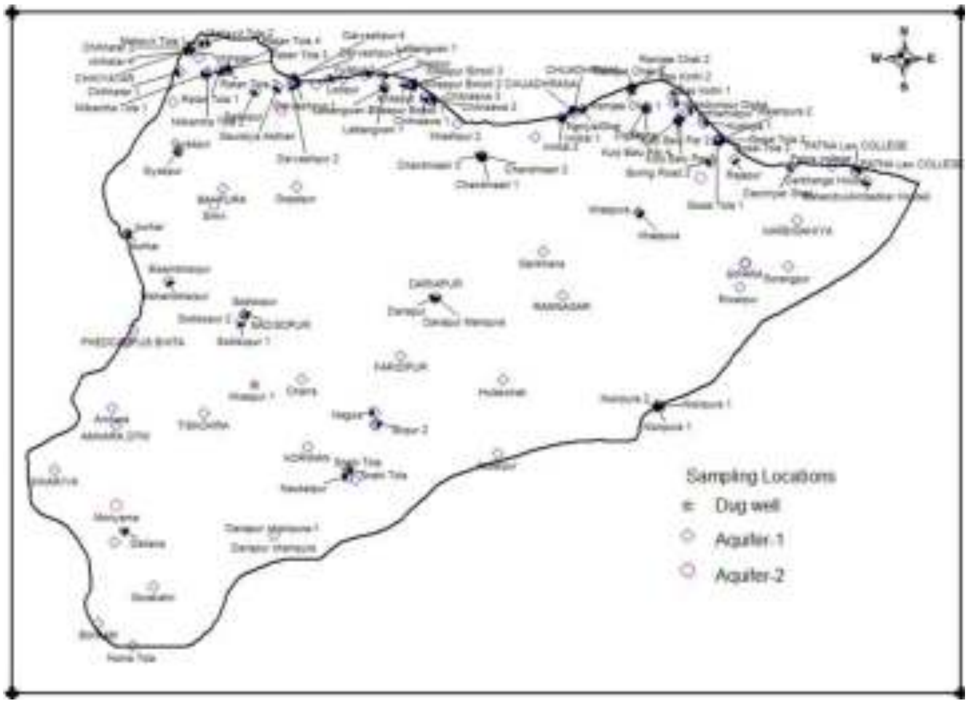


Fig. 3.9(c) Location of samples collected for arsenic and iron analysis.

Table 3.9 (a): Salient statistical details of the chemical parameters of groundwater of the area.

Parameters	Groundwater sample collected from Dug well representing Aquitard layer			Groundwater sample collected from Hand Pump/tube wellrepresenting aquifer-1			Groundwater sample collected from Hand Pump/tube well representing aquifer-2		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
pH	6.50	7.50	6.99	6.28	8.24	7.17	7.08	8.52	7.78
EC	380	1940	1090	310	1240	520	315	556	428.5
TDS	247	1261	705	201	806	330	205	361	278
TH	220	876	420	125	484	246	95	268	169
Alkalinity	240	780	519	215	660	328	20	301	207
Calcium	16	165	61	24	86	51.5	7	34	18
Magnesium	6	198	67	1.94	91.3	29.3	7.3	34	17.68
Sodium	12	142	75	9.18	252	30.5	9.17	34.9	24.5
Potassium	1.12	337	50	0.53	65.91	7.43	1.6	4.55	2.73
Chloride	28	340	133	6	167	37	7	34	18
Nitrate	0.11	1.03	0.55	0.11	3	0.65	0.2	7	2.64
Sulphate	4.27	153	53	0.29	69.89	13.19	0.9	6.3	3.32

Parameters	Groundwater sample collected from Dug well representing Aquitard layer			Groundwater sample collected from Hand Pump/tube wellrepresenting aquifer-1			Groundwater sample collected from Hand Pump/tube well representing aquifer-2		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
% Sodium	9.82	64.62	31.37	6.95	78.32	19.5	8.47	45.84	26.52
SAR	0.35	2.94	1.59	0.20	6.51	0.73	0.18	1.18	0.71
PI	34.98	70.28	53.65	29.2	94.03	57.46	40.54	95.94	65.95

(EC: µmho/cm at 25ºC. Except pH, % Na, SAR and PI all are in mg/l)

3.9.3 Suitability of ground water for drinking purpose

The suitability of groundwater of the area for drinking purposes has been assessed as per the guide line laid down by Indian Standard Drinking Water Specification (BIS, 2012), which assure, in general, the protection of human health. Accordingly, the concentration of various major and trace elements in the groundwater samples of the study area are compared with the drinking water standard of Indian Standard Drinking Water Specification (BIS, 2012) as summarized in Table-3.9(b).

Table-3.9 (b): Comparison of various parameters of groundwater of the area with drinking water standards (B.I.S- 2012)

Parameters	BIS (2012) (mg/l)		Concentration in groundwater of the Study Area (mg/l)		
	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate Source	Dug well	Aquifer-1	Aquifer-2
pH	6.5 -8.5	No relaxation	6.5 to 7.5	6.28 to 8.24	7.08 to 8.52
Total Hardness	300	600	220 to 876	125 to 484	95 to 268
TDS	500	2000	247 to 1261	321 to 999	116 to 357
Calcium	75	200	16 to 165	24 to 86	16 to 80
Magnesium	30	100	6 to 198	1.94 to 91.36	7.3 to 34
Sodium	--	--	12 to	9.18 to	9.17 to 34.9

Parameters	BIS (2012) (mg/l)		Concentration in groundwater of the Study Area (mg/l)		
	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate Source	Dug well	Aquifer-1	Aquifer-2
			142	252.15	
Chloride	250	1000	28 to 340	5.66 to 167	7 to 33.96
Sulphate	200	400	4 to 153	0.29 to 69.89	0.9 to 6.3
Fluoride	1	1.5	0.33 to 1.14	0.13 to 1.37	0.01 to 0.64
Nitrate	45	No relaxation	0.11 to 1.03	0.11 to 3	0.2 to 7
Iron	0.3	No relaxation	.01 to .4	0.01 to 5.77	0.009 to .72
Manganese	0.1	0.3	.009 to 1.368	.005 to .667	
Chromium	0.05	No relaxation	0.0003 to 0.0332	0.0002 to 0.00 48	
Zinc	5	15	.024 to .192	.0112 to .4386	
Arsenic	0.01	0.05	.003 to .017	0.0001 to 0.087	0.008 to .025
Mercury	0.001	No relaxation	.00015 to .00071	0.00015 to 0.00095	

(EC: µmho/cm at 25ºC. Except pH all are in mg/l)

3.9.3a Electrical conductivity

In the area, electrical conductivity values of ground water from dug well, aquifer-1 & aquifer-2 ranges between 380-1940 µmho/cm, 310-1240 µmho/cm, and 315-556 µmho/cm, respectively. EC contour map was prepared for the top auitard (dugwell zone), aquifer-1, and aquifer-2 are shown in figure 3.9 (d), 3.9(e) & 3.9(f) respectively. Table-3.9 (c) shows the classification of groundwater of the area on the basis of electrical conductance (Sarma and Narayanaswamy, 1981).

Table-3.9(c) Classification of groundwater on the basis of electrical conductivity

Electrical conductivity (µmho/cm at 25°C)	Water Classes	Number of groundwater samples		
		Aquitard (Dw)	Aquifer-1	Aquifer-2
<250	Excellent (C1)	0	0	0
250–750	Good (C2)	5	39	14
750–2,250	Permissible (C3)	20	3	0
>2,250	Unsuitable (C4)	0	0	0

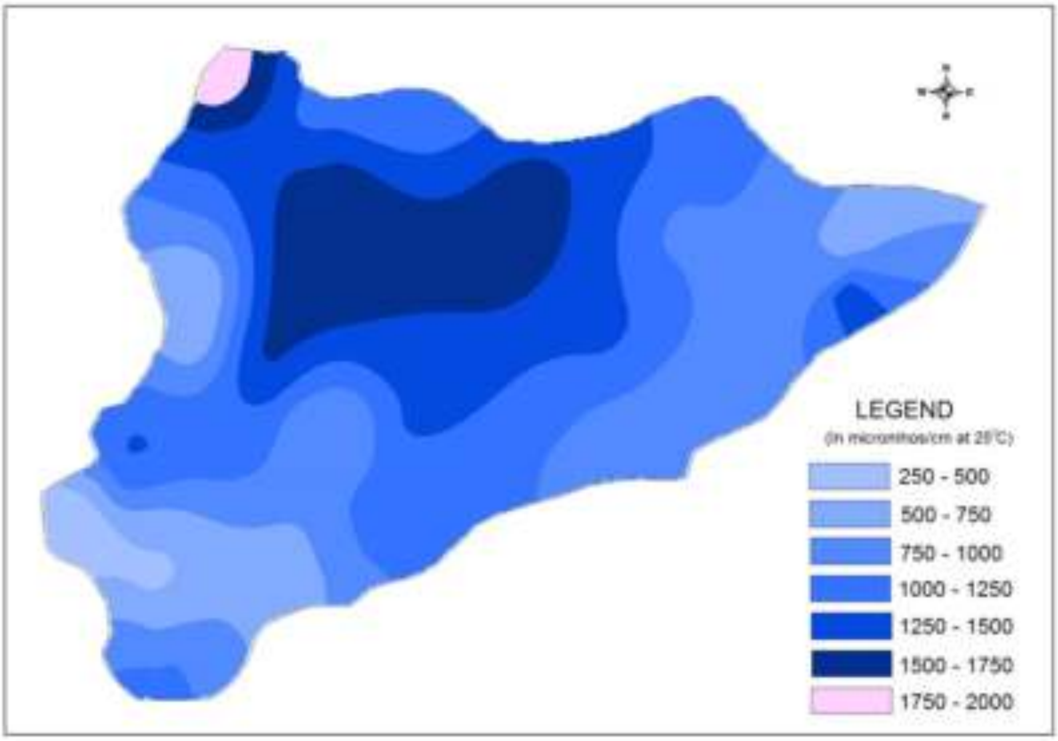


Fig. 3.9(d) Electrical conductivity contour map (dug well zone)

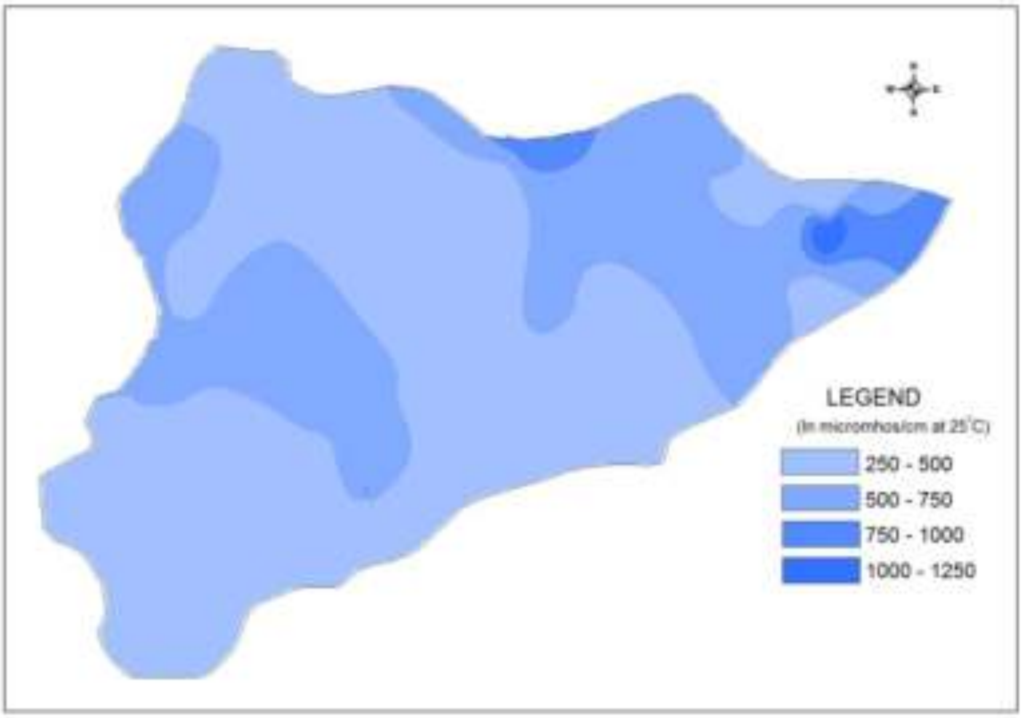


Fig. 3.9(e) Electrical conductivity contour map (Aquifer-1)

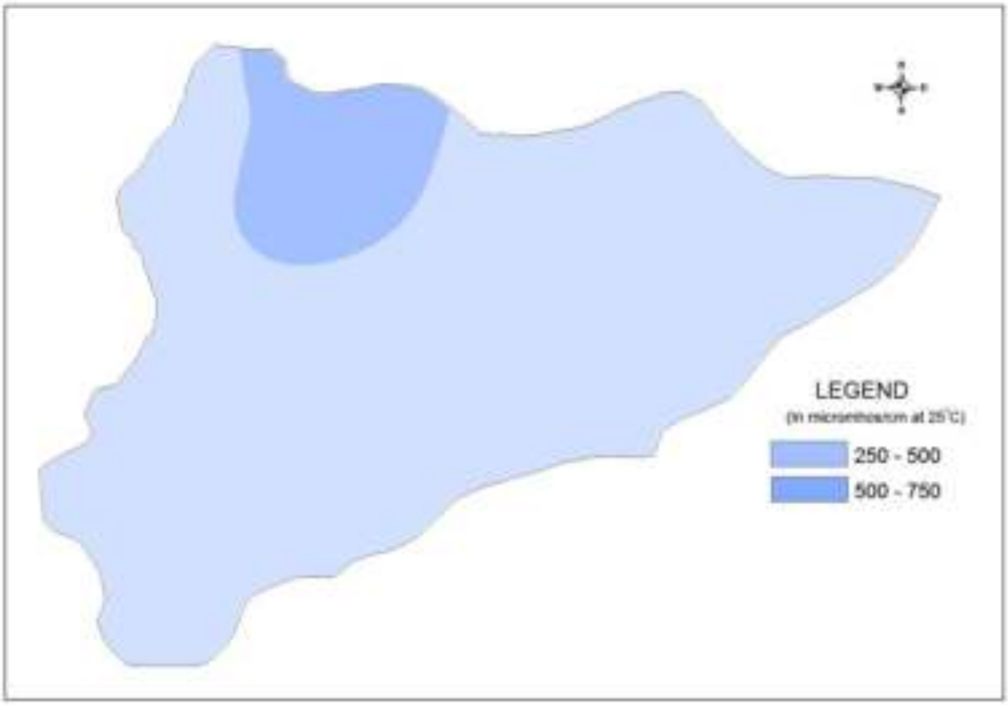


Fig. 3.9(f) Electrical conductivity contour map (Aquifer-2)

3.9.3b Hydrogen Ion Concentration (pH)

pH is defined as the negative logarithm of hydrogen ion activity and reflects the degree of acidity or alkalinity of water. pH of the analyzed water samples of dug wells tapping aquitard layer varies from 6.5 to 7.5 with average value of 6.99. It ranges from 6.28 to 8.24 and from 7.08 to 8.52 in groundwater of aquifer 1 and aquifer 2 respectively. In general, pH of groundwater was mildly alkaline in nature.

3.9.3c Total Dissolved Solids (TDS)

Total dissolved solids (TDS) have been calculated by multiplying factor of 0.65 with electrical conductivity. TDS values for dug well, aquifer-1 & aquifer-2 samples ranges from 247 to 1261 mg/l (average 705 mg/l), 201 to 806 mg/l (average 330 mg/l) & 205 to 361 mg/l (average 278 mg/l) respectively. 19 out of 25 samples (dug well), 2 out of 42 samples (aquifer- 1) have values of TDS>500 mg/l, respectively. TDS of all the groundwater samples from aquifer-2 have been found to be remain within 500 mg/l.

3.9.3d Total Hardness

In the area, the hardness value in dug well, aquifer-1 & aquifer-2 varies from 220 to 876 mg/l (average 420 mg/l), 125 to 484 mg/l (average 246 mg/l) and 95 to 268 mg/l (average 172 mg/l), respectively. TH contour maps were prepared for the top aquitard (dugwell zone), aquifer-1 and aquifer -2 and are shown in figure 3.9(g), 3.9(h) &3.9(i) respectively. It was found that, except few samples in dug well, all the samples of study area including samples from aquifer-1 & 2 are within the permissible limit of drinking water standard BIS (2012) & WHO (1997). The hardness results from the divalent metallic ions of which the calcium and magnesium are the most abundant ions in groundwater. These ions react with soap to form precipitates, and with certain anions present in water form scales. Table 3.9(d) shows the classification of groundwater of the area based on TDS.

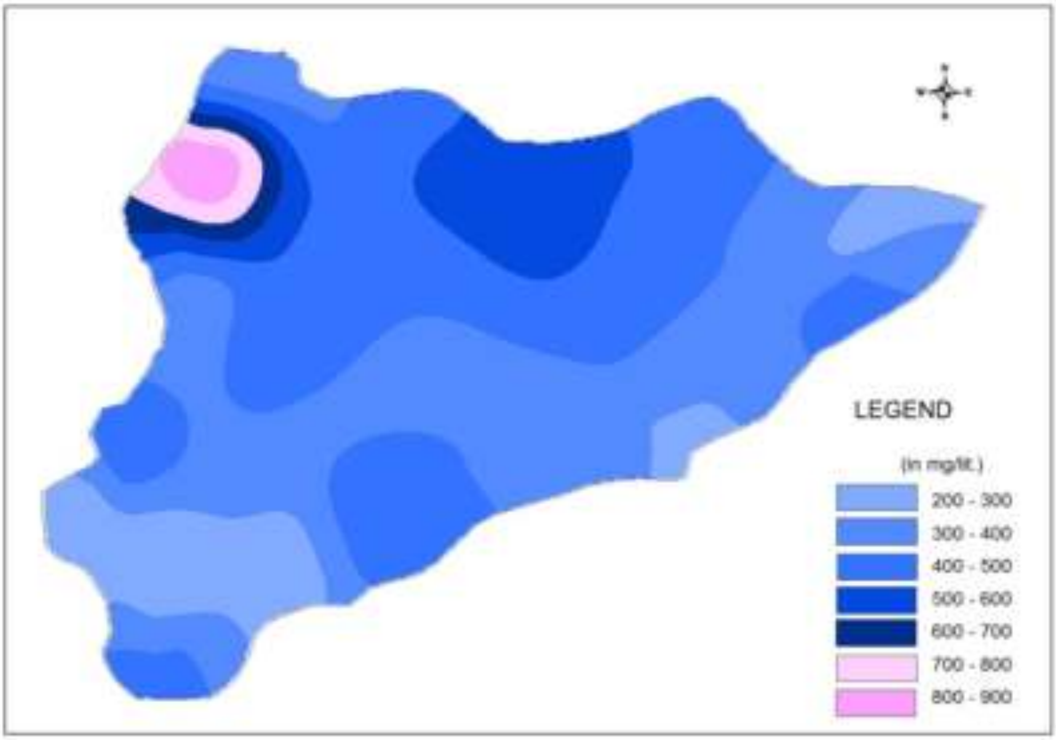


Fig. 3.9 (g) Contour of total hardness (dug well)

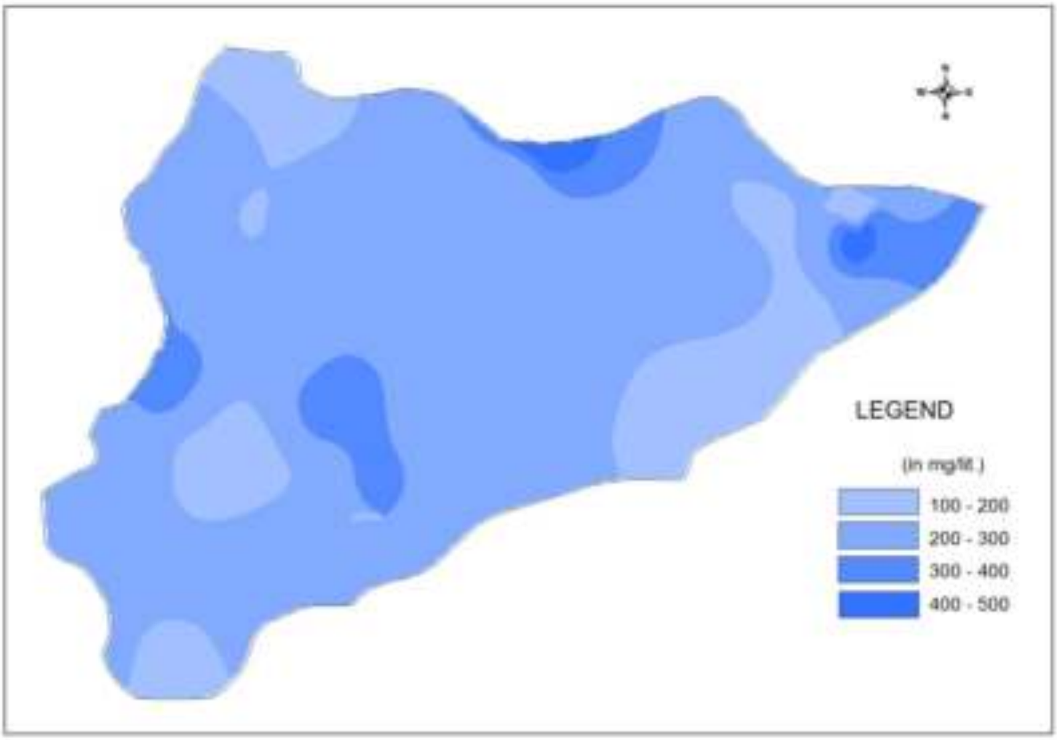


Fig. 3.9(h) Contour of total hardness (Aquifer-1)

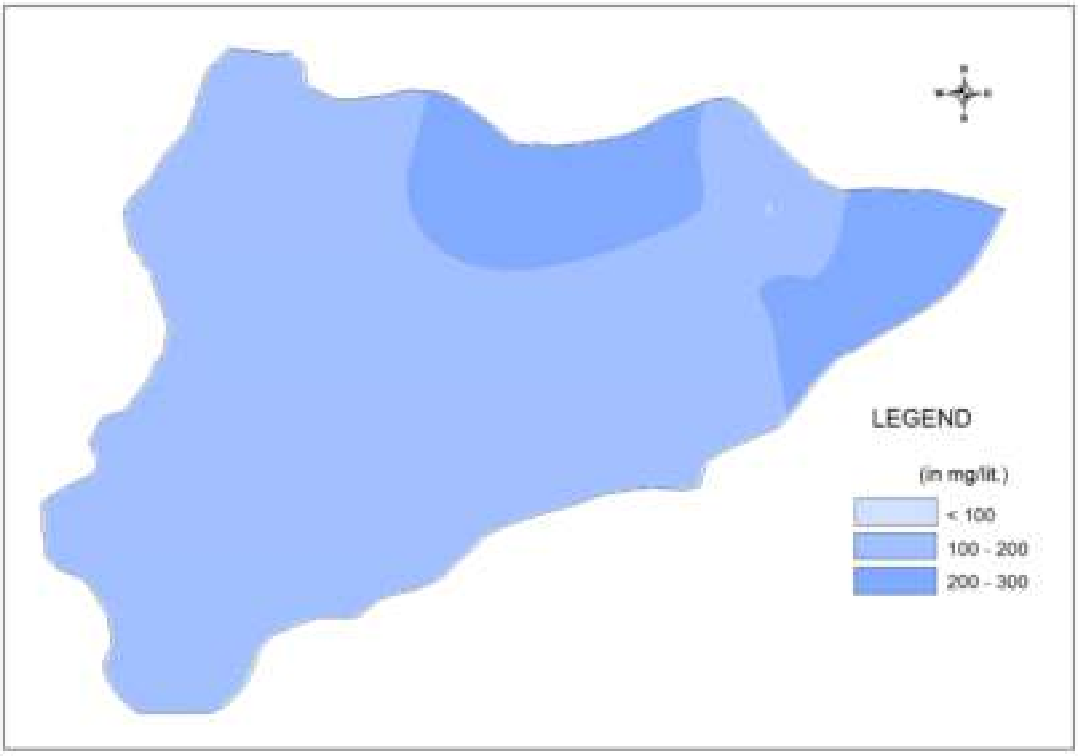


Fig.3.9 (i) Contour of total hardness (Aquifer-2)

Table-3.9(d): Classification of groundwater (based on hardness)

Hardness of $CaCO_3$(mg/l)	Water Class	Aquifer-wise % of groundwater Samples		
		Dug Well	Aquifer-1	Aquifer-2
0 – 75	Soft	-Nil-	-Nil-	-Nil-
75 – 150	Moderately hard	-Nil-	2% (1 Sample)	69% (9 Samples)
150-300	Hard	20% (5 Samples)	86% (36 Samples)	31% (4 Samples)
> 300	Very hard	80% (20 Samples)	12% (5 Samples)	-Nil-

3.9.3e Alkalinity

In most natural water the alkalinity is produced by the dissolved carbon-dioxide species, bi-carbonate (HCO_3-) and carbonate ($CO_3^{-\ 2}$) ions, (Hem, 1989). In most natural water HCO_3-) is the dominant carbon species (Stednick, 1991). According to Hem (1989), carbonate species can contribute only small amounts to alkalinity in water.

In the area, the concentration of HCO_3- in dug well sample ranges between 240 to 780 mg/l and in ground water samples of aquifer- 1 and aquifer- 2 ranges from from 215 to 660 mg/l and 20 to 301.35 mg/l, respectively.

Alkalinity (HCO_3-) contour map has been prepared for the top aquitard (dug well), aquifer-1 and aquifer -2 and are shown in figure 3.9 (J), 3.9(k) & 3.9(l) respectively.

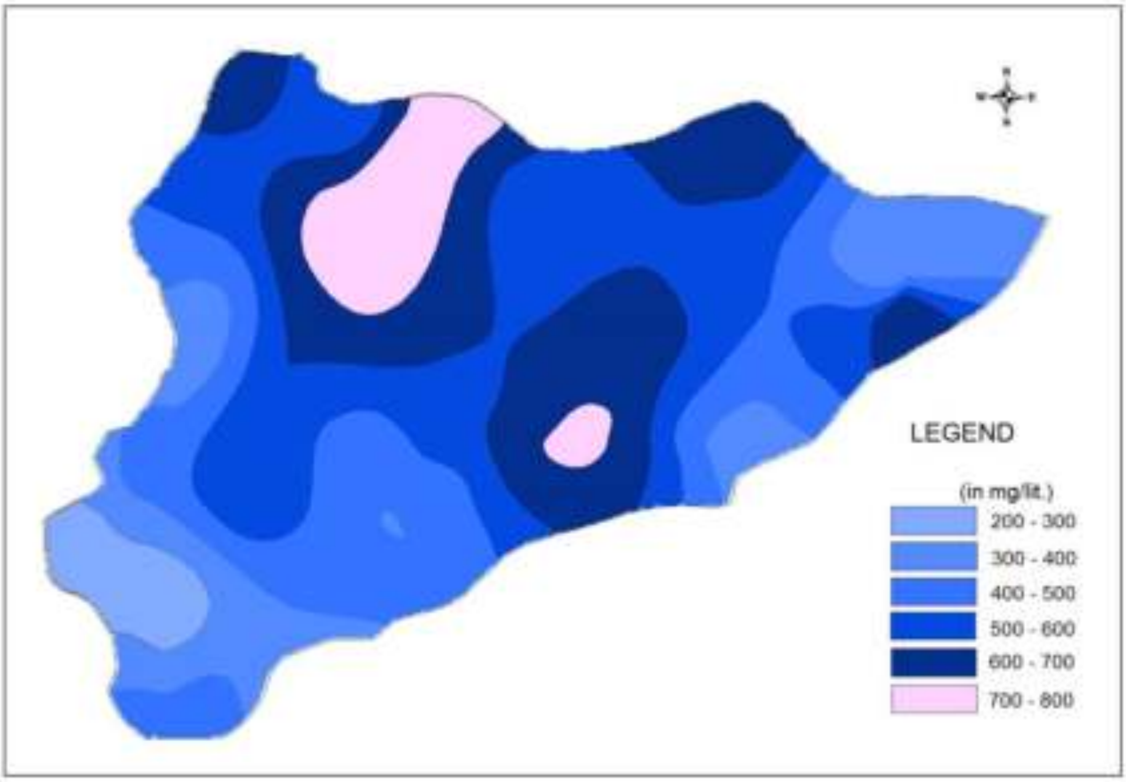


Fig. 3.9 (j) Contour of bicarbonate concentration (dug well)

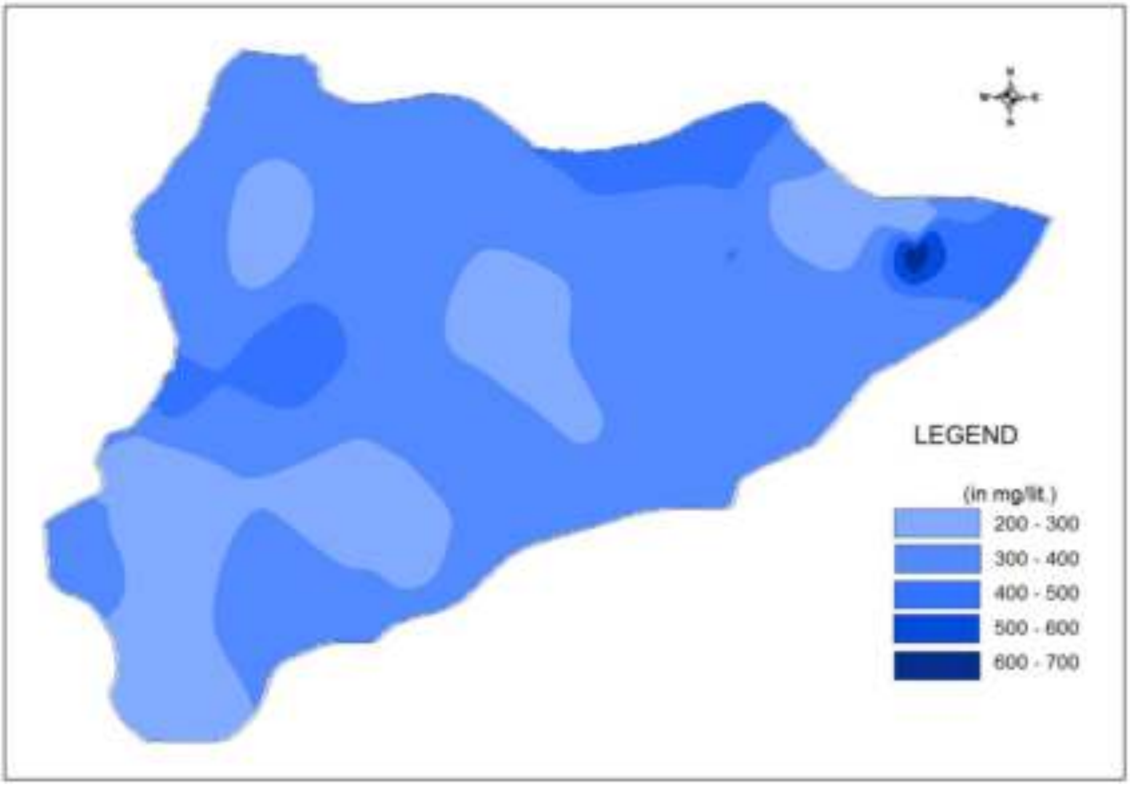


Fig. 3.9(k) Contour of bicarbonate concentration (Aquifer-1)

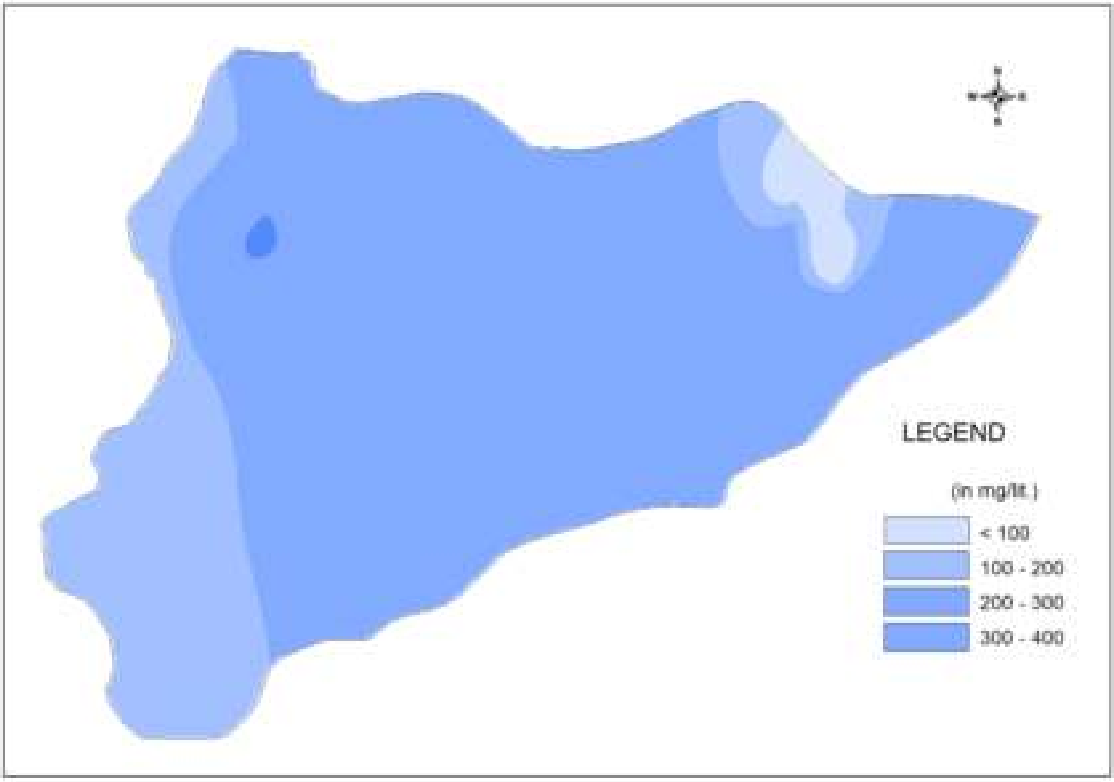


Fig. 3.9 (l) Contour of bicarbonate concentration (Aquifer-2)

3.9.3f Chloride

Chloride is one of the major inorganic anions in groundwater. The major sources of chloride in groundwater are - (i) Rainwater, (ii) solution of dry fallout from the atmosphere, (iii) solution of halite and other minerals & (iv) source related to the activities of man such as domestic sewage and industrial effluents etc.

The concentration of chloride in all samples collected from dug well, aquifer-1 & aquifer-2 are within the permissible limit. It ranges from 28.36 to 339.6 mg/l in the groundwater of dug wells tapping the top aquitard, while it's concentration in groundwater of aquifer-1 and aquifer-2 ranges 6 to 166.97 mg/l and 7 to 33.96 mg/l respectively.

Contour map of chloride concentration has been prepared for the top aquitard (dug well), aquifer-1 and aquifer -2 and shown in figure 3.9(m), 3.9(n) & 3.9(o) respectively.

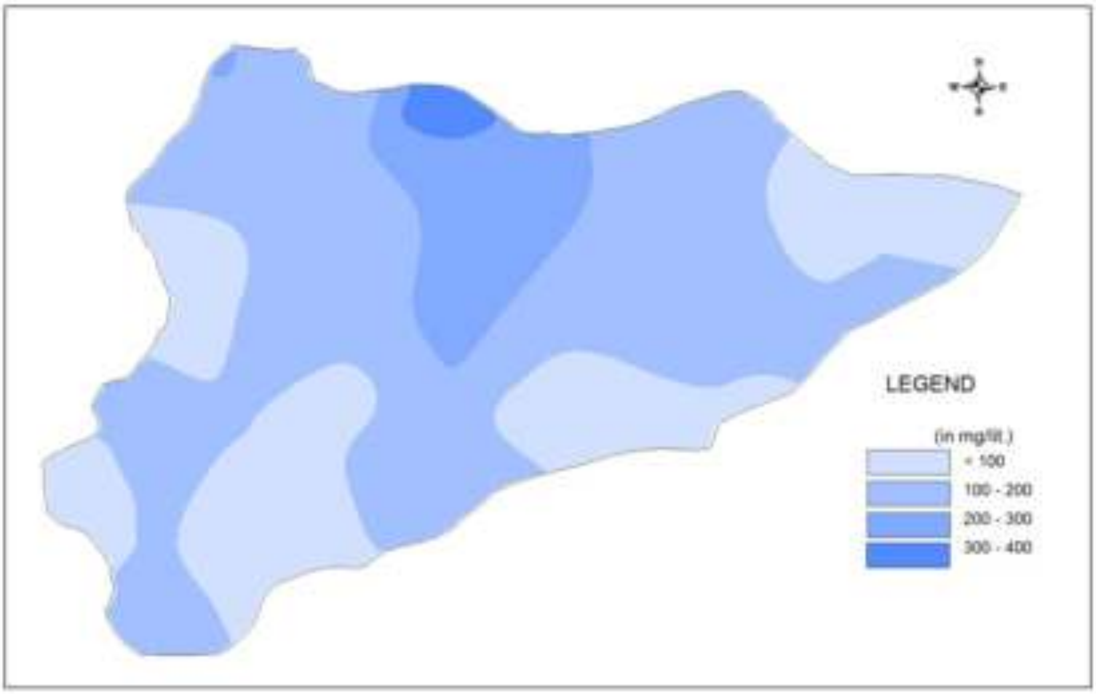


Fig.3.9 (m) Contour of chloride concentration (dug well)

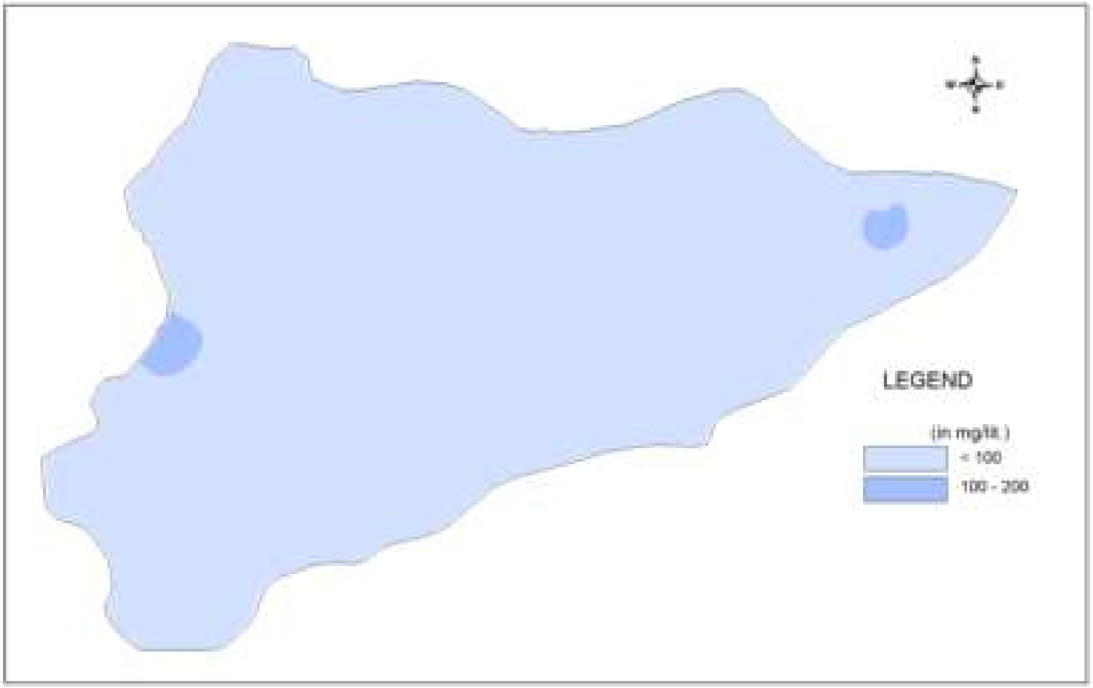


Fig.3.9 (n) Contour of chloride concentration (Aquifer-1)

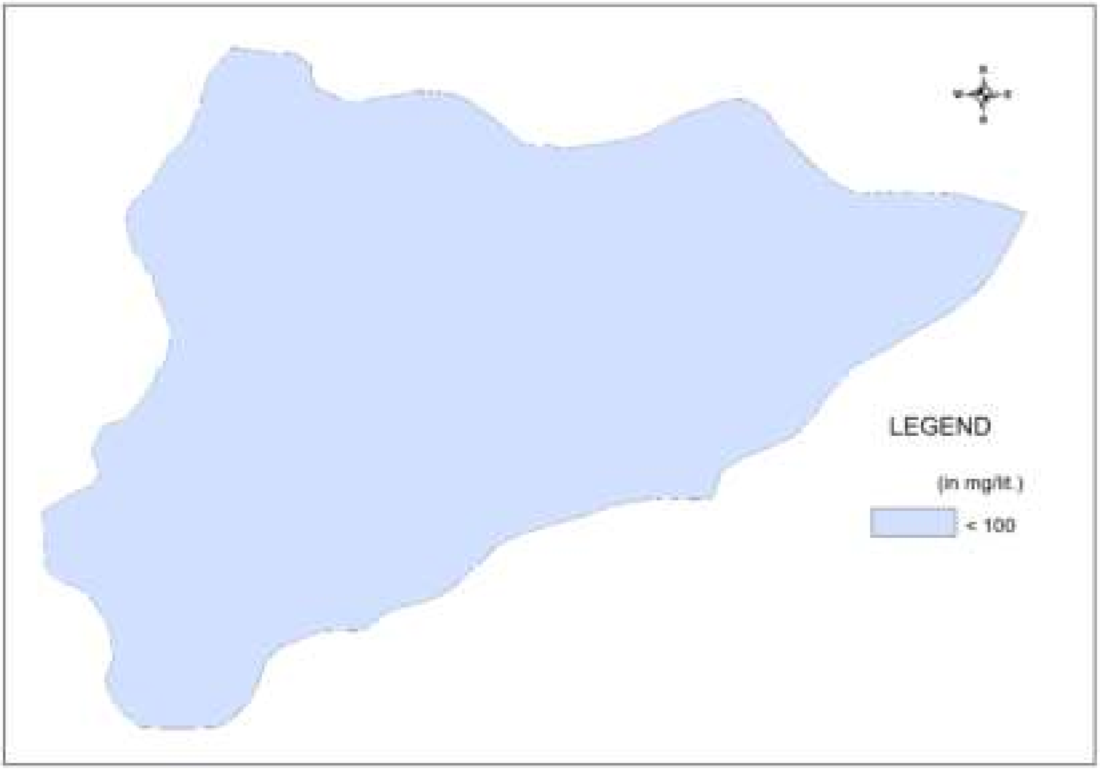


Fig.3.9 (o) Contour of chloride concentration (Aquifer-2)

3.9.3g Sulphate

As per BIS (IS: 10500 – 2012) the permissible limit of sulphate for drinking purposes is 400 mg/l. The high intake of sulphate may result in gastrointestinal irritation and respiratory problems to the human system (Maiti, 1982; Subba Rao, 1993; Subramani et al. 2005).

The concentration of sulphate in dug well sample ranges between 4.27 to 152.7 mg/l and in groundwater of aquifer-1 and aquifer-2 ranges from 0.29 to 69.89 mg/l and 0.9 to 6.3 mg/l, respectively. The concentration of sulphate in groundwater of the area is within the permissible limit.

3.9.3h Calcium (Ca)

It is found in minerals from sedimentary rocks such as calcite, aragonite, gypsum, anhydrite and silicate mineral like anorthite, diopside etc. The main source of calcium in ground water are (i) rain water, (ii) dissolution of evaporate deposits, (iii) weathering of calcium silicate minerals, (iv) fertilizers and soil amendments and (v) release of calcium ion by ion exchange. It is the most common constituent in natural water. The absence of calcium in drinking water causes rickets in the body, while excess concentration causes gout and rheumatism.

The concentration of calcium in groundwater of the area is within the permissible limit. The concentration of calcium in groundwater of dug well, aquifer-1 & aquifer-2 samples ranges from 16 to 165 mg/l, 24 to 86 mg/l and 16 to 80 mg/l, respectively.

3.9.3i Magnesium (Mg)

The concentration of magnesium in aquifer-1 & aquifer-2 samples ranges from 1.94 to 91.36 mg/l and 34 to 17.68 mg/l and are within the permissible limit (BIS 2012).The concentration of magnesium in ground water of dug well tapping aquitard zone are within the permissible limit and ranges from 5.83 to 198.28 mg/l.

3.9.3j Sodium (Na)

Sodium is found in varying concentrations in all natural waters. It is found in high concentration in evaporates and sea water. The main sources of sodium in groundwater are (i) rain water, (ii) evaporate deposits, (iii) weathered rock minerals present in the soil, (iv) disposal of sewage and industrial wastes containing sodium. The higher concentration of sodium in drinking water is harmful especially to those suffering from cardiac, renal diseases pertaining to circulatory system of the human body.

The concentration of sodium in groundwater of dug well and aquifer-1 ranges from 12.2 to 141.9 mg/l and 9.2 to 252.2 mg/l respectively, whereas in aquifer-2 it ranges from 9.17 to 34.9 mg/l.

3.9.3k Potassium (K)

Although potassium is more abundant than sodium in sedimentary rocks, it's concentration in natural waters is quite low due to greater resistance to weathering of potassium bearing minerals. The main sources of potassium in natural waters are (i) rain water, (ii) weathering of potash silicate minerals, (iii) potash fertilizers. Potassium is an essential plant nutrient.

The concentration of potassium in groundwater of dug well, aquifer-1 & aquifer-2 ranges from 1.12 to 337 mg/l, 0.53 to 65.91 mg/l and 1.6 to 4.55 mg/l, respectively.

3.9.4 Distribution and concentration of trace metals

Trace metals are widely distributed in the environment with sources mainly from weathering of minerals and soils (Merian, 1991; O'Neil, 1993). Trace elements in ground water are defined as chemical elements dissolved in water in minute quantities, always or almost always, in concentration less than one mg/l (USGS, 1993). Trace metals are needed by the body to satisfy it's nutritional requirements. However, only minute quantities are required as high doses lead to health hazards which are sometimes lethal. The excess or deficiency both may pose health hazard.

Some metals present in trace concentration are important for physiological functions of living tissue and regulate many biochemical processes. The same metals, however, at increased concentration may have severe toxicological effects on human being (Chapman, 1992).

In the study area groundwater samples were collected for analysis of Cr, Mn, Zn, Fe, Mn (Annexure 3.9j to m) and Fe & As (Annexure 3.9g to i). Cr, Mn, Hg and Zn have been analysed by CMRI Dhanbad. As and Fe in groundwater have been analysed by PHED, Govt. of Bihar. A brief description on concentration levels and chemical behavior of these trace metals is given below:

3.9.4a Chromium (Cr)

Hexavalent chromium (Cr 6+) is highly toxic and in higher concentration is found to be carcinogenic (Goel, 1997; Sawyer and Mccarty, 1978). Trivalent chromium rarely occurs in drinking water. Chromium concentrations in the study area range from 0.0003 to 0.0332 mg/l in the groundwater of dug well, and it varies from 0.0002 to 0.0004.8 mg/l in Aquifer-1. The concentration of Chromium in groundwater of the area is within the permissible limit (BIS, 2012).

3.9.4b Manganese (Mn)

Manganese is one of the most abundant metals in the earth's crust and usually occurs together with Fe. Dissolved manganese concentrations in ground and surface waters, poor in oxygen, can reach higher concentration levels. The concentration of manganese ranges from 0.009 to 1.368 mg/l in the groundwater of dug well and from 0.005 to 0.667 mg/l in the Aquifer-1. Except two sample of dug well & one sample of aquifer-1, all are within maximum permissible (BIS limit of 0.3 mg/l).

3.9.4c Zinc (Zn)

Zinc concentration in groundwater of dug well ranges between 0.024 to 0.192 mg/l and in aquifer-1, it ranges from from 0.0112 to 0.4386 mg/l. Zinc concentration in the area are within the permissible limit (15 mg/l).

3.9.4d Iron (Fe)

Iron is one of the most abundant metals in the earth's crust. Iron is an essential element for human nutrition. As per BIS (2012), acceptable limit for iron concentration in potable water is 0.3 mg/l. Iron concentration in the groundwater of the area is within 1mg/l (except in 20 samples from the aquifer-1). Its concentration in the groundwater of dug well, aquifer-1 and aquifer-2 ranges from BDL to 0.4 mg/l, from 0.01 to 5.77 mg/l and from 0.009 to 0.72 mg/l respectively. Table 3.9(e) shows the number of samples having concentration more than acceptable limit (0.3 mg/l) and permissible limit (> 1mg/l). Figure 3.9 (p) shows the location of Iron concentration > 1 mg/l.

Table-3.9(e): Number of groundwater samples having iron concentration (=>0.3mg/l and < 1.0 mgl/l) and (=> 1 mg/l)

Aquifer type	Total sample analysed	number of samples (> 0.3 mg/l and < 1.0 mgl/l)	number of samples (> 1 mg/l)
Aquitard(dug well)	12	1	Nil
Aquifer -1	111	32	20
Aquifer-2	9	2	Nil

3.9.4e Arsenic (As):

One of the major groundwater issuesin the area is the elevated arsenic concentration in groundwater in northern and north-western part of the area along the river Ganga falling under Danapur and Maner block, which has been reported by PHED, Govt. of Bihar. Arsenic is widely distributed throughout the earth's crust and it is toxic in nature. It is introduced into groundwater from industrial effluents, atmospheric deposition, and geological sources and also from pesticides. The excess arsenic damages the skin, causes circulatory system problems and results in an increased risk of cancer.

Groundwater samples were collected for arsenic analysis from different aquifers. The permissible level of arsenic is 0.05 mg/l according to BIS, 2012. The concentration of arsenic in the area ranges from BDL to 0.017 mg/l (dug well) from BDL to .087 mg/l (aquifer-1) and from BDL to 0.025 mg/l (aquifer-2). Out of 128 samples analysed, at five locations namely Mahavirtola, Ratantola, Chihattar, Nilkanthtola, Sherpur and Kurjibalupar falling in Maner and Danapur block arsenic concentration is found beyond permissible limit of 50 ppb. (Fig. 3.9 p).

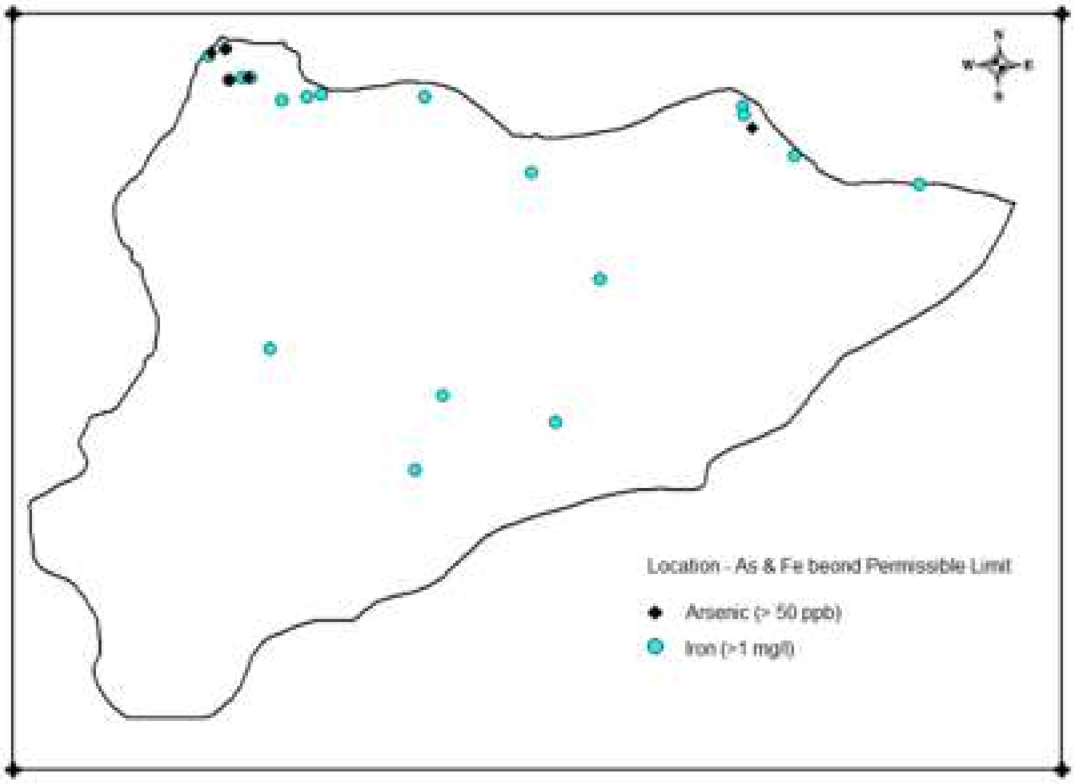


Fig. 3.9 (p) Map showing location of high arsenic (>50 ppb) and iron concentration (>1 mg/l)

Perusal of the Table-3.9(f) shows that maximum arsenic concentration in the ground water of the area is 0.087 mg / l at Chihhatar village falling in the Maner block of the area. It is evident from the table that elevated concentration of arsenic is confined up to 50 mbgl (aquitard and top portion of the aquifer-1).

Table-3.9(f): Locations of elevated arsenic concentration (> 0.05 mg/l)

Sl.No.	Place/ Block	Source	Depth (m)	Arsenic concentration (mg/l)
1	Nilkantha Tola 2	HP	29	0.068
2	Kurji Balu Par 3	HP	50	0.072
3	Chihhatar 2	HP	30	0.087
4	Mahavir Tola 2	HP	26	0.074
5	Ratan Tola 3	HP	30	0.076

3.9.5 Uranium concentration in ground water

42 Groundwater samples were collected for analysis of uranium concentration in ground water (Table 3.9 g). Out of 42 samples, 15 were collected from dug well (depth varying from 4.35 to14.00 m bgl), 20 from hand pumps (depth varying from 20 to 79 m bgl) and 7 were collected from the deep tube wells (up to 100 m depth). These samples were analyzed for uranium concentration at Chemical Laboratory, Atomic Minerals Directorate for Exploration and Research (AMD), Eastern Region, Khasmahal, Jamshedpur. The locations from where ground water samples were collected for uranium concentration are shown in Fig 3.9 (q).

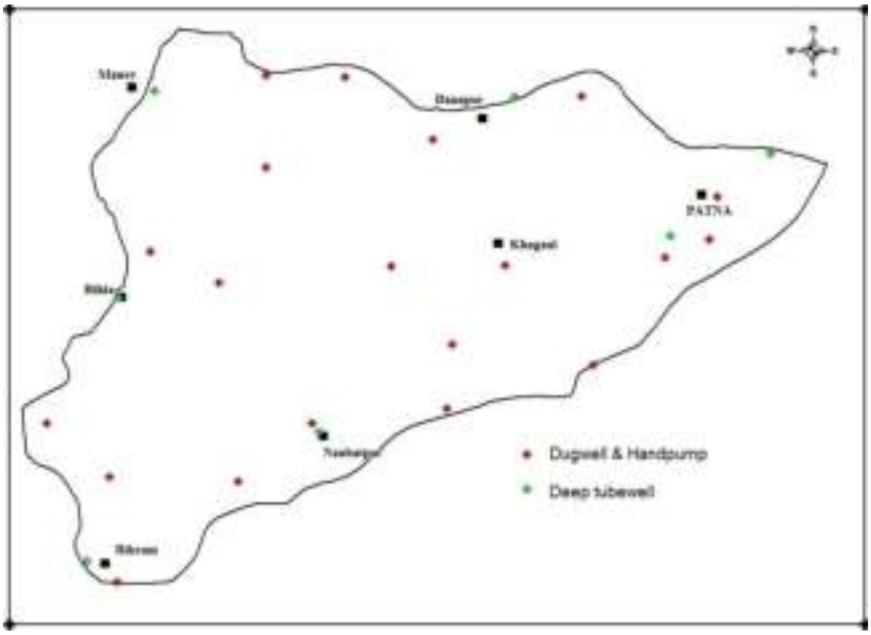


Fig 3.9 (q) Map showing Locations of Groundwater sample collected for uranium analysis

As per World Health Organization (WHO), the permissible limit of uranium concentration in the ground water is 15 µg/l. The Atomic Energy Regulatory Board, India has put the limit of 60 µg/l in drinking water. The uranium concentration in the groundwater of the area is found to be within the permissible limiting (< 15 µg/l as per WHO). The results of uranium concentration analysis are given in table 3.9 g.

Table 3.9 (g): Uranium concentration in ground water of the area

Sl. No.	Location	Type of well	Type of aquifer	U (ppb)
1	Soranpur	HP	aquifer-1	1
2	Karbighaiya	Dw	aquitard	< 1
3	Karbighaiya	HP	aquifer-1	< 1
4	Digha	DW	aquitard	< 1
5	Digha	HP	aquifer-1	1
6	Lalbengwan	DW	aquitard	< 1
7	Lalbengwan	HP	aquifer-1	< 1
8	Ramnagar	DW	aquitard	< 1
9	Ramnagar	HP	aquifer-1	2
10	Hulaschak	DW	aquitard	< 1
11	Hulaschak	HP	aquifer-1	< 1
12	Akbarpur	HP	aquifer-1	1
13	Gopalpur	DW	aquitard	< 1
14	Gopalpur	HP	aquifer-1	1
15	Bishambharpur	DW	aquitard	< 1
16	Bishambharpur	HP	aquifer-1	< 1
17	Snehitola	DW	aquitard	< 1
18	Snehitola	HP	aquifer-1	< 1
19	Sadisopur	DW	aquitard	< 1
20	Sadisopur	HP	aquifer-1	1
21	Chandmari	HP	aquifer-1	3
22	Nisirpura	DW	aquitard	< 1
23	Nisirpura	HP	aquifer-1	< 1
24	Etwarpur	DW	aquitard	< 1
25	Etwarpur	HP	aquifer-1	< 1

Sl. No.	Location	Type of well	Type of aquifer	U (ppb)
26	Datina	DW	aquitard	< 1
27	Datina	HP	aquifer-1	4
28	Darbeshpur	DW	aquitard	< 1
29	Darbeshpur	HP	aquifer-1	1
30	Sikaria	DW	aquitard	< 1
31	Sikaria	HP	aquifer-1	< 1
32	Noniatola	DW	aquitard	< 1
33	Noniatola	HP	aquifer-1	< 1
34	Dariapur(Chainpura)	HP	aquifer-1	2
35	Dariapur (Mainpura)	HP	aquifer-1	1
36	Chudrana	DTW	aquifer-1	1
37	Maner	DTW	aquifer-2	< 1
38	Naubatpur	DTW	aquifer-1	< 1
39	Bikram	DTW	aquifer-1	1
40	Bihta	DTW	aquifer-1	< 1
41	PatnaLawCollege	DTW	aquifer-2	2.0
42	Sipra (JaiprakashNagar)	DTW	aquifer-2	< 1

By and large, the groundwater of area was found to be suitable for drinking purposes as per available analyzed chemical data. Presence of some constituents beyond the permissible limit at some locations in the aquitard zone and top part portion of the aquifer-1renders the water unfit for public water supply and need proper attention before using(Fig 3.9 r).

PILOT PROJECT ON AQUIFER MAPPING
MANER - KHAGAUL AREA (GNDK013), PATNA, BIHAR

Suitability for drinking and irrigation purposes

Aquifer - 1
Depth of occurence: (35-130 m bgl)

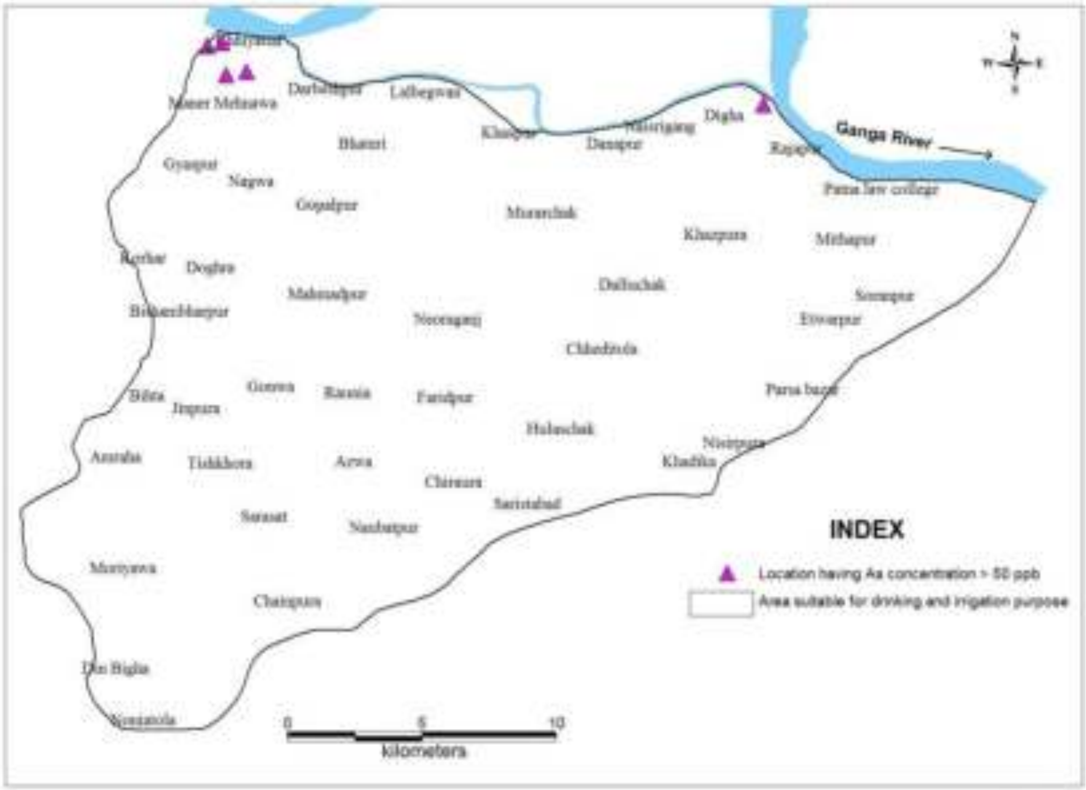


Fig 3.9 (r) Map showing suitability of groundwater for drinking purposes (aquifer-1)

3.9.6 Quality of ground water for irrigation purposes

The chemical quality of water is an important factor to be considered in evaluating its usefulness for irrigation purposes. Irrigated plants absorb and transpire the water but leave nearly all the salts behind in the soil, where they accumulate and eventually prevent plant growth. The suitability of groundwater for irrigation is dependent on the effects of the mineral constituents of water on both the plant and soil. Electrical conductivity and sodium play a vital role in suitability of water for irrigation. Higher Electrical conductivity in water creates soil salinity. Harmful effects of irrigation water increases with the total salt concentration, irrespective of the ionic composition. Higher salt content in irrigation water causes an increase in soil solution osmotic pressure (Txorne and Peterson, 1954). The salts apart from affecting the growth of plants also affect the soil structure, permeability and aeration which indirectly affect plant growth.

Salt may harm plant growth physically by limiting the uptake of water through modification of osmotic processes, or chemically by metabolic reactions such as those caused by toxic constituents. Effects of salts on soils in causing changes in soil structure, permeability and aeration directly affect plant growth (Todd, 1980).

The irrigation water containing a high proportion of sodium will increases the exchange of sodium content of the soil, affecting the soil permeability, and texture making the soil hard to plough and unsuitable for seeding emergence (Triwedy and Goel, 1984; Sujatha and Reddy, 2003). If the percentage of Na^{+} with respect to (Ca^{+2} +Mg^{+2} +Na^{+}) is considerably above 50% in irrigation waters, soils containing exchangeable calcium and magnesium take up sodium in exchange for calcium and magnesium causing deflocculation and impairment of the quality and permeability of soils (Karanth,1987). Soil amendments, such as, gypsum or lime may correct the situation.

The total dissolved content, measured in terms of specific electrical conductance gives the salinity hazard of irrigation water. The electrical conductivity is a measure of salinity hazard to crop as it reflects the TDS in the groundwater. In addition to problems caused by excessive concentration of dissolved solids, certain constituents in irrigation water are especially undesirable and some may be damaging even when present in small concentrations. Various parameters viz. Total Dissolved Solids (TDS), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), chloride concentration have been evaluated to assess the suitability of groundwater for irrigation.The salt present in the water, besides affecting the growth of plants directly, also affects soil structure permeability and aeration, which indirectly affect plant growth (Mohan et al. 2000; Umar et al. 2001).

3.9.6a USSL diagram and Sodium Adsorption Ratio (SAR)

The interpretation of water quality suitable for the irrigation purposes are given by Richard (1954) in the form of EC versus SAR values. Electrical Conductivity (E.C.) has been treated as index of salinity hazards and sodium adsorption (SAR) as index of sodium hazards.

USSL diagram

The chemical data has been plotted on USSL diagram i.e. salinity hazard versus sodium hazard using Aquachem software. Salinity hazard is represented by electrical conductivity where as sodium hazard is by SAR.The class range considered in USSL diagram is 250, 750, and 2250 microsiemens /cm.

Salinity Hazard – The irrigation waters have been divided into four classes with respect to the EC value ranges as given below:

Class	Type of water	EC range (µS/cm at 25º C)	Remarks
C1	Low Salinity Water	<250	Such waters can be used for irrigation of most of the soils and crops with little or no problem of salinity and practically with no leaching requirements.
C2	Medium Salinity Water	250-750	Such waters can be used for irrigation of most of the soils and crops with little or no problem of salinity and practically with no leaching requirements.
C3	High Salinity Water	750-2250	Such water requires adequate drainage and special management for salinity control to grow plants with good salt tolerance.
C4	Very High Salinity	>2250 µS/cm	Such water can be used occasionally under very special conditions.

The data has been plotted (Figure-3.9 s to u) to assess the suitability of ground water for irrigation purposes. The analytical data of dug well indicate good to excellent class of groundwater of the area as these samples fall in C2S1 and C3S1 class. Majority of groundwater samples of aquifer-1 are falling in C2S1 class indicating good to excellent class, except three samples. Out of these three samples one sample falls in C2S2 class and two samples fall in C3S1 class. All the groundwater samples of aquifer-2 belong to excellent class as they fall in C2S1 class. The quality classification of groundwater is given in Table 3.9h (USSL, 1954).

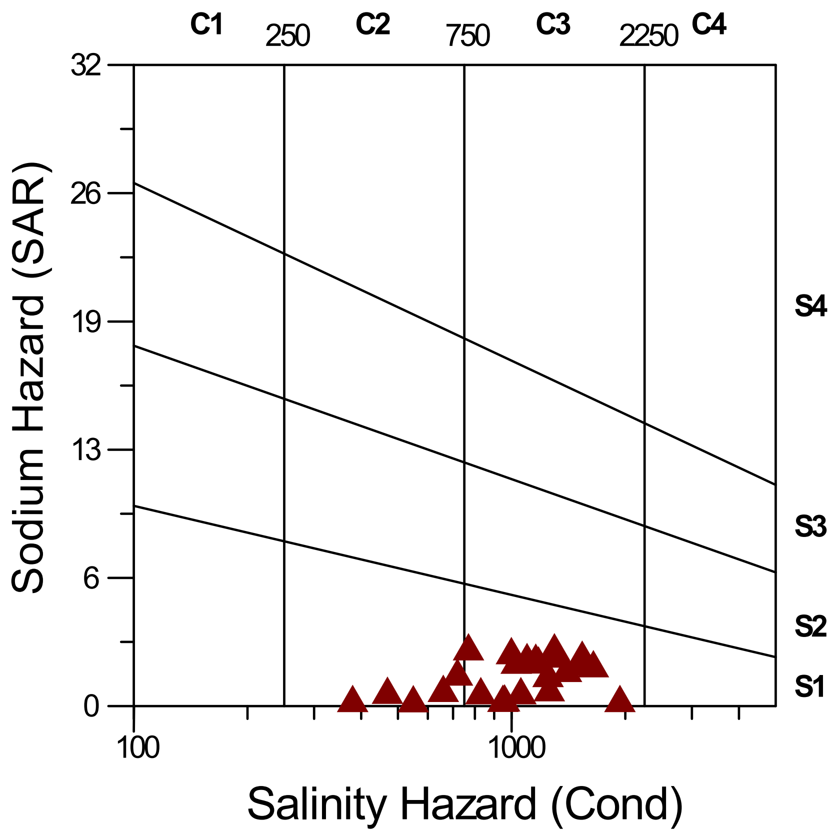


Fig 3.9(s): USSL PLOT (aquitard)

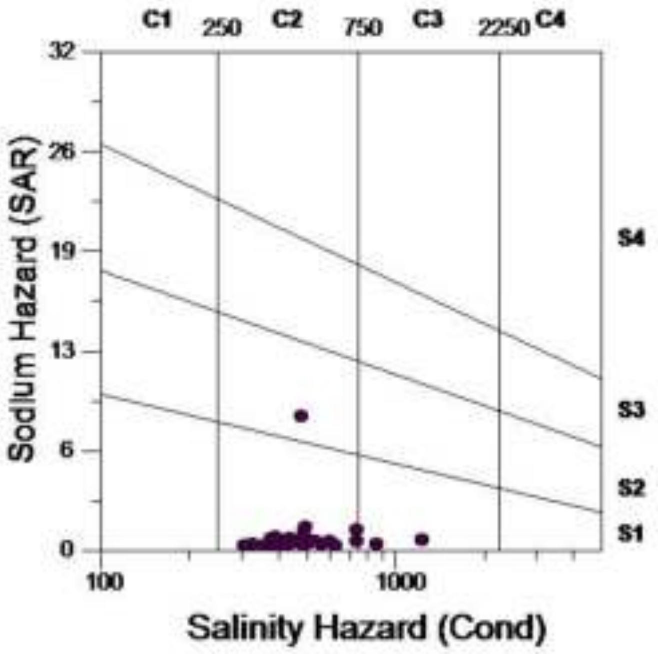


Fig 3.9 (t): USSL PLOT (Aquifer-1)

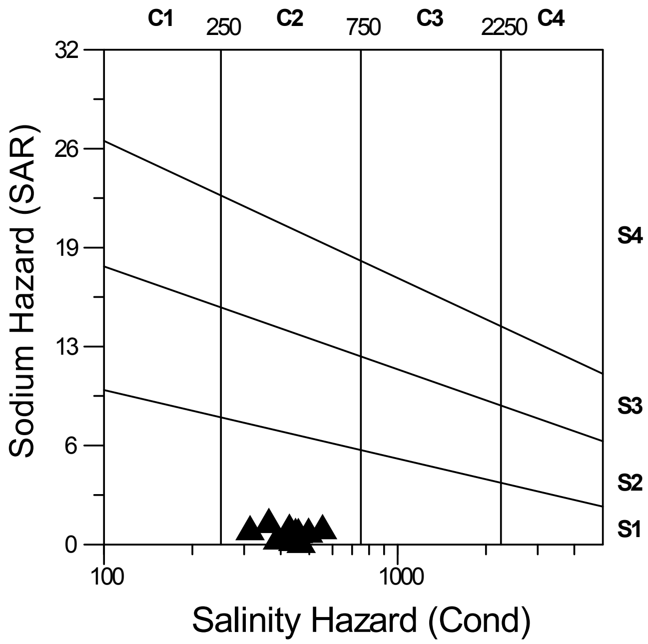


Fig 3.9 (u): USSL PLOT (Aquifer-2)

Table (3.9 h) indicates suitability of groundwater for irrigation purposes as most of the groundwater belong to good to fair type.

Table-3.9 (h): Classification of irrigation water (after USSL 1954)

Water type	**Salinity Hazard E.C (Micromhos/ cm at 25^0 C)**	**Aquitard(Dug well)**	**Aquifer-1**	**Aquifer-2**
Excellent	<250	Nil	Nil	Nil
Good	250-750	5	39	14
Fair	750- 2250	20	3	Nil
Poor	>2250	Nil	Nil	Nil

3.9.6a (i) Sodium Adsorption Ratio (SAR):

The salinity laboratory of U.S. Dept. of Agriculture adopted the sodium Adsorption (SAR) for studying the suitability of groundwater for irrigation purposes. SAR is calculated from the ionic concentration (in meq) of sodium, calcium and magnesium according to following relationship (Karanth, 1987).

$$\text{SAR} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca}+\text{Mg}}{2}}}$$

SAR value of dug well, aquifer-1 & aquifer-2 ranges from 0.35 to 2.94 (average 1.59), 0.07 to 2.20 (average 0.27) and 0.976 to 6.317 (average 3.797) respectively. On perusal of Table (3.9 i), it is found that SAR value in the area are less than 10 indicating excellent water type and thus suitable for irrigation purposes.

Table-3.9 (i): Classification of irrigation water based on SAR value

Water type	**SAR Value**	**Aquitard (DW)**	**Aquiver-1**	**Aquiver-2**
Excellent	<10	25	41	14
Good	10-18	Nil	1	Nil
Fair	18-26	Nil	Nil	Nil
Poor	>26	Nil	Nil	Nil

3.9.6a (ii) Residual Sodium Carbonate (RSC)

Eaton (1957) suggested that the excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium also influences the suitability of ground water for irrigation. This is denoted as residual sodium carbonate (RSC), which is calculated as follows (Raghunath, 1987):

$$RSC = (CO_3^{--} + HCO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where the concentrations are reported in meq/l.

Water with RSC below 1.25 is good; 1.25 - 2.5 is marginal or tolerable and above 2.5 is not suitable for irrigation purposes. If RSC> 2.5, irrigation water may cause formation of salt peter (KNO_3).

The value of residual sodium carbonate have been calculated and compared with above classification. It is inferred that 60%, 79% and 100% samples of dug well, aquifer-1 and aquifer-2, respectively, are of good quality. The remaining samples of dug well and aquifer-1 belong to doubtful to unsuitable quality (Table-3.9 j).

Table-3.9 (j): Quality of groundwater based on Residual Sodium Carbonate (RSC)

RSC (meq/l)	Quality	Chemical Analysis		
		Dug well	Aquifer-1	Aquifer-2
<1.25	Good	15	33	14
1.25-2.5	Doubtful	6	7	-
>2.5	Unsuitable	4	2	-

3.9.6a (iii) Classification based on chloride:

Based on chloride contents, Scolfield (1993) had classified water into three classes for irrigational use as shown in table below. Chloride is not a very harmful anion for drinking purposes, but regarding irrigation it is the most troublesome anion.

Perusal of Table 3.9 (k) indicates that 98% ground samples collected from aquifer-1 and 100% groundwater samples collected from aquifer-2 fall under class-I.68% groundwater samples collected from dug well tapping aquitard zone belongs to under class-I. This indicates suitability of groundwater for irrigation purposein respect of chloride.

Table 3.9(k): Classification of groundwater for irrigation use based on chloride concentration (Scolofield, 1993)

Water class	Chloride value (mg/l)	No. of ground water sample (aquitard)	No. of ground water sample (aquifer -1)	No. of ground water sample (aquifer-2)
I	<150	17(68%)	42 (98%)	14(100%)
II	150-500	8(32%)	1(2%)	Nil
III	>500	Nil	Nil	Nil

3.9.6a (iv) Permeability Index (PI)

Permeability of soil is affected, if high salt content water stays within the rock for a long time. Sodium, calcium, magnesium, chloride and bicarbonate content in the soil are more responsible for influencing the soil permeability. Based on permeability index Doneen (1964) evolved criteria for assessing the suitability of groundwater for irrigation purposes. Permeability index, (where all the ions are expressed in milliequivalents per liter) can be derived as:

$$PI = [(Na + \sqrt{HCO3})/ (Ca + Mg + Na)] \times 100$$

Permeability index of groundwater samples from dug well, aquifer-1 & aquifer-2 ranges from 34.98 to 70.28 (average 53.65,), 29.2 to 94.03 (average 57.46) & 40.54 to 95.94 (average 65.95, , respectively. 36% of dug well samples fall in class 1 and 64% fall in class 2. In aquifer-1, 98% samples fall in class 2 and 2% samples fall in class 3. All the samples of aquifer-2 fall in class 2. Fig 3.9 (v to x) shows the permeability index map of groundwater of the area.

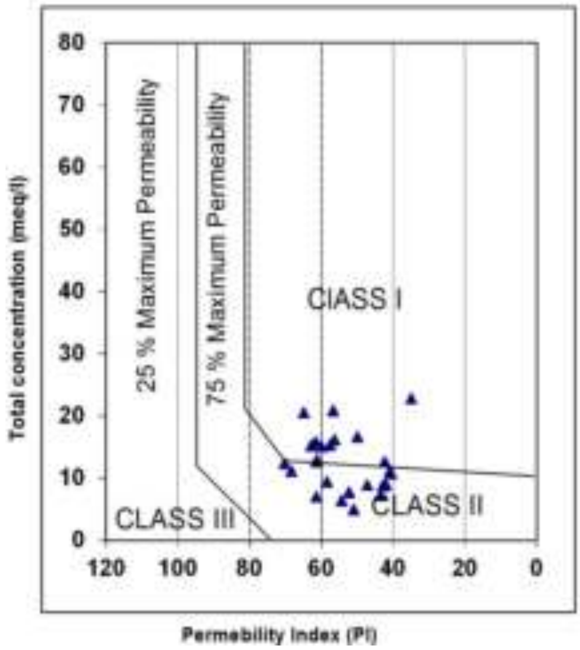


Fig. 3.9 (v) Permeability Index map (Auitard/ Dug well)

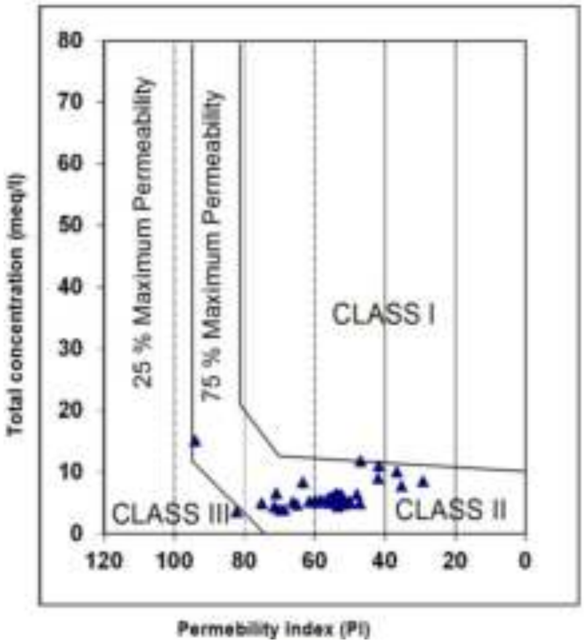


Fig. 3.9 (w) Permeability Index map (aquifer-1)

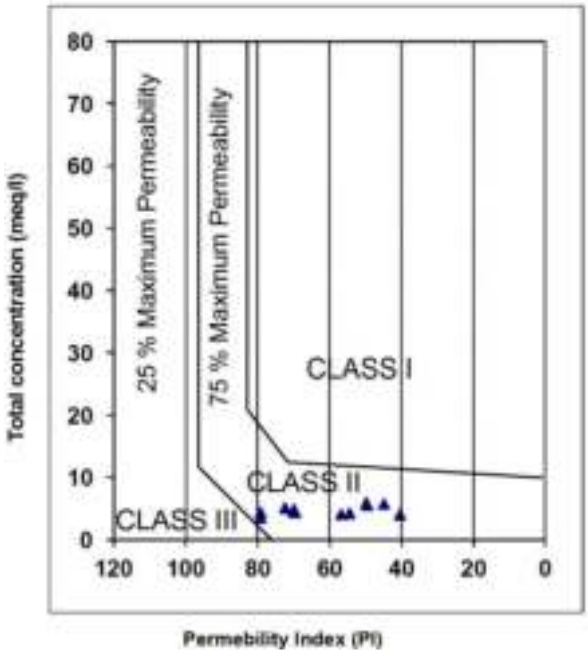


Fig. 3.9 (x) Permeability Index map (aquifer-2)

By and large, the groundwater of area was found to be suitable for irrigation and drinking purposes as per analysis of various parameters in aquitard, aquifer-1 and aquifer-2.

3.9.7 Types of ground water

The major ion composition of groundwater was used to classify groundwater into various types based on the dominant cations and anions (Deutsch, 1997). The pipers diagrams were prepared for groundwater collected from different aquifers of the area (Fig3.9y (i to iii). Piper diagram of groundwater of aquiterd layer, aquifer-1 and aquifer-2 indicate that groundwater of the area is mainly of ($Ca+Mg+HCO_3$) type. However, one sample from aquitard layer and two samples from aquifer-1 are showing (alkali-Cl-SO_4) type.

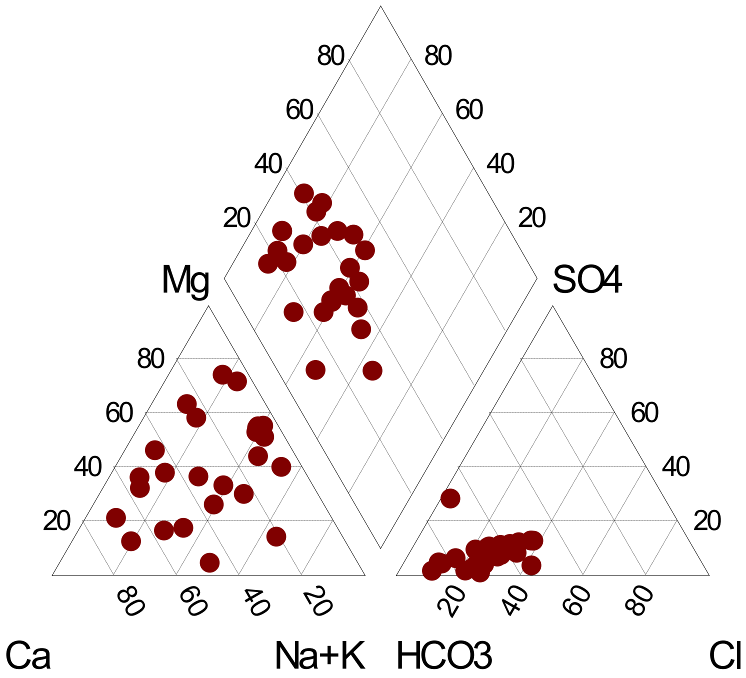


Fig 3.9 (y-i): Piper's Diagram (Dug well/aquitard zone).

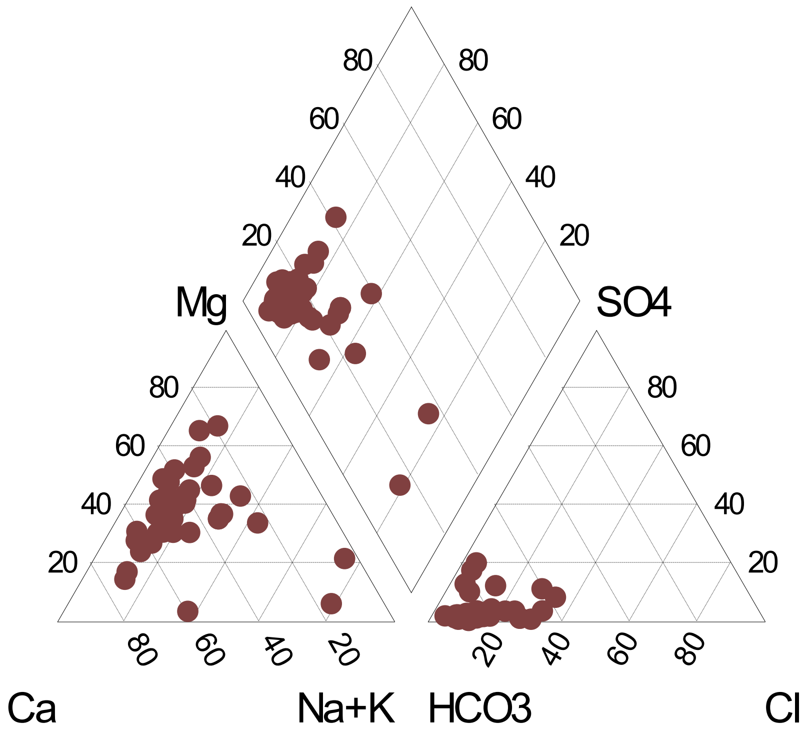


Fig 3.9(y-ii): Piper's Diagram (Aquifer-1).

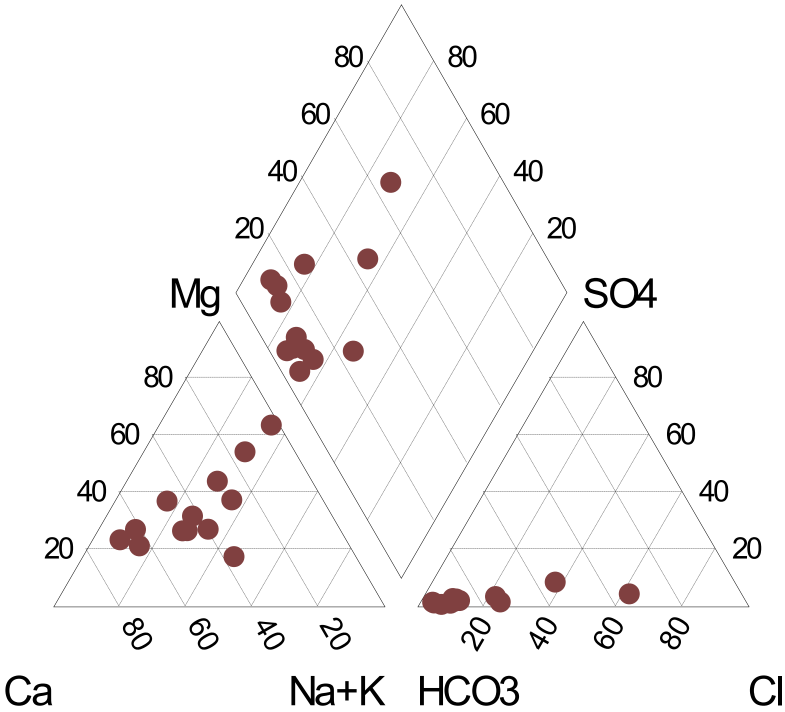


Fig 3.9(y-iii): Piper's Diagram (Aquifer-2)

3.10 Recharge Parameters

Groundwater recharge may be explained as the process whereby the amount of water present in or flowing through the interstices of the sub-soil increases by natural or artificial means. Rainfall is the principal source for recharge of groundwater. Other sources include recharge from rivers, streams, and irrigation water etc. The amount of natural groundwater recharge depends on the rate and duration of rainfall, the subsequent conditions at the upper boundary, hydraulic conductivity, the water table depth and the soil type. 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.

Annual precipitation within the study area averages about 1051 mm, part of which seeps through the fine-grained material overlying the aquifer to the water table. Recharge estimates are a function of vertical hydraulic conductivity which is a function of geology.

Infiltration rate of top soil has been determined by infiltration test. The infiltration rate of top soil has been given in table (3.2 b).

Pumping test data of CGWB wells were used to obtain the hydraulic conductivity and storage parameter of the aquifers. Beside this , Hydraulic conductivity was also estimated using grain size analysis from the litholog sample of drill cut sample at Simri and was used to estimate assigning the hydraulic conductivity of first layer. The hydraulic conductivity map prepared on the basis of pumping test data of wells constructed by CGWB is shown in fig 3.10 (a & b).

Recharge estimates are a function of vertical hydraulic conductivity which is a function of geology and lithology. Hence, surficial geologic units are likely to represent a reasonable initial distribution of recharge. Three recharge zones have been demarcated in the study area considering the nature of the surficial material and geomorphic units. At the extreme southern and the western part with predominance of study material in the overlying unit a rainfall infiltration factor of 20% has been considered. In the central part of the study area, monthly recharge considering rainfall infiltration of 10% and for the core urban areas the recharge rate has been considered as 2% of rainfall as these are the most urbanised part with less of open space and the nature of the surficial material here is also more clayey.

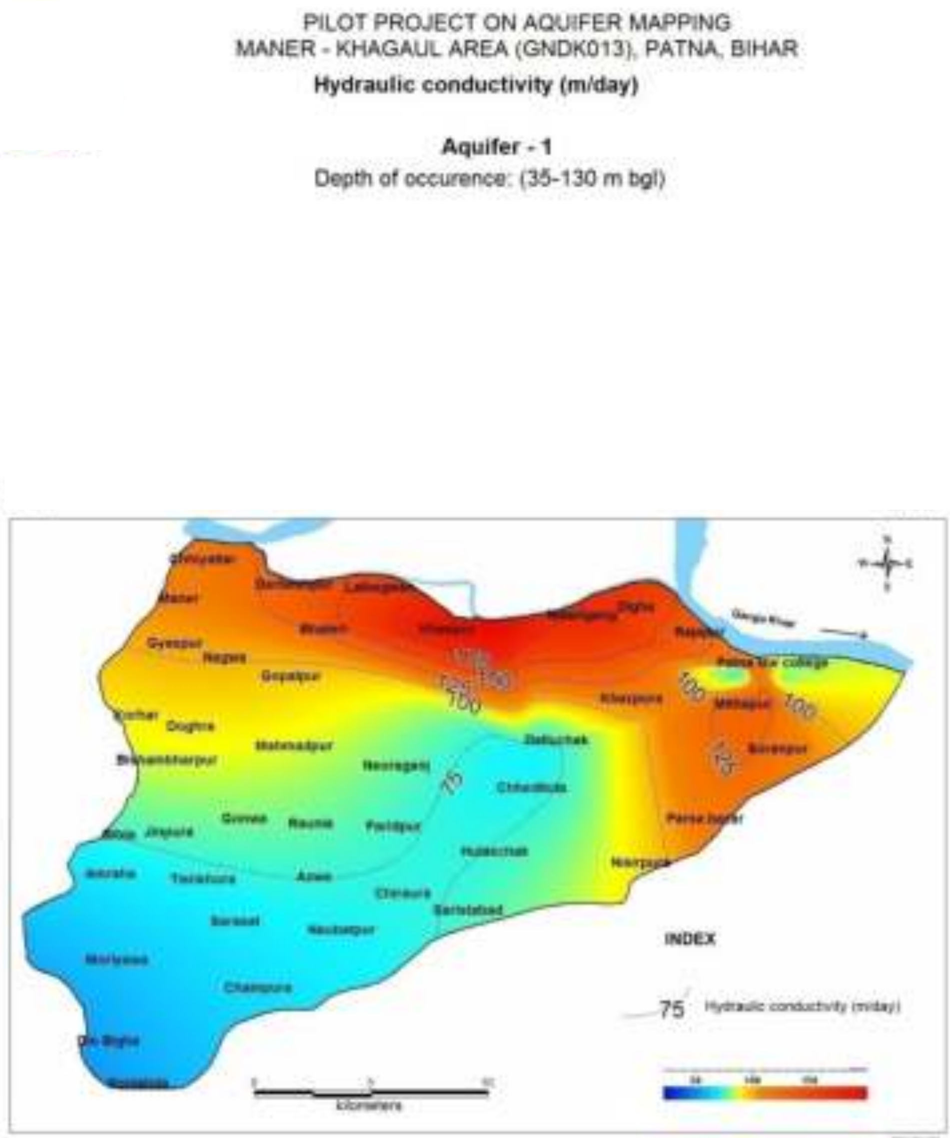


Fig 3.10(a): Hydraulic conductivity map (aquifer-1)

PILOT PROJECT ON AQUIFER MAPPING
MANER - KHAGAUL AREA (GNDK013), PATNA, BIHAR

Hydraulic conductivity (m/day)

Aquifer - 2

Depth of occurence: (110 - 265 m bgl)

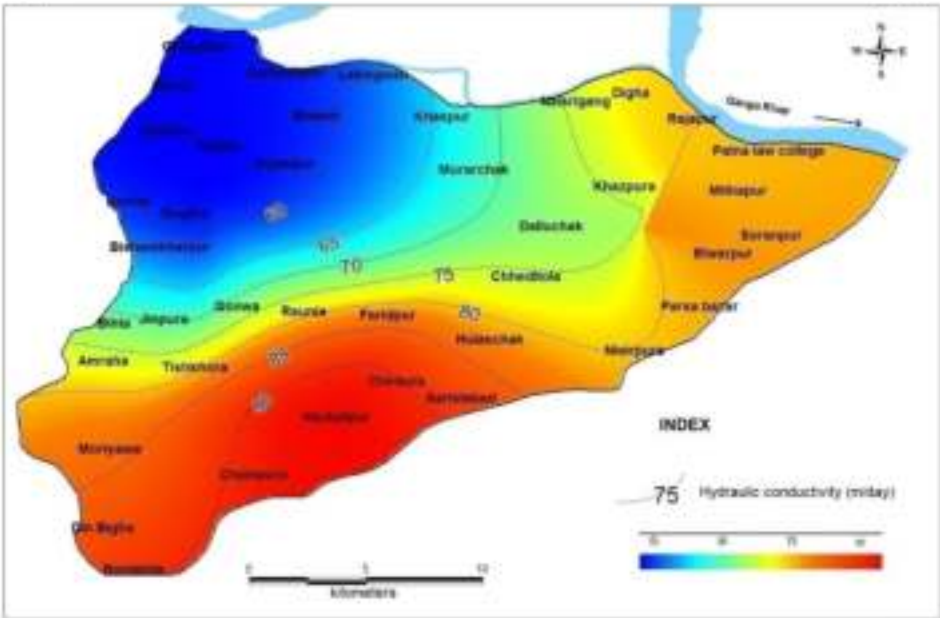


Fig 3.10 (b): Hydraulic conductivity map (aquifer-2)

3.10.1 Hydraulic conductivity estimation using grain size analysis

3.10.1 (A) Sediment grain size analyses

Grain size is the most fundamental physical property of sediment. The hydrogeological parameters like porosity, hydraulic conductivity and permeability are greatly dependent on the size of sediment grains and the percentage of various sediment fractions. The accuracy of grain-size analysis is limited by sampling techniques, storage conditions, equipment, and the capability of the operator.

Sediment grain size based empirical methods are alternatively used as laboratory techniques since 19^{th} century (e.g. Hazen 1892) for estimating conductivity of aquifers materials. Various researchers on groundwater have tried to find out a relation between the grain size of aquifer material and the hydraulic conductivity (e.g. Hazen 1892; Kozeny 1927; Krumbein and Monk 1942; Carman 1937, 56; Breyer 1964; Terzaghi and Peck 1964; Masch and Denny 1966; Freeze and Cherry 1979; Shepherd 1989; Alyamani and Sen 1993). However, the equations have limits of applications and give only approximate values of hydraulic conductivity for point samples (e.g. Detmer 1995; Odong 2007; Song et al. 2009; Mc Donald et al. 2012; Takounjou et al. 2012). It has been observed that, for Quaternary fluvial deposits comprising fine to coarse sand and sandy gravels, the K values determined by using the empirical equations lies between values determined from pumping tests and slug tests. The conductivity values derived from particle size analysis may be different depending upon which formulae are used (Vuković and Soro 1992; Kasenow 2002; Odong, 2007; Song et al. 2009; Vienken and Dietrich 2011). It is generally observed that the grain size based empirical equations are best suited to loose sand and gravel dominated sediments and is less suited to deposits dominated by silt and clay (Vokovic and Soro 1992; Chapuis 2004).

The borehole was drilled at Simri using a rotary rig and the drill-cut samples were collected during drilling operation at 3 m intervals up to depth of 300m. However, the possibilities of slight mixing up of the samples particularly in the transitional zones cannot be completely ruled out. The samples were ringed mildly to remove the drill mud left in it and during the process care was given so that even the finest of fine of the aquifer materials are not lost. The lithology thus prepared was finally calibrated for correction of depth by reconciling it with the drill time log and the electrical logging report. For the present study, only the sand samples obtained from the granular zones were considered for analysis and determination of the hydraulic conductivities.

3.10.1 (B) Empirical equations used in calculating the hydraulic conductivity (K) of aquifer materials

(I) Hazen Equation (later modified by Lambe 1958)

$$K = \frac{g}{v} Ch\ f(n) d_{10}{}^{2}$$

$$Where,\ Ch = 6 \times 10^{-4}$$

$$g = acceleration\ due\ to\ gravity$$

$$v = kinetic\ viscosity\ of\ water$$

$$f(n)\ \left(a\ function\ of\ porosity\ n\right) = 1 + 10\ (n - 0.26)$$

d_{10} is the effective grain diameter, which represents the largest grain diameter of the smallest 10 % grains in the samples). In 1893, while studying filter sand, Allen Hazen developed the term “Effective Size”. He defined it as the particle size where 10 percent of the sand is finer and 90 percent is coarser, i. e. 90 percent retained size in the sieve analysis.

The equation is most suitable for sediments with uniformity coefficient (Uc) <5 & 0.1 mm<d_{10}<3 mm. The slope of the grain size distribution curve or the range of the grains present in the sample is better defined by “Uniformity Coefficient” (Uc). It was developed by Hazen at the same time he adopted the idea of effective size. He defined uniformity coefficient as;

$$Uc = d_{60}/d_{10}$$

Where d_{60} is the 40 % retained size and d_{10} is the 90 % retained size. Lower the value of uniformity coefficient; the more is the grading of the sample. Larger values represent less uniform grading.

(ii) Kozeny-Carman Equation (proposed by Kozeny, 1927 and later modified by Carman 1956)

$$K = \frac{g}{v} Ck\ f(n) d_{10}{}^{2}$$

$$Where,\ Ck = 8.3 \times 10^{-3}$$

$$f(n) = n^{3} / (1 - n)^{2}$$

This formula is not appropriate for either soil with effective size (d_{10}) above 3 mm or for clayey soils.

(iii) Slitcher Equation (1897-98)

$$K = \frac{g}{v} \times 1 \times 10^{-2} n^{3.287} d_{10}^{2}$$

This formula is most applicable for grain-size between 0.01 mm and 5 mm.

(iv)Breyer Equation (1964)

$$K = \frac{g}{v} Cb\, d_{10}{}^{2}$$

Where $Cb = 6 \times 10^{-4} \log \frac{500}{Uc}$

The $U_c$is the uniformity coefficient of formation samples as defined earlier.

This formula does not express the hydraulic conductivity as a function of porosity. It is applicable for $1 < U_c < 20$ and 0.06 mm$< d_{10} <$0.6. Thus, it is useful for analysing heterogeneous porous media with the poorly sorted grains.

3.10.1 (C) Sieve analyses of the lithological sample collected at Simri, Patna

Sieve analyses of the lithological sample collected at Simri were carried out using Sieve shaker (Fig. 3-10c) to determine grain size distribution. For the purpose of sieve analysis, from the lithological log of the boreholes, different water bearing zones were identified with the help of their physical and textural characters and the samples of respective zones were mixed together properly. A sediment sample of 250 gm by weight was taken for sieving out of the bulk by repeated process of coning and quartering. This was then put in the coarsest sieve at the top of a stacked set of sieves with the mesh diameters decreasing downward. The stacked sieves (of sizes 2000, 1000, 500, 250, 180, 125 and 70 µm) were placed in a mechanical shaker for sieving up to 10 minutes. The weight of each sand fraction retained in individual sieve was measured and expressed as percent of the initial (total) weight of the sample.

Fig 3.10 (c): Sieves shaker for grain size analysis

The silt/clay (<0.07 mm) fraction in each sample was found to be < 1.0% and hence only dry sieve analysis of the sand fraction was undertaken (Alyamani and Sen 1993). Since, the samples were collected from a mud rotary rig and there may be chances of missing of finer size ranges, it was essential to assess the representability of samples. Earlier study has indicated that the silt/clay fraction is either lacking or constitutes a very minimal part of the samples of Sone sand obtained from deeper portions of boreholes (Maitra and Ghosh 1992).

From the grain size distribution curves, the grain size parameters such as d_{10}, d_{50}, d_{60} were determined. The uniformity coefficients (Uc) of the sand populations were calculated using the relation as cited earlier. All these results have been utilized by the formulae as described above to estimate the hydraulic conductivity of the aquifer samples. A value of 1.14×10^{-6} m^2/s has been taken as the kinematic coefficient of viscosity of water at a temperature of 25°C. Porosity (n) values of sand for determining hydraulic conductivity have been calculated using the following equation given by Vukovic ans Soro (1992).

$$n = 0.255\left(1 + 0.83^{Uc}\right)$$

3.10.1 (D) Results and discussion

A total of 67 sand samples from different depth zones of the bore-hole were analyzed for their grain size grading. Most of the samples beyond ~36 m depth are craton derived Sone sand, which are brownish yellow and coarser in nature in comparison to the finer Himalayan derived gray sand lying at the top parts in the area.

Table 3.10 a: Standard mesh used for grain-size analysis and grain size classes (Wentworth 1922).

Sl. No	Mesh no.	Size (mm)	Size (φ)	Grain type as per Wentworth scale (1922)
1	200	>2	-1 to -5	>2 mm, granule and pebble
2	100	1-2	0 to -1	1 to 2 mm, very coarse sand
3	50	0.5-1.0	1 to 0	0.5 to 1 mm, coarse sand
4	25	0.25-0.5	2 to 1	0.25 to 0.5 mm, medium sand
5	12	0.12-0.25	3 to 2	0.12 to 0.25, fine sand
6	7	0.063 (0.070)-0.12	4 to 3	0.07 to 0.12 mm, very fine sand
7	Pan	<0.07	> 4	silt and clay

As per the Wentworth scale (1922) (Table3.10 a), the median grain diameters (d_{50}) reflect the sand samples analyzed to vary from medium to very coarse in nature (Table 3.10 b). The effective grain size 'd_{10}' of the sand samples are found to vary between 0.15 mm and 0.50 mm, except the depth range 70.5-73.5, where the d_{10} stands at 0.94 indicating very coarse nature of the sample with gravel admixture. The values of uniformity coefficient (U_c) in majority remain within 2.0-7.5, though the samples in the depth range 292.2-300.0 depict values of Uc in the greater range of 31.3-37.5, indicating good sorting. It may be noted that the sediment sample with U_c values <4 is well sorted, whereas those with U_c>6 are poorly sorted.

Table 3.10 b: Grain size and statistical parameters.

Sl. No	Depth range (m bgl)	*d_{10} (mm)*	*d_{60} (mm)*	*U_c (d_{60}/d_{10})*	*d_{50} (mm)*	*Sand particle size*
1	4.0-7	0.31	1.3	4.19	1.05	Very coarse sand
			clay mix zone			
2	36-39.25	0.25	1.32	5.28	1.08	-do-
3	39.25-42.25	0.23	1.32	5.74	1.01	-do-

Sl. No	Depth range (m bgl)	*d_{10} (mm)*	*d_{60} (mm)*	*U_c (d_{60}/d_{10})*	*d_{50} (mm)*	*Sand particle size*
4	42.25-45.5	0.27	1.46	5.41	1.14	-do-
5	45.5-48.5	0.28	1.55	5.54	1.26	-do-
6	48.5-51.50	0.20	0.52	2.60	0.42	Medium sand
7	51.5-54.75	0.20	0.78	3.90	0.58	Coarse sand
8	54.75-58.00	0.21	0.81	3.86	0.7	-do-
9	58.00-61.00	0.20	0.81	4.05	0.68	-do-
10	61-64.25	0.42	1.52	3.62	1.40	Very coarse sand
11	64.25-67.25	0.36	1.49	4.14	1.34	-do-
12	67.25-70.5	0.20	1.0	5.00	0.72	Coarse sand
13	70.5-73.5	0.94	1.9	2.02	1.72	Very coarse sand
14	73.5-76.75	0.48	1.61	3.35	1.43	-do-
15	76.75-79.75	0.41	1.22	2.98	1.01	-do-
16	79.75-83.00	0.50	1.63	3.26	1.49	-do-
17	83.0-86.0	0.41	1.46	3.56	1.3	-do-
			clay mix zone			
18	111-114.25	0.33	1.62	4.91	1.46	-do-
19	114.25-117.25	0.35	1.64	4.69	1.5	-do-
20	117.25-120.5	0.20	0.7	3.50	0.55	Coarse sand
21	120.5-123.5	0.29	0.85	2.93	0.65	-do-
22	123.5-126.75	0.19	0.88	4.63	0.66	-do-
23	126.75-129.75	0.19	0.81	4.26	0.62	-do-
24	129.75-133.00	0.21	0.94	4.48	0.77	-do-
25	133.0-136.0	0.20	0.92	4.60	0.75	-do-
26	136-139.25	0.19	0.7	3.68	0.60	-do-
27	139.25-142.25	0.22	1.0	4.55	0.80	-do-
28	142.25-145.50	0.21	0.7	3.33	0.60	-do-
29	145.5-148.5	0.21	0.7	3.33	0.60	-do-
30	148.5-151.75	0.21	0.88	4.19	0.71	-do-

Sl. No	Depth range (m bgl)	*d_{10} (mm)*	*d_{60} (mm)*	*U_c (d_{60}/d_{10})*	*d_{50} (mm)*	*Sand particle size*
31	151.75-154.75	0.22	0.99	4.50	0.80	-do-
32	154.72-158.00	0.20	0.78	3.90	0.61	-do-
33	158.00-161.00	0.20	0.8	4.00	0.64	-do-
34	161.0-164.25	0.21	0.89	4.24	0.75	-do-
35	164.25-167.25	0.20	0.96	4.80	0.74	-do-
36	167.25-170.50	0.21	1.25	5.95	0.97	-do-
37	170.5-173.5	0.20	1.12	5.60	0.83	-do-
38	173.5-176.75	0.20	1.38	6.90	1.10	Very coarse sand
39	176.75-179.75	0.31	1.55	5.00	1.31	-do-
40	179.75-183.0	0.29	1.53	5.28	1.25	-do-
41	183.0-186.0	0.30	1.45	4.83	1.19	-do-
42	186.0-189.25	0.28	1.51	5.39	1.23	-do-
43	189.25-192.25	0.27	1.48	5.48	1.21	-do-
44	192.25-195.5	0.25	1.35	5.40	1.10	-do-
45	195.5-198.5	0.24	1.35	5.63	1.10	-do-
46	198.5-201.75	0.22	1.2	5.45	0.90	Coarse sand
47	201.75-204.75	0.23	1.23	5.35	0.96	-do-
48	204.75-208.00	0.24	1.09	4.54	0.82	-do-
49	208.00-211.00	0.29	1.58	5.45	1.22	Very coarse sand
	clay mix zone					
50	214.25-217.25	0.21	1.13	5.38	0.88	Coarse sand
51	217.25-220.50	0.23	1.28	5.57	0.96	-do-
52	220.5-223.5	0.19	0.80	4.21	0.60	-do-
	clay mix zone					
53	226.75-229.75	0.19	0.80	4.21	0.60	-do-
54	229.75-233.00	0.18	0.64	3.56	0.49	Medium sand
55	233.48-236.00	0.19	0.62	3.26	0.49	-do-
56	236-239.25	0.15	0.50	3.33	0.39	-do-

Sl. No	Depth range (m bgl)	d_{10} (mm)	d_{60} (mm)	U_c (d_{60}/d_{10})	d_{50} (mm)	*Sand particle size*
57	239.25-242.25	0.18	1.01	5.61	0.32	-do-
	clay mix zone					
58	264.00-267.25	0.20	0.95	4.75	0.95	Coarse sand
59	267.25-270.25	0.22	1.65	7.50	1.25	Very coarse sand
60	270.25-273.5	0.40	1.30	3.25	1.05	-do-
61	273.5-276.5	0.30	1.63	5.43	1.35	-do-
	clay mix zone					
62	282.75-286.00	0.18	0.84	4.67	0.68	Coarse sand
63	286.00-289.00	0.18	0.88	4.89	0.68	-do-
64	289.00-292.25	0.23	1.0	4.35	0.75	-do-
65	292.25-295.25	0.17	6.0	35.29	2.0	Very coarse sand
66	295.25-298.5	0.16	6.0	37.50	2.0	-do-
67	298.5-300.00	0.16	5.0	31.25	2.0	-do-

3.10.1 (E) Applicability of empirical equations and estimation of hydraulic conductivity

Four empirical equations namely, the Breyer, Kozeny-Carman, Slitcher and Hazen have been applied for estimating the hydraulic conductivity values of the aquifer zones. As far as the desired application limits are concerned for calculating hydraulic conductivity, only the empirical equations given by Breyer, Kozeny-Carman and Slitcher are applicable to all the aquifer samples obtained from the bore-hole. The equation of Hazen (d_{10} as effective size) set the condition of applicability only when U_c<5 and d_{10} within 0.1-0.30 mm, whereas in some of the cases in the presently studied samples, U_c and d_{10} exceeds the desired limit. In that case the conductivity values of the zones having U_c and d_{10} within limit have only been estimated.

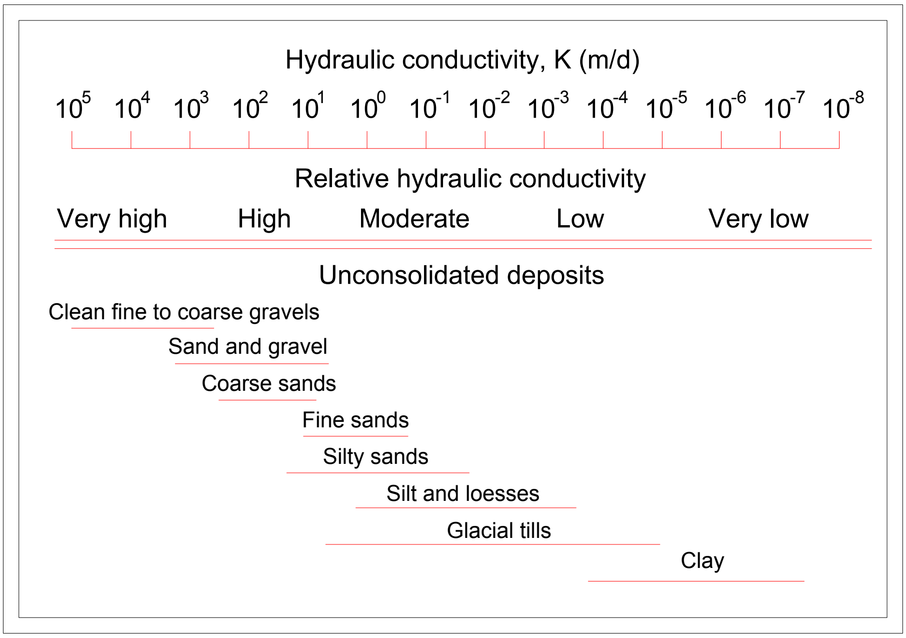


Fig 3.10 (d): Range of typical hydraulic conductivity (K) values for geological materials (Driscoll 1986 and Todd 1980).

Fig 3.10 (d) depicts typical ranges of K values for granular formations of different size groups as suggested by early workers (Todd 1980; Driscoll 1986). It is observed that, with few exceptions in the cases of poorly sorted medium to very coarse sand, the formulae suggested by Breyer, Hazen and Kozeny-Carman estimate hydraulic conductivities of the sand samples within acceptable ranges (Table 3.10 c & f). For the medium sand, the methods predict the average K values at 31.8-34.6 m/day respectively (Table 3.10 d). For the coarse and very coarse sands, the methods yield the K values in the ranges of 35-42.1 and 77.5-93.6 m/day respectively. The methods seem to estimate more realistic K values for the moderately well sorted to well sorted sand populations and for the poorly sorted sediment samples the values are low. The Slitcher method calculates lower values of K in all cases (range: 10.8-27.6 m/day) which is in consistent with the observations made by Vukovic and Soro 1992 and Cheng and Chen 2007. It may be due to a lower porosity function (n3.287) used in the formula.

Table 3.10 (c): Porosity and hydraulic conductivity of aquifer sediments through empirical equations.

Depth range (m bgl)			*k(m/day)*			
	Degree of sorting	porosity (n)	Breyer	Hazen	Kozeny-Carman	Slitcher
4.0-7.0	Mod. well sorted	*37.2%*	*88.9*	na	*77.1*	*27.6*
	C L A Y Z O N E					
36.0-39.25	Mod. well sorted	*35.0%*	*55.0*	na	*39.3*	*14.8*
39.25-42.25	Mod. well sorted	*34.3%*	*45.7*	na	*30.3*	*11.6*
42.25-45.5	Mod. well sorted	*34.8%*	*63.9*	na	*44.6*	*16.9*
45.5-48.5	Mod. well sorted	*34.6%*	*68.3*	na	*46.8*	*17.8*
48.5-51.50	*Wells sorted*	*41.2%*	*40.7*	*44.9*	*49.9*	*16.1*
51.5-54.75	*Wells sorted*	*37.8%*	*37.6*	*38.9*	*34.5*	*12.2*
54.75-58.00	*Wells sorted*	*37.9%*	*41.5*	*43.1*	*38.5*	*13.5*
58.00-61.0	Mod. well sorted	*37.5%*	*37.3*	*38.3*	*33.3*	*11.8*
61.0-64.25	*Wells sorted*	*38.5%*	*168.3*	na	*163.9*	*56.8*
64.25-67.25	Mod. well sorted	*37.3%*	*120.3*	na	*105.4*	*37.6*
67.25-70.5	Mod. well sorted	*35.5%*	*35.7*	na	*26.7*	*9.9*
70.5-73.5	*Wells sorted*	*43.0%*	*848.5*	na	*1332.6*	*409.5*
73.5-76.75	*Wells sorted*	*39.1%*	*221.3*	na	*230.2*	*78.5*
76.75-79.75	*Wells sorted*	*40.1%*	*161.4*	na	*187.2*	*62.2*
79.75-83.00	*Wells sorted*	*39.4%*	*240.1*	na	*256.4*	*86.9*
83.00-86.00	*Wells sorted*	*38.6%*	*161.4*	na	*158.7*	*54.8*
	Clay mix zone					
111.00-114.25	Mod. well sorted	*35.7%*	*104.6*	na	*74.0*	*27.4*
114.25-117.25	Mod. well sorted	*36.2%*	*117.6*	na	*87.5*	*32.1*
117.25-120.5	*Wells sorted*	*38.8%*	*38.4*	*40.6*	*38.4*	*13.2*
120.5-123.5	*Wells sorted*	*40.3%*	*80.8*	*91.0*	*94.9*	*31.4*
123.5-126.75	Mod. well sorted	*36.3%*	*34.7*	*32.6*	*26.1*	*9.6*
126.75-129.75	Mod. well sorted	*37.0%*	*34.7*	*33.8*	*28.5*	*10.2*

Depth range	k(m/day)					
(m bgl)	Degree of sorting	porosity (n)	Breyer	Hazen	Kozeny-Carman	Slitcher
129.75-133.00	Mod. well sorted	*36.6%*	*42.3*	*40.4*	*33.1*	*12.0*
133.0-136.0	Mod. well sorted	*36.3%*	*38.4*	*36.2*	*29.1*	*10.6*
136.0-139.25	*Wells sorted*	*38.3%*	*34.7*	*35.9*	*33.0*	*11.5*
139.25-142.25	Mod. well sorted	*36.4%*	*46.5*	*44.1*	*35.7*	*13.0*
142.25-145.50	*Wells sorted*	*39.2%*	*42.3*	*45.6*	*44.3*	*15.1*
145.5-148.5	*Wells sorted*	*39.2%*	*42.3*	*45.6*	*44.3*	*15.1*
148.5-151.75	Mod. well sorted	*37.2%*	*42.3*	*41.6*	*35.4*	*12.7*
151.75-154.75	Mod. well sorted	*36.5%*	*46.5*	*44.3*	*36.1*	*13.1*
154.72-158.00	Wells sorted	*37.8%*	*38.4*	*38.9*	*34.5*	*12.2*
158.00-161.00	Mod. well sorted	*37.6%*	*38.4*	*38.5*	*33.7*	*11.9*
161.0-164.25	Mod. well sorted	*37.1%*	*42.3*	*41.4*	*35.0*	*12.6*
164.25-167.25	Mod. well sorted	*35.9%*	*38.4*	*35.5*	*27.9*	*10.3*
167.25-170.50	Mod. well sorted	*33.9%*	*42.3*	na	*24.3*	*9.4*
170.5-173.5	Mod. well sorted	*34.5%*	*38.4*	na	*23.6*	*9.0*
173.5-176.75	*Poorly sorted*	*32.5%*	*38.4*	na	*18.7*	*7.4*
176.75-179.75	Mod. well sorted	*35.5%*	*92.3*	na	*64.0*	*23.8*
179.75-183	Mod. well sorted	*35.0%*	*80.8*	na	*52.9*	*19.9*
183.0-186.0	Mod. well sorted	*35.9%*	*86.4*	*79.7*	*62.2*	*23.0*
186.0-189.25	Mod. well sorted	*34.8%*	*75.3*	na	*48.1*	*18.2*
189.25-192.25	Mod. well sorted	*34.7%*	*70.0*	na	*43.9*	*16.7*
192.25-195.5	Mod. well sorted	*34.8%*	*60.0*	na	*38.3*	*14.5*
195.5-198.5	Mod. well sorted	*34.4%*	*55.3*	na	*33.7*	*12.9*
198.5-201.75	Mod. well sorted	*34.7%*	*46.5*	*40.4*	*29.3*	*11.1*
201.75-204.75	Mod. well sorted	*34.9%*	*50.8*	na	*32.8*	*12.4*
204.75-208.00	Mod. well sorted	*36.4%*	*55.3*	*52.5*	*42.5*	*15.5*
208.00-211.00	Mod. well sorted	*34.7%*	*80.8*	na	*51.0*	*19.3*
			Clay mix zone			

Depth range (m bgl)	Degree of sorting	porosity (n)	k(m/day) Breyer	Hazen	Kozeny-Carman	Slitcher
214.25-217.25	Mod. well sorted	34.9%	42.3	na	27.1	10.3
217.25-220.50	Mod. well sorted	34.5%	50.8	na	31.4	11.9
220.5-223.5	Mod. well sorted	37.1%	34.7	34.0	28.8	10.3
	Clay mix zone					
226.75-229.75	Mod. well sorted	37.1%	34.7	34.0	28.8	10.3
229.75-233.00	Mod. well sorted	38.6%	31.1	32.7	30.6	10.6
233.48-236.00	Mod. well sorted	39.4%	34.7	37.6	37.0	12.5
236.0-239.25	Mod. well sorted	39.2%	21.6	23.3	22.6	7.7
239.25-242.25	*Wells sorted*	34.5%	31.1	na	19.0	7.3
	Clay mix zone					
264.00-267.25	Mod. well sorted	36.0%	38.4	35.7	28.2	10.4
267.25-270.25	*Poorly sorted*	31.8%	46.5	na	20.6	8.3
270.25-273.5	Mod. well sorted	39.4%	153.7	na	164.6	55.7
273.5-276.5	Mod. well sorted	34.8%	86.4	na	54.8	20.7
	clay mix zone					
282.75-286.00	Mod. well sorted	36.2%	31.1	29.1	23.2	8.5
286.00-289.00	Mod. well sorted	35.8%	31.1	28.5	22.1	8.2
289.00-292.25	Mod. well sorted	36.8%	50.8	49.1	40.9	14.8
292.25-295.25	Mod. well sorted	25.5%	27.8	na	5.3	2.4
295.25-298.5	*Poorly sorted*	25.5%	24.6	na	4.7	2.1
298.5-300.00	*Poorly sorted*	25.6%	24.6	na	4.8	2.2

***na**: The method not applicable, Mod. Well sorted- Moderately well sorted*

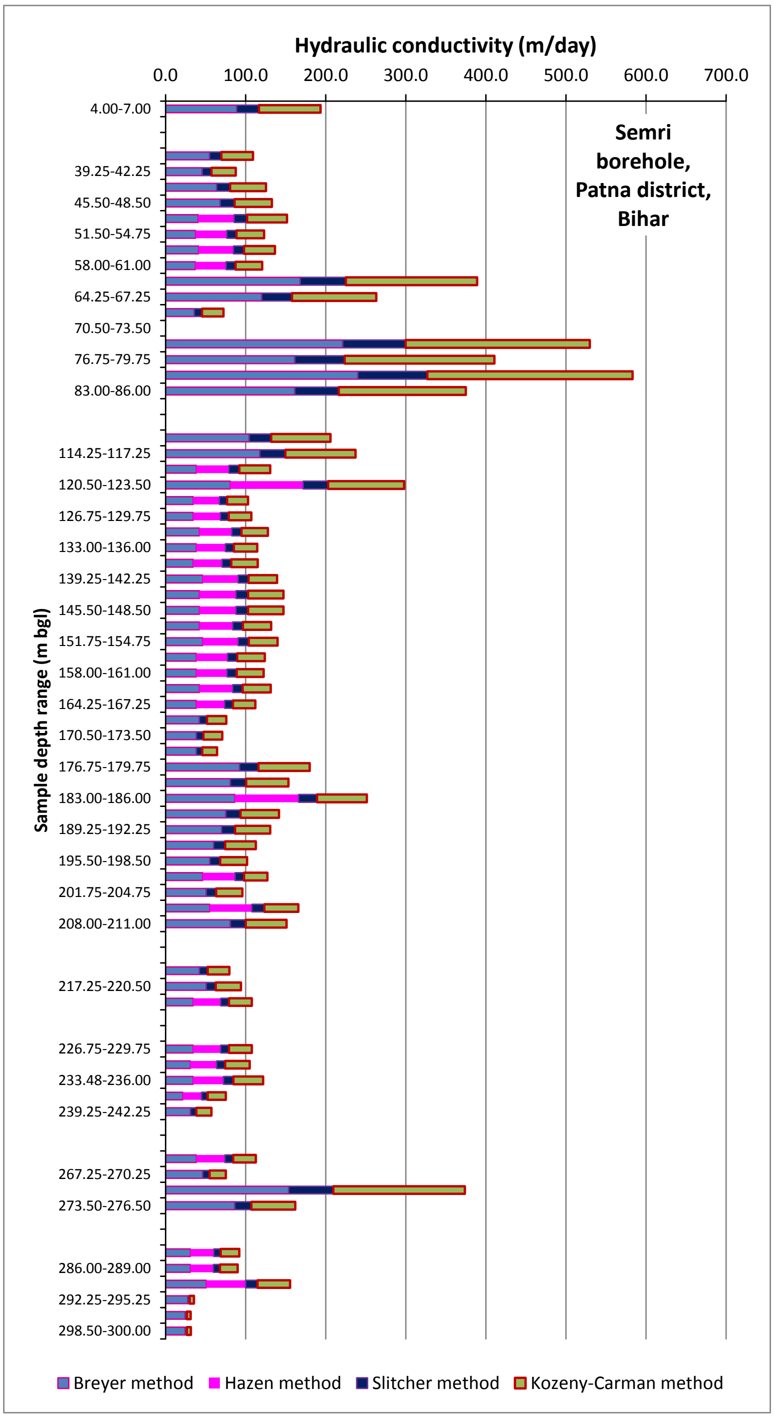


Fig 3.10 (e): Depth-wise variation of hydraulic conductivity (*K*) of the sand (aquifer) zones at in the Simri borehole as estimated using the empirical equations of Breyer, Hazen, Kozeny-Carman and Slitcher.

3.10.1 (F) Average hydraulic conductivity from the empirical equations

The average horizontal hydraulic conductivity (Kx) values for different aquifer groups and various textural groups produced in table 3.10d, have been calculated using the following formula (Raghunath 1987);

$$K_x = \frac{1}{b}(K_1 b_1 + K_2 b_2 + K_3 b_3 \ ....)$$

Where

K= horizontal hydraulic conductivity

b = total thickness of the aquifer

= b1+b2+b3 ……

b1, b2, b3 = thickness of each layer

K1, K2, K3 …. = horizontal hydraulic conductivity of each layer

Table 3.10 (d): Average hydraulic conductivity values

	Sand texture	***Method/ Average K (m/day)***			
		Breyer	**Hazen**	**Kozeny-Carman**	**Slitcher**
Grain size	*Medium sand*	31.7	34.4	31.7	10.8
	Coarse sand	41.8	41.1	34.1	12.2
	Very coarse sand	93.8	79.7	77.8	27.7
Degree of sorting	*Well sorted*	95.85	48.2	99.5	33.9
	Mod. well sorted	56.3	39.3	42.1	15.4
	Poorly sorted	33.5	Na	12.2	5

The 1st aquifer group (average d_{10}: 0.34 mm) within the depth range 36.0-86.0 m bgl, which lie above the 1st major clay (depth range: 86.0-111.0 m bgl) possess higher average hydraulic conductivity (41, 102 and 106 m/day) as estimated respectively by the methods of Breyer, Hazen and Kozeny-Carman. This excludes the zone in the depth range of 70.5-73.5 within the aquifer group which shows overestimated conductivity values due to the higher effective grain size (d_{10}) of 0.94 mm. The Slitcher method also gives a reasonable average K value of 35 m/day for the aquifer group, which is mostly composed of coarse to very coase sand. The aquifer group within the depth range of 111.0-211.0 m bgl with the mean d_{10} at 0.24 mm shows moderate average K values of 55, 47 and 42 m/day as predicted by the Breyer, Hazen and Kozeny-Carman methods respectively. The bottom aquifer group (average d_{10}: *0.21 mm)* within the depth range of 214.2-300.0 m bgl reflects still lower K values of 44, 17 and 33 m/day respectively by the equations.

3.11 Discharge Parameters

The main discharge input is the groundwater pumping within the study area. Groundwater caters the domestic and irrigation needs of the population within the study area. Available pumping data as per Minor Irrigation (MI) Census 2001 data along with the available records of pumping from the Municipal Corporation and insights gained from sample draft survey made during the present study have been used to arrive at the pumping estimate.

Though part of the area falls under the tail end of Son and Patna canal, irrigation need of the area is mainly catered by ground water through construction of shallow tube wells. Dug wells and deep tube wells are also used. The water lifting device of these shallow tube wells are mainly diesel operated 4-6 HP pumps. Average pumping hours of these shallow tube wells during peak season is mainly 4-8 hrs and some time, it is 8 -12 hrs. Sample draft survey also indicates the same. Fig 3.11 a shows irrigation in the area by using groundwater.

Fig 3.11a: Irrigation in the area by using groundwater

Total irrigated area of blocks falling under Pilot Aquifer Mapping is 51967.45 ha. The irrigation intensity and the cropping intensity in the pilot aquifer mapping area is 59% and 126% respectively. The source wise irrigation potential created / utilised (ha) through minor irrigation schemes in blocks of Patna district under Pilot Aquifer Mapping project is given in table 3.11 a.

Table 3.11 a: Source wise irrigation potential created / utilised through minor irrigation schemes (in ha) (Source: Minor irrigation census, 2001)

Sl.No	Block	Ground water schemes		Surface water schemes		Total	
		Potential created	Potential utilised	Ultimate potential created	Potential utilised	Potential created	Potential utilised
1	Patna Sadar	1798	1729	0	0	1798	1729
2	Danapur	4024	2707	0	0	4024	2707
3	Maner	3228	2687	0	0	3228	2687
4	Phulwari	7030	6300	27	27	7057	6327
5	Naubatpur	9308	8172	0	0	9308	8172
6	Bikram	4975	4427	0	0	4975	4427
7	Bihta	10591	8088	65	60	10656	8148

The cropwise area irrigated (ha) through different sources in blocks falling under Pilot Aquifer Mapping project, Patna district is given in table 3.11 b.

Table 3.11 b: Cropwise area irrigated (ha) through different sources in blocks falling under Pilot Aquifer Mapping project, Patna district (Source: Minor irrigation census, 2001)

Sl.No.	Block	Ground Water					Surface Water				
		Kharif	Rabi	Perenial	others	Total	Kharif	Rabi	Perenial	others	Total
1	Patna Sadar	789	835	94	12	1730	0	0	0	0	0
2	Danapur	1435	1272	0	0	2707	0	0	0	0	0
3	Maner	1249	1142	34	262	2687	0	0	0	0	0
4	Phulwari	2593	3260	36	411	6300	13	14	0	0	27
5	Naubatpur	4108	4060	4	0	8172	0	0	0	0	0
6	Bikram	1981	2445	1	0	4427	0	0	0	0	0
7	Bihta	2656	3661	636	1136	8089	10	25	0	25	60

Groundwater is the main source of drinking water and is mainly tapped through hand pumps in rural areas of Pilot Aquifer Mapping area, Patna. Public Health Engineering Department is the nodal agency for providing safe drinking water to rural areas as well as urban areas (except Patna urban area -PUA). Generally, drinking water supply is provided through dispersed sources such as different types of hand pumps. In some areas it is done through hand pumps as well as Piped Water Supply Schemes in which water supply is provided through stand posts and vats. Besides this, sample survey conducted during the project indicate that common people depends on dug wells, shallow tube well, hand pump for tapping ground water for their drinking purposes.

The city of Patna has high dependability on groundwater sources The Patna Municipal Corporation (PMC) responsible for the drinking water supply. The public water supply system comprises 98 tube wells (11 non-functional) distributed in the different localities within Patna urban limit and that pump water directly to the distribution mains. These tube wells are in depth range of 150 to 200 meter below ground level. The tube wells operate for 15 hours a day .The pumping rate of these well are in between 3000 – 4000 m^3 / day. 141244 m^3 / day groundwater is extracted from 77 operational deep tube wells (BRJP, 2003). Besides PMC, deep aquifer is being pumped by the private apartments and households.

The piped water supply covers 60% of households. The gross water supply in the city is around 186 MLD with about 91 lpcd as per 2011 population. The projected water demand in 2030 is 688.8 MLD. (Source: City Development Plan (2010-30), Patna, Urban Development and Housing DepartmentGovt. of Bihar,)

In Danapur city, PHED is providing safe drinking water by extracting groundwater through six tube wells. The gross water supply in the city is around 10 MLD with about 53 lpcd as per 2011 population. (Source: City Development Plan, 2010-30, Danapur, Urban Development and Housing Department Govt. of Bihar)

Groundwater is the main source in Phulwarisharif city also. The PHED is providing water supply in the Phulwarisharif city by extracting groundwater through five tube wells. The gross supply in the city is around 6.15 MLD with about 38 lpcd as per 2001 population. Water supply is for 8 hours a day. (Source: City Development Plan, 2010-30, Phulwarisharif Urban Development and Housing Department Govt. of Bihar).

About 400 sample surveys were carried out to know draft for irrigation and domestic purposes, aquifer zone used, crops grown and dependency on groundwater. Questionnaire were prepared in Hindi for draft sample survey to know about the aquifer zone used, crop grown and dependency on groundwater for irrigation purposes and likewise aquifer zone used, dependency on groundwater for domestic purposes (annexure 3.11a &b).

Data from the available records of pumping from the municipal corporation besides insights gained from sample draft survey made during the present study have been used to arrive at the pumping estimatefor a grid area of 1 sq km from the different aquifers and is summarized in Table 3.11 c.

Table 3.11 c: Block wise unit area groundwater draft in the study area

Administrative Block	Unit area (sq kms) draft in ham			
	Total	Monsoon	Non Monsoon	Domestic
Bihta	17.98	10.01	6.14	1.83
Maner	16.59	7.96	4.88	3.76
Danapur	11.55	4.84	2.97	3.73
Phulwari	17.85	8.80	5.39	3.66
Bikram	18.44	10.35	6.34	1.75
Naubatpur	19.09	10.82	6.63	1.64
Patna Sadar	19.65	4.59	2.82	12.24

3.12 Application of Isotope

3.12.1 Introduction:

Isotope based investigations are gaining importance in improved assessment and understanding of several groundwater issues. Stable isotopes like ^{2}H and ^{18}O are a powerful tool in hydrologic investigations as these are naturally occurring and are essentially the constituents of the water molecule itself. The other advantages are that they do not readily chemically react with rocks and minerals at temperatures normally encountered at or near earth's surface and these undergo fractionation during evaporation/condensation with light isotopes preferentially evaporated and heavy isotopes condensing with precipitation

The journey of a water molecule can be traced from its source to an end place can be traced based on its fractionation. Stable isotopes are useful tools for characterizing several different water dynamics like characterization of the movement of water within the watershed and determination of mixing and flow paths of water within a system.

In spite of the great complexity in different components of the hydrological cycle, variation in $\delta^{18}O$ and δD in meteoric waters behave in a predictable manner and correlate to define a global meteoric water line (GMWL). GMWL, fist defined by Craig (1961) has been modified by, Rozanski et al. (1993) based on compilation of the isotope data of precipitation from 219 stations of the IAEA/WMO operated Global Network for Isotopes in Precipitation (GNIP). This refined relationship between $\delta^{18}O$ and δD in global precipitationis given by:

$$\delta D = 8.17\ (\pm 0.07)\ x\delta 180 + 11.27\ (\pm 0.65)\ (\%\ VSMOW) \qquad (2)$$

Deviations of many regional or local meteoric water lines (LMWLs) from GMWL identify the climatic and geographical dimensions of hydrological processes and provenance of different water masses. The GMWL is average of many local or regional meteoric water lines, which may differ somewhat in slope and intercept from each other due to varying climatic and geographic parameters. A Local Meteoric Water Line (LMWL) can differ from global line in both slope and deuterium intercept. However, GMWL provides a reference for interpreting the hydrological processes and provenance of different water masses.

In the present study, the isotopic investigation has been carried out in collaboration with BARC, Mumbai.

3.12.2 Sampling and measurement

Water samples were collected for analysis of environmental isotope (^{2}H and ^{18}O) and radioactive isotope (tritium and C-14). Samples were collected mainly during the month of June and October 2012 from various sources like existing hand pumps, deep tube wells, rivers (Ganga, Son and Punpun), from wells constructed under the present project and rain water. On spot measurement of physico-chemical parameters like temperature, pH, electrical conductivity, dissolved oxygen and alkalinity was done. The location of the sampling points is shown in Fig. 3.12 a. A field photograph showing the collection of sample for carbon-14 is depicted in Fig 3.12 b. The details of sampling points and physico-chemical parameters are presented in table 3.12a. Environmental isotopes (^{2}H and ^{18}O) were measured using isotope ratio mass spectrometer (IRMS) at BARC, Mumbai. Environmental tritium (^{3}H) was measured using liquid scintillation counter (LSC). The results of the environmental isotopes are given in table 3.12 a.

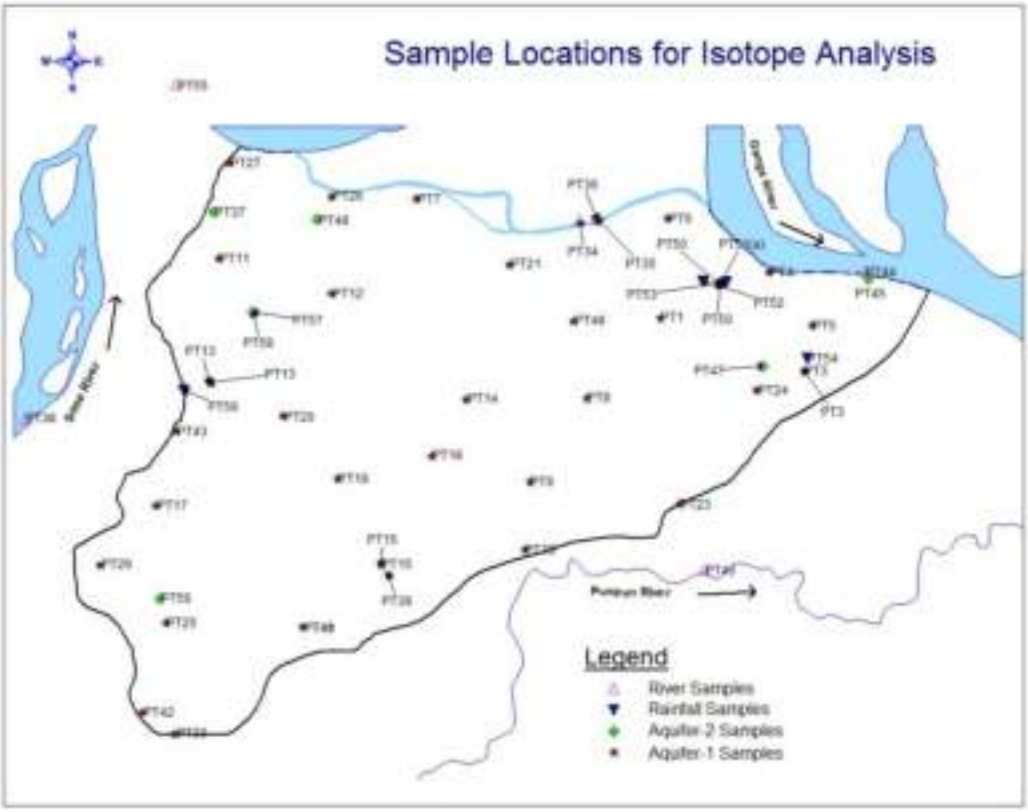


Fig. 3.12 a: Location maps of the sampling points for Isotope analysis

Fig: 3.12 b: A field photograph showing the collection of samples for C-14

The isotopic study has thrown light on the complex recharge mechanism of the multi-aquifer system of the area. Cross-plot of δD versus $\delta^{18}O$ reveals markedly different slopes for Aquifer I and II. The number of samples from Aquifer II is limited as these could only be collected from the wells constructed by CGWB. Though limited in number, the most striking aspect of Aquifer II is the very low values of tritium (0.11±0.14 to 2.98±0.2 TU) and C-14 (23.12±0.96 to 45.42±1.2 pMC). The un-corrected age of samples from Aquifer II falls in the range of 6526 to 12109 years. Values of C-14 and tritum clearly indicate that aquifer II has been recharged much before. However, connectivity of Aquifer II with I is also evident as tritium is still measurable in the samples from Aquifer II and the stable isotopic variation in both the aquifers fall in the same range, δD: -50 to -28‰ and $\delta^{18}O$: -7 to -3.5‰. The other significant observations are noted as under

- From the plot of δD versus $\delta^{18}O$ (Fig. 3.12c), it can be observed that samples from aquifer I falls below the LMWL for Patna indicating slight evaporation effect, whereas aquifer II samples are much deviated from the LMWL with lesser slope (1.1)
- Box plot of the tritium content of the samples from Aquifer I and II reveal marked difference in the median values (Fig 3.12d)
- To further understand the source of recharge to groundwater, the parameter d-excess was employed. The parameter d-excess (d= δD-8* $\delta^{18}O$), first proposed by Dansgaard (1964) characterises the deuterium excess in global

precipitation. On global basis it averages about 10‰, however, it gets affected by local factors.Highly negative d-excess values generally indicate that groundwater is recharged by sources that were subjected to high evaporation. From the plot it can be observed that samples from aquifer I show d-excess values in the range of 0 - 5‰ while samples from aquifer II fall in two clusters, 3 to 5‰ and -10 to 0‰ .

- From the d-excess versus $\delta^{18}O$ plot (Fig.3.12e), it seems groundwater from aquifer II is recharged by River Son but a few samples indicate recharge from River Punpun.

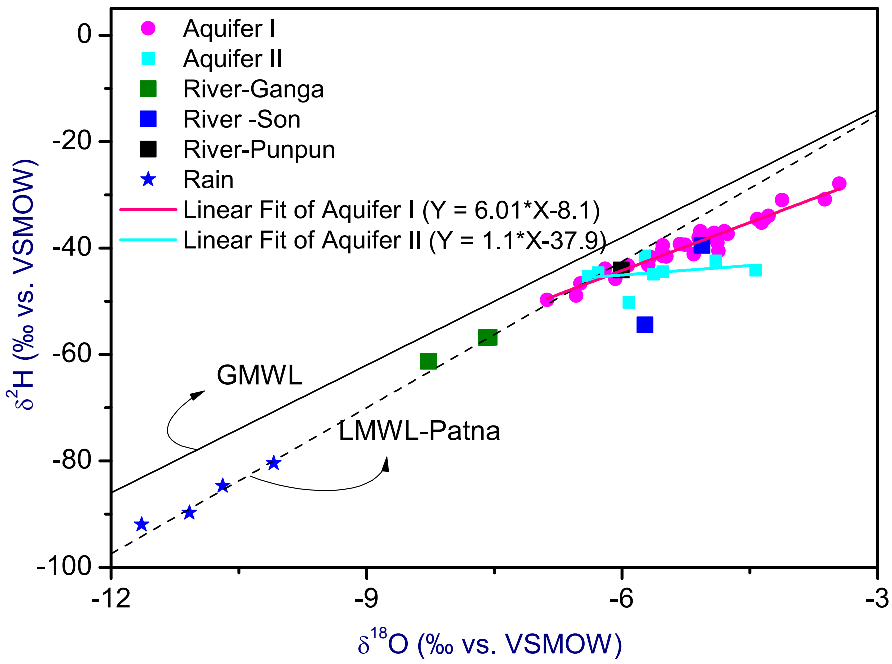


Fig. 3.12c: Plot of δD versus $\delta^{18}O$

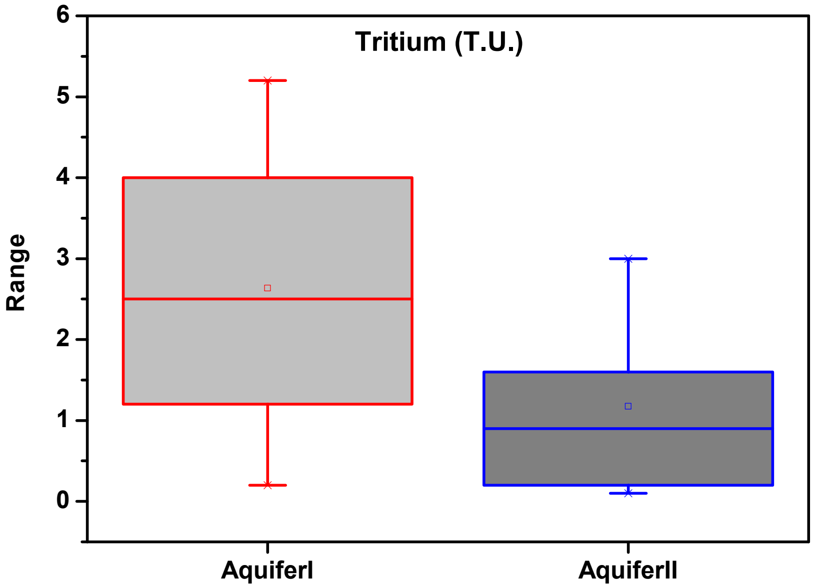


Fig. 3.12d: Box plot of Tritium data of groundwater

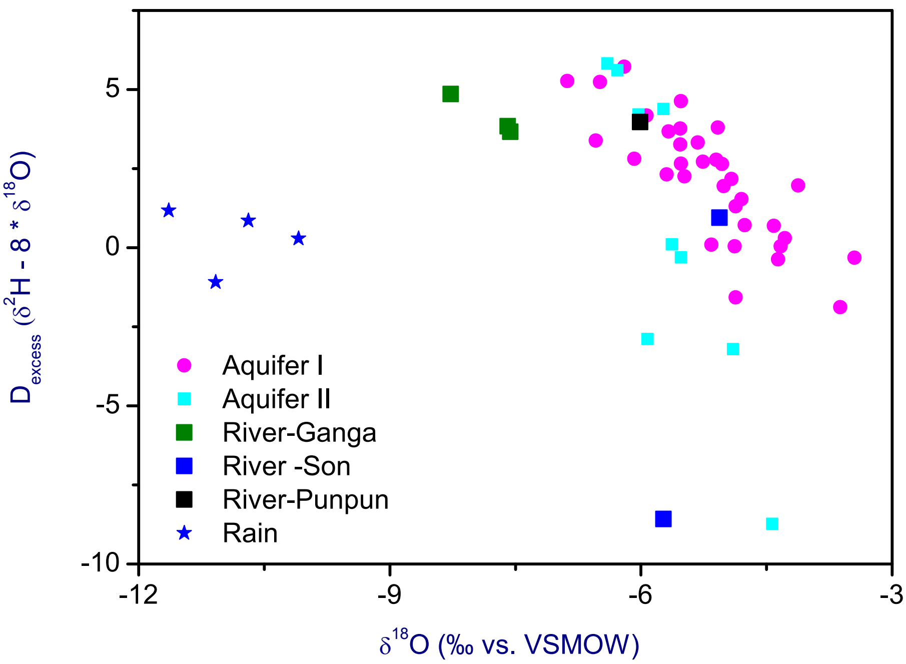


Fig. 3.12e: Plot of D_{excess} versus $\delta^{18}O$

Table-3.12(a) Results of isotopic analysis along with physico-chemical parameters

Sl. No.	Sample ID	Place	Sample Source	Date	Depth (m)	Temp. (^{0}C)	pH	EC (µS/cm)	DO (mg/l)	δD (‰)	$\delta^{18}O$ (‰)	^3H (TU)	C-14 (pMC)	Uncorrected age (years BP)
1	PT1	Khazpura	Aquifer-1	18.04.14	55	29	6.81	560		-41.51	-5.52	0.31 ± 0.15		
2	PT3	Soranpur	Aquifer-1	16.09.14	50	29.2	6.54	1150	1.6	-40.53	-4.87	1.79 ± 0.2		
3	PT4	Patna law college	Aquifer-1	13.06.12	70	29	7.01	490	1.86	-43.88	-6.2	1.23 ± 0.2		
4	PT5	Karbighayia	Aquifer-1	12.06.12	60		6.64	1240		-39.53	-5.52			
5	PT6	Digha	Aquifer-1	13.06.12	65	28.68	6.87	600	1.23	-43.26	-5.93	1.05 ± 0.33		
6	PT7	Lalbengwan	Aquifer-1	06.06.12	79	28.39	7.16	510		-37.6	-5.03			
7	PT8	Ramnagar	Aquifer-1	09.06.12	59	29	7.29	420		-36.84	-5.08	0.19 ± 0.15		
8	PT9	Hulaschak	Aquifer-1	09.06.12	30	28	6.89	410		-30.99	-4.12			
9	PT10	Akbarpur	Aquifer-1	09.06.12	61	28	6.9	430		-30.84	-3.62	3.96 ± 0.26		
10	PT11	Gyaspur	Aquifer-1	07.06.12	49	28	6.79	590		-40.47	-5.53	2.49 ± 0.43		
11	PT12	Gopalpur	Aquifer-1	07.06.12	61	28	6.99	430		-41.69	-5.67			
12	PT13	Bishambharpur	Aquifer-1	07.06.12	52	28.5	6.97	430		-34.59	-4.41	4.91 ± 0.34		
13	PT14	Dariapur, Mainpura	Aquifer-1	07.06.12	55		6.86	490		-37.37	-4.76	5.25 ± 0.56		
14	PT15	Snehi Tola	aquitard	07.06.12	25		6.36	760		-33.94	-4.28	3.92 ± 0.47		
15	PT17	Amahara	Aquifer-1	07.06.12	40	29	6.28	360		-38.14	-5.01			
16	PT18	Faridpur	Aquifer-1	07.06.12	55	29.5	6.86	460		-36.87	-4.8	1.86 ± 0.19		
17	PT19	Charra	Aquifer-1	12.06.12	30	29	7.1	630		-46.68	-6.49	0.68 ± 0.20		
18	PT20	Sadisopur	Aquifer-1	07.06.12	52	28.5	7.11	740		-40.98	-5.53	2.38 ±0.40		
19	PT21	Chandmari	Aquifer-1	07.06.12	57	28	7.29	480		-41.59	-5.48	0.61 ± 0.19		
20	PT23	Nisirpura	Aquifer-1	09.06.12	53	29.6	7.33	480		39.36	-5.26	1.11 ± 0.40		
21	PT24	Etwarpur	Aquifer-1	09.06.12	40	26.5	7.09	530		-37.65	-4.87	2.06 ± 0.24		
22	PT25	Datiana	Aquifer-1	12.06.12	52	27	7.31	410		-27.92	-3.45	5.18± 0.53		
23	PT26	Darbeshpur	Aquifer-1	06.06.12	76	28.5	7.32	430		-43.21	-5.69	0.15 ± 0.10		
24	PT27	Chhiyattar	Aquifer-1	06.06.12	30	27.5	7.25	330		-49.77	-6.88	3.22 ± 0.21		
25	PT29	Padri	Aquitard	07.06.12	25	28.5	6.8	370		-38.02	-5.1	4.08 ± 0.27		
26	PT39	Naubatpur	Aquifer-1	11.10.12	110	29.6	6.6	950	6.8	-39	-4.88	3.93 ± 0.45		
27	PT40	Dariapur, Chainpura	Aquifer-1	11.10.12	50	27.7	6.6	525	2.6	-37.19	-4.92	3.10 ± 0.41		
28	PT41	Dariapur-1, Chainpura	Aquifer-1	11.10.12	20	29.6	6.5	300	2.75	-41.19	-5.16	3.78 ± 0.47		
29	PT42	Bikram	Aquifer-1	11.10.12	76	31.2	7.1	444	6	-34.6	-4.33	4.32 ± 0.47		
30	PT43	Bihta	Aquifer-1	11.10.12	90	27.2	6.66	873	8.7	-39.24	-5.32	3.49 ± 0.42		
31	PT48	Garikhana	Aquifer-1	16.09.14	55	29.4	7.04	97	1.6	-45.83	-6.08	1.69 ± 0.48		
32	PT50	A.NCollege, Shallow	Aquifer-1	23.11.13	77		7.85	412		-48.94	-6.54	1.17 ± 0.19	54.28 ± 1.3	5052
42	PT15	Snehi Tola	Aquifer-1	07.06.12	14		6.36	760		-33.94	-4.28	3.92 ± 0.47		
43	PT29	Padri	Aquifer-1	07.06.12	11	28.5	6.8	370		-38.02	-5.1	4.08 ± 0.27		
44	PT33	Nonia Tola	Aquifer-1	07.06.12	30	28.5	6.68	500		-	-4.36	3.58 ±		

Sl. No.	Sample ID	Place	Sample Source	Date	Depth (m)	Temp. (⁰C)	pH	EC (µS/cm)	DO (mg/l)	δD (‰)	$\delta^{18}O$ (‰)	^{3}H (TU)	C-14 (pMC)	Uncorrected age (years BP)
										35.25		0.26		
33	PT36	Choudrana	Aquifer-2	10.10.12	173	28.3	7.25	1010	3.2	-41.46	-5.73	1.57 ± 0.39		
34	PT37	Maner	Aquifer-2	10.10.12	170	30.9	7.26	890	7.87	-44.03	-6.03	2.43 ± 0.36		
35	PT45	Patna law college - Mahendru	aquifer-2	12.10.12	137	29.1	6.7	970	8.2	-44.63	-6.28	0.88 ± 0.19		
36	PT47	Sipara (Jaiprakash nagar)	Aquifer-2	12.10.12	150	28.8	3.8	480	8.2	-45.38	-6.4			
37	PT49	Jibrakhantola	Aquifer-2	21.05.14	232		8.06	419		-44.94	-5.63	0.19 ± 0.14	35.45 ± 1.1	8575
38	PT51(a)	A.NCollege, Deep	Aquifer-2		186		7.62	362		-44.47	-5.52	1.00 ± 0.17	45.42 ± 1.2	6526
39	PT57	Simri	Aquifer-2	29.01.14	281		8.04	434		-44.17	-4.43	0.11 ± 0.14	23.32 ± 0.9	12038
40	PT58	Simri 1	Aquifer-2	04.10.13	196		7.87	357		-42.41	-4.9	2.98 ± 0.2		
41	PT59	Moriyama	Aquifer-2	18.01.14	227		7.6	253		-50.25	-5.92	0.22 ± 0.14	23.12 ± 0.9	12109
45	PT 34	Akharaghat - Danapur	Surface water	10.10.12		29	7.03	204	6.8	-56.82	-7.56	5.93 ± 0.58		
46	PT 35	Chudrana	Surface water	10.10.12		29.5	7.5	300	7.5	-56.88	-7.59	5.89 ± 0.57		
47	PT 38	Kadamghat	Surface water	10.10.12		29.5	8.38	240	8.7	-39.53	-5.06	3.97 ± 0.46		
48	PT 44	Gandhighat - Mahendru	Surface water	12.10.12		29.9	6.7	297	9	-61.3	-8.27	6.25 ± 0.55		
49	PT 46	Punpun ghat	Surface water	12.10.12		29.9	6.8	230	10	-44.11	-6.01	4.17 ± 0.30		
50	PT55	HaldichapraTinmuhani ghat	Surface water	15.09.14		32.8	6.8	336	3.7	-54.42	-5.73			
51	PT52	PatelNagar	Rainwater	14.08.14			7.51	74		-91.95	-11.64	2.46 ± 0.24		
52	PT53	Boring Road near A.N.College	Rainwater	14.08.14			7.57	183		-84.67	-10.69	2.85 ± 0.22		
53	PT54	Kankarbagh	Rainwater	14.08.14			7.61	147		-89.73	-11.08	2.4 ± 0.24		
54	PT56	Shri Rampur	Rainwater	15.09.2014		28.6	7.25	216	2.5	-80.43	-10.09			

3.13 Radiometric logging to estimate the radio elemental concentration in the sediments

3.13.1 Principles and methodology:

Borehole logging means record of one or more physical properties as a function of depth. Gamma Ray Logging of borehole introduced in 1939 by Well Surveys Inc. (WSI) is a comparative radioactive, non-destructive, rapid and cost effective method to estimate the radio-elemental concentration along the depth of the borehole. It is an indispensable tool to know the concentration of uranium and thus its exploration. Gamma Ray Logging of borehole provides much of the basic data needed for establishing disposition and grade of the uranium ore body.

Gamma ray logging of borehole can be carried out in continuous manner or on point-to-point basis. Point-to-point gamma ray logging is carried out by estimating eU_3O_8content at every 10 cm interval in active region (>100 ppm) and at every 20 cm interval (<100 ppm) in inactive region. For this, probe is held at a particular point to get a reading and then moved to another point to record the next reading and so on. Depth recorder gives the depth of a particular point with respect to the zero point of the borehole.

The value of K (Calibration constant) obtained from the calibration curve is used to assign the grade of the portable secondary standard. Secondary standard simulates primary standard and is carried to the drill site for checking the calibration of gamma logging equipment.

Gamma ray logging system comprises of a probe contained in a brass housing of length 1m (approx.) sealed with rubber gland and a neoprene gasket against ingress of water and is capable of withstanding water pressure as high as 1000 lbs. /inch^2, a winch (double steel armored cable or rubber cable), a depth recording pulley and a count rate meter (CRM). Probe contains a Geiger-Muller tube detector. Probe is connected at one end of the cable wrapped over the winch. CRM is connected to the winch. Depth recording pulley is used to facilitate the lowering the probe in the borehole and record its depth at particular points. A sleeve type secondary uranium standard is used to calibrate the logging system. The probe houses detector (GeigerMuller tube) and the associated electronic circuitry to supply high voltage (DC) required for the operation of the GM tube and line driver circuitry to send the signal back to the CRM connected to the winch. CRM supplies 9 V DC to the probe and receives the signal from the probe. The CRM is calibrated to read the concentration of radioelements in terms of eU_3O_8.

Gamma ray logging samples a very large volume. Sample volume is defined as the volume of the formation surrounding the detector within which 99% of the detected gamma rays originate. It is assumed to be a sphere of radius 30 to 50 cm, centered at the detector. The radius of the sphere depends on:

- The maximum primary energy of the γ-rays emitted by the radioisotopes.
- The density of the formation.
- The chemical composition of the medium.
- The minimum γ-ray energy to which the detector will respond.

The minimum value of eU_3O_8 that can be reported with this gamma ray logging system is 100 ppm.

3.13.2 Gamma ray logging of boreholes under Pilot Aquifer Mapping Project

Gamma ray logging of boreholes was carried out by Atomic Mineral Directorate for Exploration and Research (AMD), Eastern Region, Khasmahal, Jamshedpur to estimate the radio elemental concentration of radioactive elements in terms of eU_3O_8 in sediments in Pilot aquifer mapping area, Patna, Bihar.

Gamma ray borehole logging was conducted in the six bore holes across the pilot aquifer mapping area, Patna (fig; 3.13a & b). The maximum logging depth was 281m, bgl at Simri. The details of logging locations and results are given in table (3.13). Gamma ray logging of all the boreholes resulted in estimation of eU_3O_8 less than 100 ppm.

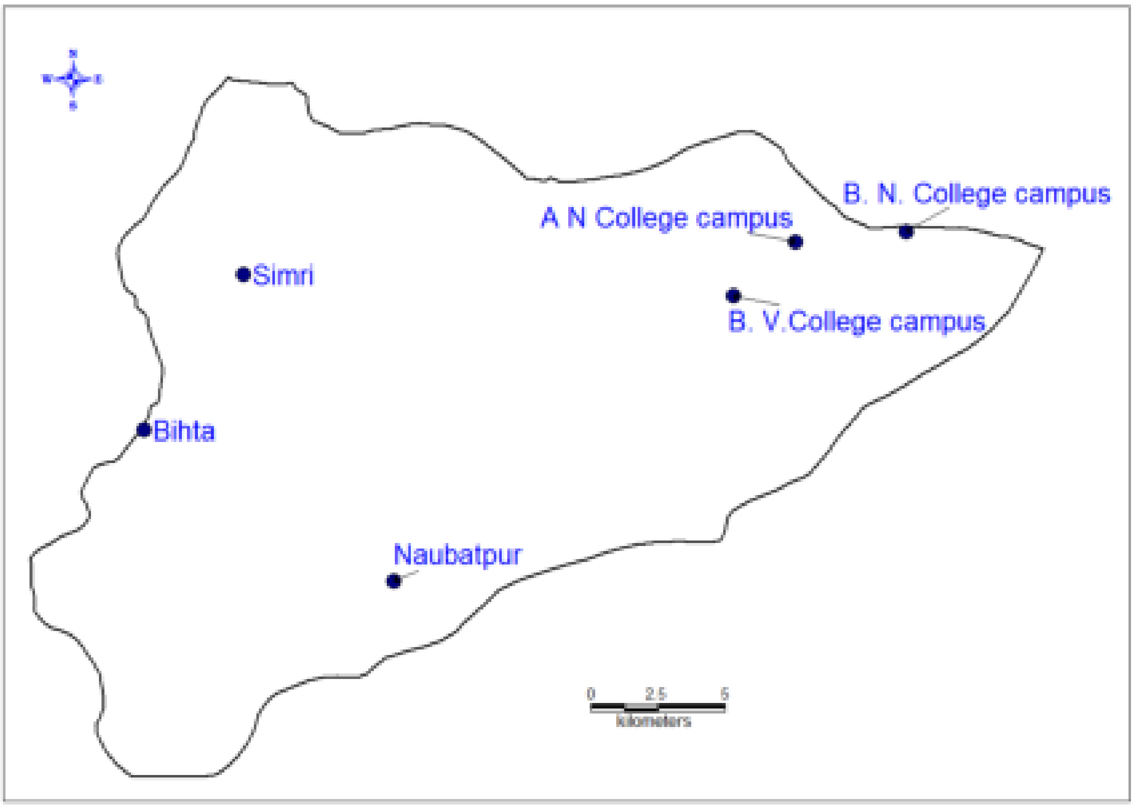


Fig: 3.13 (a) Locations of gamma ray logging for radio-elemental concentration in the boreholes

Fig: 3.13 b Field photograph showing gamma borehole logging carried out for radio-elemental concentration in the boreholes of the area

Table: 3.13 a Details of gamma borehole logging locations and results

S. No	Name	Type of well	Gamma ray logging depth	eU_3O_8 (%)
1	A N College campus	Deep Tube well	164.5	<0.010
2	B.V.College campus	Deep Tube well	163.4	<0.010
3	B.N.College campus	Deep Tube well	181.4	<0.010
4	Naubatpur	Deep Tube well	177	<0.010
5	Bihta	Deep Tube well	200.9	<0.010
6	Simri	Deep Tube well	281	<0.010

CHAPTER-4
DATA INTEGRATION

4.1 Integration of data from conventional & advanced techniques

Data generated during pilot project by CGWB and historical data/information of CGWB were integrated with data generated by different geophysical survey (ground and SKY-TEM) of NGRI, Hyderabad to decipher the aquifer configuration. Data integration was carried out jointly by CGWB, MER, Patna and NGRI, Hyderabad at NGRI Hyderabad in multi phase.

During first phase data from VES (CGWB and NGRI), e-logs, geological lithologs, TEM results, ERT results etc. were integrated with the help of the Aarhaus software. It was observed that the TEM results and ERT results of NGRI was showing very less depths (up to 100m, bgl). Data of VES and TEM, electrical logs were relooked and reinterpreted for delineating aquifer configuration and incorporated. During second phase, the SKY-TEM data were integrated with the e-logs and VES data of MER-CGWB and ground geophysical data (i.e., VES, TEM& ERT) collected by NGRI at the selective sites and sections for the calibration.Though The SKY-TEM was carried out for very small area of 52 sq.Km. falling in the South- Western part of the area within the project area of Patna, Bihar (Fig: 3.6 a), it helped in deciphering the continuity and discontinuity of layers.

All data generated were brought into one platform using WELCAD software for comparative study. Attempt has been made to accumulate the data of VES (CGWB and NGRI), e-logs, geological lithologs, TEM results, ERT, Occum (single data from SKY-TEM) results etc. of a particular place in WELCAD platform. Validation and comparisons of SKY-TEM results and conventional geophysical results, e-logs data for few sections along different orientations have been done for integration. Validation and comparisons of sections prepared based on data generated by various tools were done. SKY-TEM sections were fitted and compared with section based on conventional geophysical methods and exploration data (e- log section) of same orientation to understand percentage of matching. The continuity of the aquifer disposition in different orientation has been checked based on the validation.

4.1.1 Integration and comparison of SKY-TEM results and geophysical logs of boreholes

Sections preapared along profile in South-North direction based on the SKY-TEM results and geophysical logs of two boreholes drilled by CGWB were compared (fig.3.6g1). The short-normal and long-normal resistivity values correlate satisfactorily with the high resistivity zones obtained from the SKY-TEM results and vise versa. Broadly it shows two principal aquifer systems up to the explored depth of 300 m.

4.1.2 Integration and comparison of SKY-TEM and VES results

The interpretation of the VES 3 data at Bikram (located towards east of bore well-I, revealed 9 geoelectrical layers, fig. 3.6 g 3). At this site the first principal aquifer is associated with 58 Ω-m resistivity. It's thickness is around 54 m which matches satisfactorily with the SKY-TEM resistivity section (Fig. 3.6 g 4). The depth to the bottom of second aquifer (230 m bgl) also matches satisfactorily with the SKY-TEM results.

Another SKY-TEM section in S-N direction was compared with the results of VES BV-19 carried out at Khoriatha village (Fig. 3.6 g 5), located around 2 km away from the borehole at Bikram. At this site the resistivity and thickness are 65 Ωm and 66 m, respectively, of the first principal aquifer deduced from VES matches with the results of the SKY-TEM results. The boundary between the first aquifer and clay deduced from the VES are corroborated with the SKY-TEM result.

4.1.3 Integration and comparison of the SKY-TEM and ERT data

The ERT surveys in the flown area were compared with the SKY-TEM data. The ERT (No. 5, Fig. 3.6 g 8-A) at Bikram village falling in the SKY-TEM flown area revealed a clay layer up to an average depth of 26 m bgl followed by a sand layer (the first principal aquifer) continuing to the explored depth of 60 m along this profile. It was confirmed through the SKY-TEM data shown in Fig. 3.6 g 8-B). The SKY-TEM sounding Occam inversion result at the centre of the ERT profile also indicates first principal aquifer occurring at a depth of 26 m bgl and continuing up to 60 mbgl (Fig. 3.6 g 8-C). ERT data was not able to resolve the clay layer at the bottom of the first principal aquifer due to limitation of instrument and proper spreading.

4.1.4 Integration and comparison CGWB litho-section with the SKY-TEM, ground based VES and TEM results

Comparison of the litho-section of CGWB prepared based on two available e-logs along Bikram-Moriyama indicates nearly perfect matching with the SKY-TEM resistivity section upto the SKY-TEM DOC along this profile. It indicates nearly perfect matching of litho-logical layers. However the prominent clay layer detected in the SKY-TEM section between 75-125 m depth appears as thin discrete layers in the well e-logs section of CGWB. Similarly deeper persistence of thin clay layer appearing on the e-logs section is not detected because of limited DOC along this section Fig. 3.6 h 1.

The continuity of the aquifer disposition upto Maner (North) has been also deciphered through the e-logs (Fig. 3.6 h 2) based on the validated litho-section (Fig. 3.6 h 1).

The SKY-TEM section has also been validated with the e-log section along Bikram-Naubatpur in the flown area. Based on this validated litho-section, the continuity of the aquifer disposition up to BN College (North-East) prepared on the basis of the e-logs (Fig. 3.6 h 3) has been checked and found matching.

Likewise, the SKY-TEM section along Bikram-Arap in the flown area has been validated with the litho-section obtained from the results of CGWB-VES data and it reveals the matching and continuity of the aquifer disposition up to Bhatehari (North) (Fig. 3.6 h 4) and along Arap-Kalapur-Pandepur (Fig. 3.6 h 5).

4.2 Value addition from geophysical studies

Validation and comparative analysis between the SKY-TEM and the drilling log results and ground geophysical results has been done to have an idea of value addition by the SKY-TEM survey and other advanced ground geophysical survey (TEM& ERT). In addition, the aquifer maps prepared based on data generated by the SKY-TEM survey, exploration data and ground geophysical survey were compared. The following value addition was observed.

(a) Value addition from ground geophysical survey:

1. The heterogeneous nature of the top layer has been deciphered very clearly by the sections generated through ERT data.ERT data also helped in deciphering the paleo-channels existing in the area.

2. The layer connectivity of top aquitard layer and the underlying aquifer-1 has been established at several locations through ERT sections and the same was used in modeling.
3. The equivalent hydraulic conductivity for top layer has been worked out by integrating the VES, TEM and ERT data of NGRI with grain size analysis data of CGWB.
4. Based on the equivalent hydraulic conductivity contours of the top layer , relative zones of higher and lower recharge potential has been demarcated.

(b) Value addition by SKY-TEM survey

1. Continuous data acquisition by SKY-TEM survey:

   Continuous subsurface information (average depth of investigation -200-250m, bgl) in very short time has been acquired by SKY-TEM survey as dense data were acquired (fig.4.1a & b).

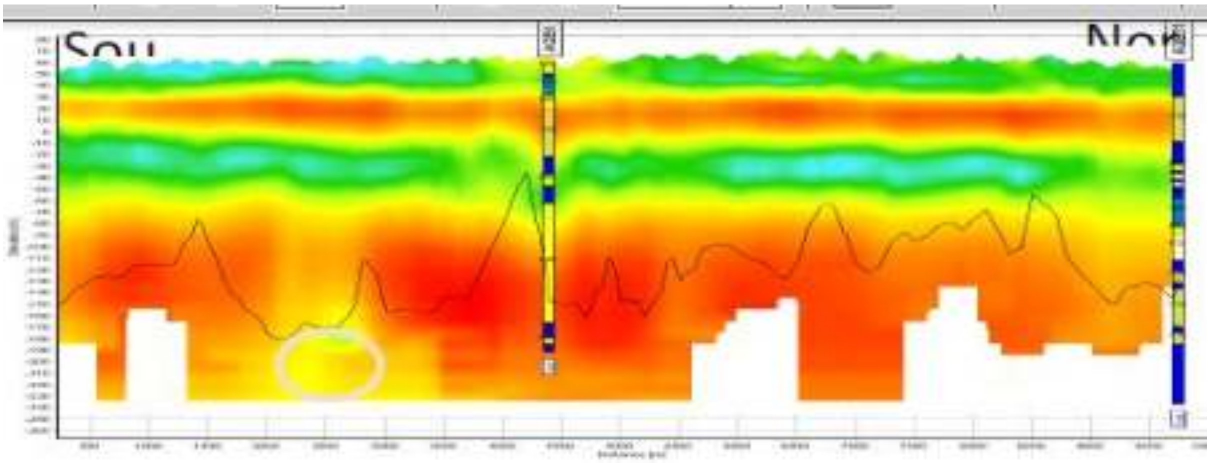


Fig.4.1 (a): Continuous data acquisition by SKY-TEM survey

2. The continuity and discontinuity of clay layers (green color) and aquifers has been resolved very clearly by the dense data acquired through SKY-TEM surveyed areas of Patna, Bihar.

   Section based on Litholog data and SKY –TEM data along Bikram - Moriyam were compared and it has been observed that the SKY-TEM data cleary picked the discontinuity of the clay layer separating first and second principal aquifer while the same section based on the litholog data could not able to decipher the discontinuity of this clay layer (Fig. 4.1 c).

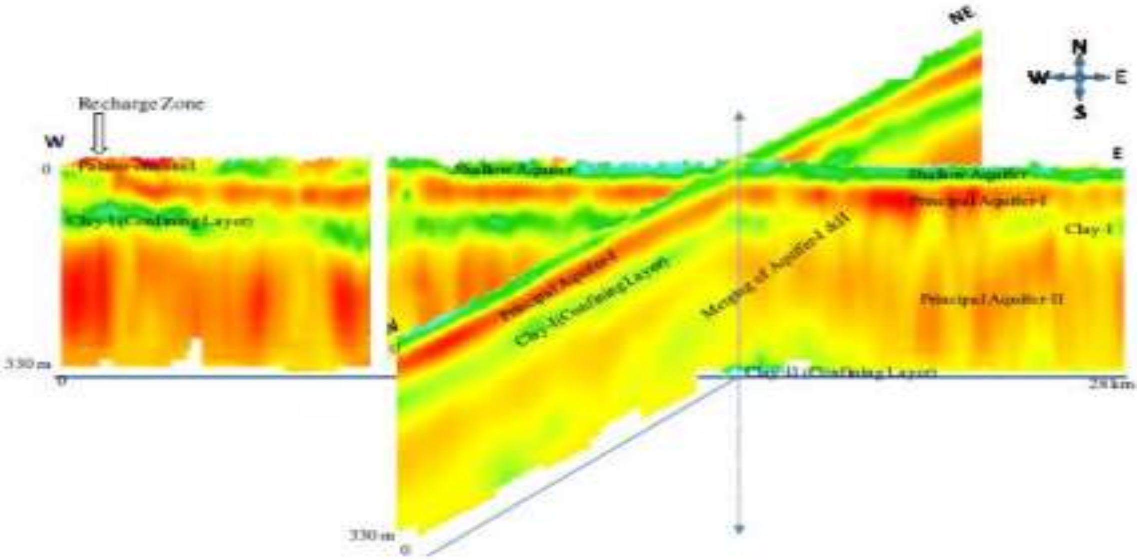


Fig.4.1 (b): Continuous data acquisition by SKY-TEM survey

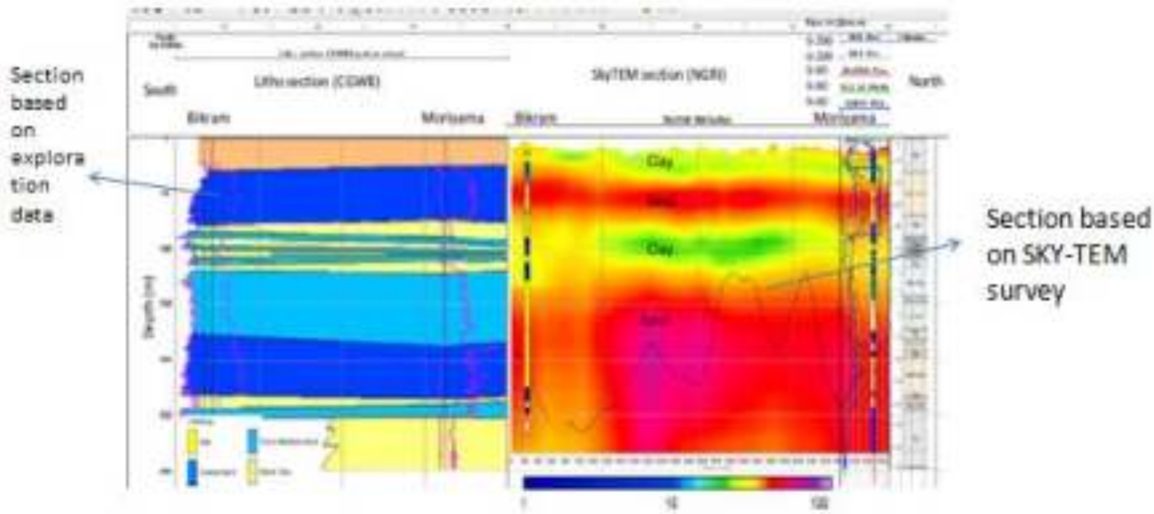


Fig 4.1 (c): SKY –TEM section resolving the continuity and discontinuity of clay layers (green color) and merging of aquifers (red & yellow color).

3. SKY-TEM survey clearly shows the merging of layers (Fig. 4.1 b & d) and thus added value in assigning the layer specific parameters for groundwater modelling.

   The dense and high quality data acquired by the SKY -TEM survey has added a major value in mapping the subsurface that revealed several features of high significance in terms of groundwater occurrence and hence in aquifer mapping.

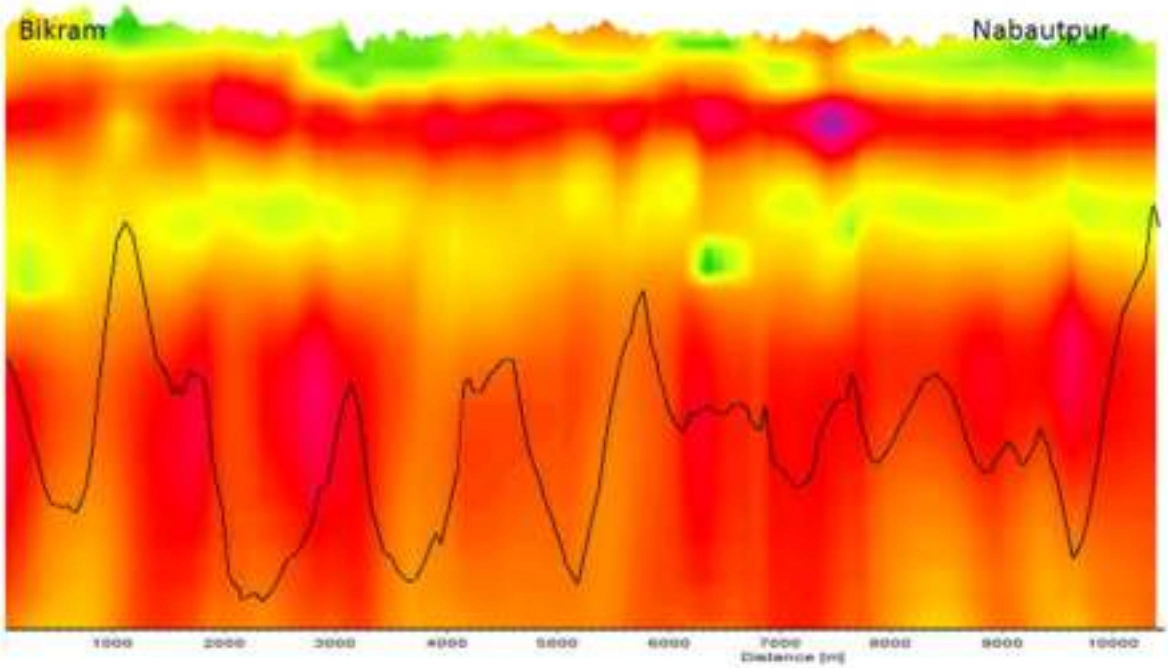


Fig 4.1 (d): Sections generated by SKY-TEM survey along Bikram-Naubatpur showing merging of Aquifer-1 and Aquifer-2 at places.

4.3 Efficacy of various geophysical techniques for alluvial hydrogeological terrain

The various geophysical surveys like VES, GTEM, ERT and SKY-TEM has been conducted in the area by NGRI, Hyderabad and their applicability for aquifer mapping in the alluvial terrain has been evaluated. Applicability of the different geophysical methods for aquifer mapping in pilot aquifer mapping area, Patna, Bihar falling in the mid-Ganga plain has been given in table 4.3(a).

Table 4.3 (a) Applicability of the different geophysical methods for aquifer mapping in pilot aquifer mapping area, Patna, Bihar

Methods	Hydrogeological Environment	Applicability	
	Alluvium	Depth Factor	
VES	yes	Shallow	Deep
ERT	yes	Shallow	Deep
GTEM	yes	Moderate	
SKY-TEM	yes	Shallow#	Deep*
Airborne Magnetic	No	No significant magnetic features associated with aquifers	

Low Moment (LM) * High Moment (HM)

4.3.1 VES instrument SYSCAL Jr/R1 used with Schlumberger Configuration

The Vertical Electrical Sounding (VES) with maximum current electrode spacing of AB = 600m to 3000m was used with the movement of current electrodes with every 50/100m spacing beyond 300m of AB/2. This should be followed at every site. The response should be plotted in the field itself simultaneously and if required the observation should be repeated with varying the current for confirmation of change in trend. The interpretation should be carried out in the field for understanding the layer parameter behavior over an area. In some cases, sounding must be repeated at nearby places or in other orientation to attain necessary additional information.

4.3.2 Multi-electrode Imaging system (ERT): SYSCALJr/RI—IRIS Instrument

Electrical Resistivity Tomography (ERT) was applied for a profile length of 480 m with inter-electrode spacing of 10m. Wenner-Schlumberger configuration was adopted at each site for understanding the efficacy on resolution of hydrogeological stratum. It resolved the shallow aquifer including the first principal aquifer up to explored depth of about 90 m.

4.3.3 Ground TEM

The TEM 48 HPC (The Netherlands) was used for TEM exploration in the aquifer mapping area Patna, Bihar. The results of the TEM soundings at the selective sites were quite significant and illustrating the utility of the method in accurately delineating the top of the clay at depth around 110m forming the base of the first principal aquifer, which could not be sometime delineated through the VES data.

4.3.4 Multi –Moment SKY-TEM-Model 504

The SKY-TEM survey comprised 770 lines Km with the flight –line spacing of 250m in E-W direction was carried out over an area of 150 Sq.km within which 52 sq. km is in the pilot project area. The average flight speed was approximately 22 m/s with an average flight altitude of 30 m (transmitter frame height). The low moment and high moment of the transmitter(s) were approximately 3397 Am^2 and 154903.2 Am^2 respectively. The SKY-TEM data are of good quality. The collected data were carefully processed to remove couplings and noise before inversion.The inversion was done initially with a smooth model using the laterally constrained inversion (LCI) approach and then spatially constrained inversion (SCI) approach .The low moment data ensured high resolution near surface mapping and high moment data for the deeper level. Thus the dual moment provided high resolution mapping of sub-surface from top to ~300m depth in alluvium.

4.4 Protocol for geophysical investigations in aquifer mapping

The various geophysical surveys like VES, GTEM, ERT and SKY-TEM has been conducted in the area by NGRI, Hyderabad. Based on the results of these surveys, NGRI, Hyderabad recommended the protocol of geophysical investigation for aquifer mapping in the alluvial area. The protocol of geophysical investigation for aquifer mapping is given in the table 4.4 a.

Table 4.4 (a) The protocol of geophysical investigation for aquifer mapping in Pilot aquifer area, Patna

Application of geophysical tool*	**Hydrogeological environment**	**Order of preference and application & reasoning****
	Alluvium	
SKY-TEM	1	1- Main tool
GTEM	2	2- 1st supportive
ERT	3	3-2nd supportive
VES	4	4- 3rd supportive

*In order to achieve greater depth penetration/information in the alluvial area, it is preferable to use a multi pulse HeliTEM system with higher moment (> 500, 00 Am^2) with low pulse rate frequency capable of late time measurement up to 20 milli seconds or beyond.

** The order of preference on application of various geophysical tools for aquifer mapping is made purely based on the results of survey in the pilot aquifer mapping area, Patna, Bihar falling in the Mid-Ganga Plains.

❖ This chapter of the report is based on the NGRI report titled AQUIM-Final report AQBHR (2015), Patna District.

CHAPTER-5
GENERATION OF AQUIFER MAP

5.1 Aquifer disposition

The watershed (GNDK013) is located in the central axial part of Middle Ganga Plain occupying the central part of the Ganga Basin. The area forms a part of the Gangetic plains underlain by immensely thick alluvial deposits of Quaternary age comprising various grades of clay, silt and sand which constitutes the groundwater reservoir. The entire alluvial thickness overlying the Precambrian basement in the area is expected to be over 700 m as inferred through deep seismic refraction survey in the southern part of Patna district (Fig 2.5 b). However, around Patna urban area, a sharp drop in bedrock depth forming a deep trough of unconsolidated alluvium has been indicated.

5.1 .1 Aquifer disposition in the area

One of the objectives of the project is to know the aquifer disposition of the area at micro-level through exploration and various geophysical methods. At the inception of the project, it was observed that borewell data of CGWB was available mainly for the north-eastern sector of the area (fig. 2.7a). Data from concerned State Government borewells have also been collected, however, these provide information only upto 110 m depth (Fig. 2.7 b). In addition, 26 VES with spread varying from 400m to 1000m conducted by CGWB were also used in deciphering the subsurface configuration (Fig. 5.1a). On the basis of the VES two geo-electrical sections have been prepared to decipher the aquifer disposition (fig 3.5 h and i). Similarly three geo-electrical sections (fig 3.5 j, k and l) and one fence diagram has been prepared on the basis of the e-logs (fig 3.5.m).

Separate sections and fence diagrams have also been prepared based on the lithological information obtained through exploratory drilling undertaken by CGWB in conjunction with the available lithological logs of tubewells constructed by State Government. Lithological sections have been prepared using ROCKWORKS software.

The strip logs (lithological logs) depicting lithological variations at individual locations have been prepared using Rockworks software and are shown in Fig 5.1a. These logs reveal the presence of a thick pile of alluvial sediments with alternation of various grades of sand, clay and silt.

From the geological sections and fence diagrams prepared the detailed aquifer geometry on regional scale has been 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.

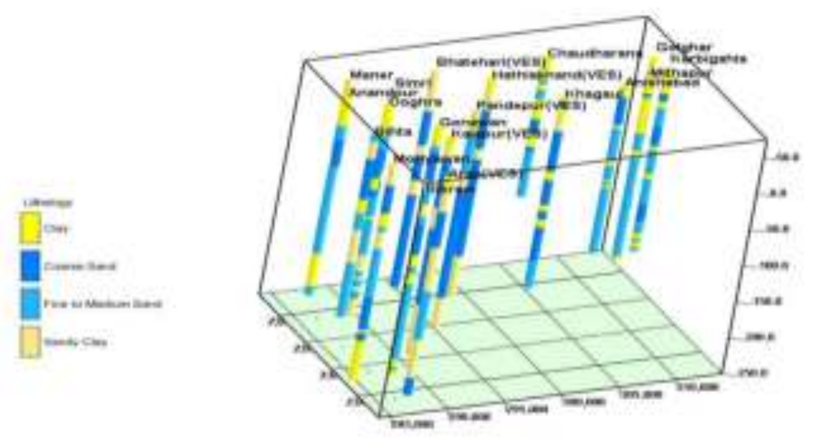


Fig 5.1(a) : Strips logs prepared using Rockworks

Aquifer disposition of the area are described through various sections and fence diagram prepared in different orientation.

5.1.1(A) Aquifer disposition along E-W direction along the northern boundary of the area

The section oriented along E-W, stretches over a length of 30 km and depicts the aquifer disposition upto a depth of 300m (fig 5.1b and 5.1c). This section reveals the presence of two principal aquifers lying below the top aquitard consisting of clay and sandy clay. The thickness of the aquitard layer varies from 62 m in the western part to 68 m in the eastern part. 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.

Underlying the top aquitard occurs a moderately thick aquifer with thickness varying from 20 to 50 m consisting of medium to coarse sand. This forms the 1st principal aquifer in the area. Perusal of the fig 5.1(b) indicates that the thickness of this zone decreases from about 50 m in the western part to 20 m at Chaudharana in the central part and again increases to 40 m at Golghar in the eastern part.

This aquifer is underlain by a thin clay bed with thickness varying from 10 m in the western part to 15 m in the eastern part; however, this clay bed is largely intercalated with thin sand lenses whereby the two aquifers nearly converge into a single aquifer system mainly in the north-eastern part around Patna urban area.

Underlying this clay layer occurs the 2nd principal aquifer, the thickness of which is significantly more than the 1st principal aquifer with an average thickness of 115 m. The 2nd principal aquifer is further underlain by a comparatively thick clay and sandy clay bed. The thickness of this clay bed at Golghar in the east in Patna urban area has been found as 63m (fig: 5.1b)

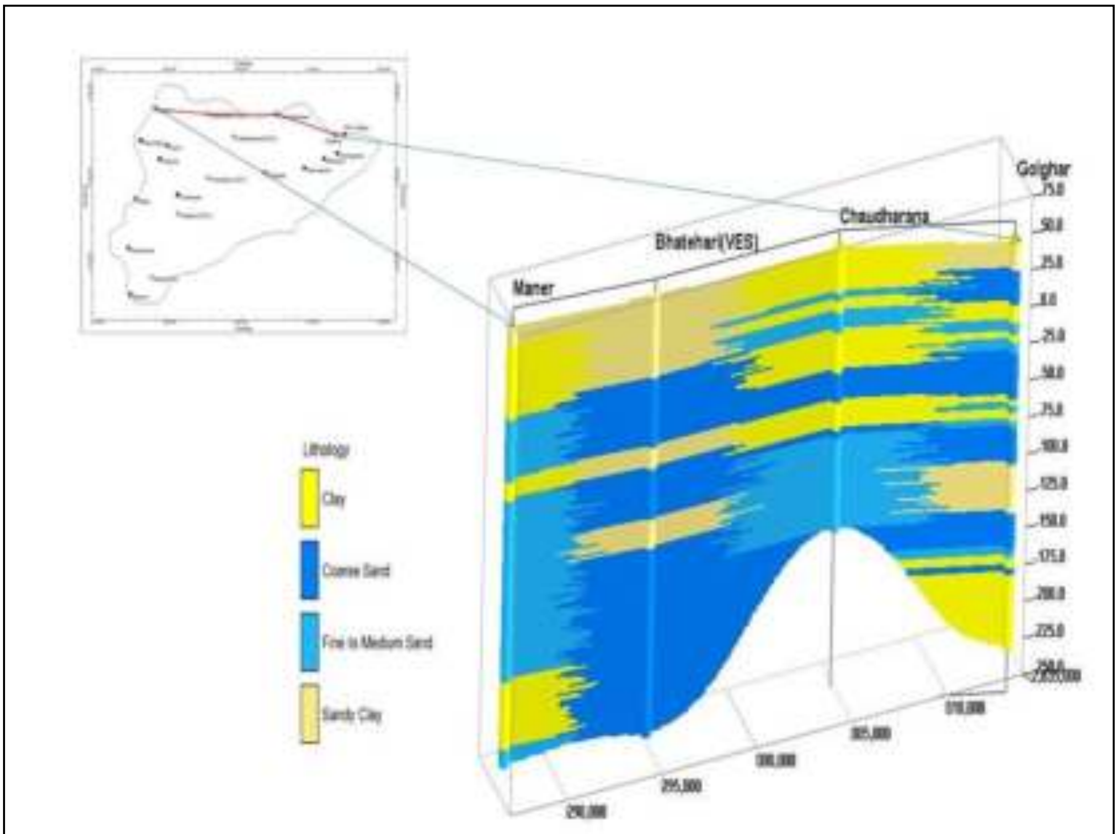


Fig 5.1 (b) Lithological section along E-W direction along the northern boundary of the area

5.1.1(B) Aquifer disposition along E-W direction in the central part of the area

This section depicts the aquifer geometry in the central part of the project area extending from Anandpur in the west to Karbigahiya in the east (fig 5.1 c). This section reveals the lithological make up upto 300 m depth in Simri to Pandepur stretch and upto 280 m elsewhere except at Anandpur in due west where it is only upto 110m.

The aquitard layer in this part varies in thickness from 30 m at Pandepur in the central part to 78 m at Karbigahiya in the east.

Underlying the aquitard layer, occurs the 1st principal aquifer with thickness varying from 46 to 68 m consisting of fine to medium and coarse sand with lesser thickness in the eastern part.

A clay layer with thickness varying from 3 to 25 munderlies the 1st principal aquifer. The thickness of this intervening clay layer decreases from 25 to a meagre 3 m in the eastern part at Karbigahiya in Patna urban area. Thus the 2nd and the 1st principal aquifer can be considered to merge into a single entity in the eastern part.

Below this confining layer, there occurs a comparatively much thick aquifer zone consisting of sands of various grades forming the 2nd principal aquifer. Perusal of sections (fig 5.1 c) indicate the general thickness of this aquifer is more than 100m and at palces even reached upto 158 m as at Pandepur in the central part. From the lithological information upto 300 m depth available for Simri and Pandepur a second confining bed of about 20 m thickness occurring at 240-258 m bgl has been indicated.

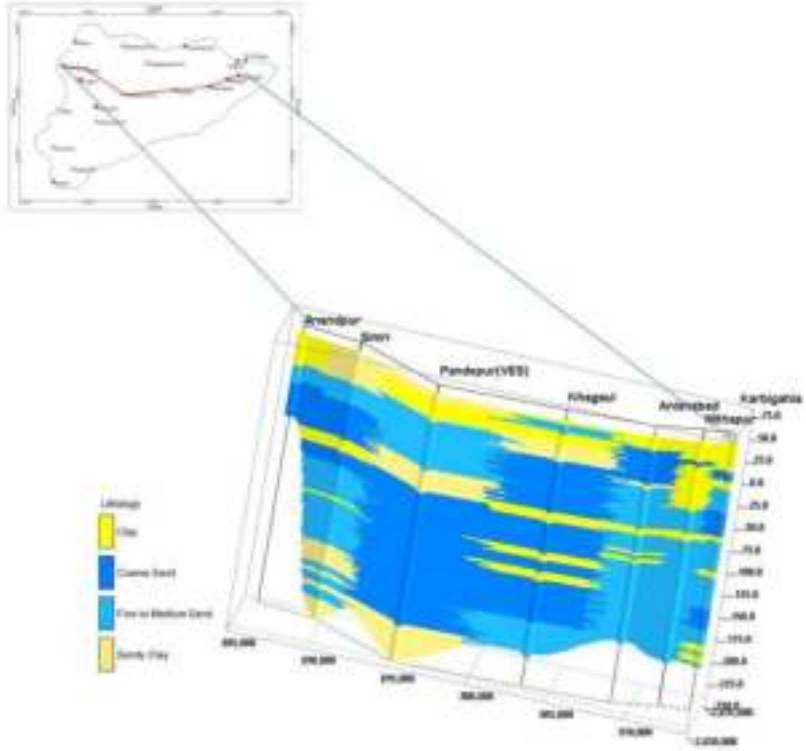


Fig 5.1 (c): Lithological section along E-W direction in the central part of the area

5.1.1(C) Aquifer disposition along Bikram-Moriyama-Bihta-Simri- Maner (in the N-S direction along the eastern boundary of the area)

Aquifer disposition along Bikram- Moriyama- Bihta-Simri- Maner from extreme south-western part to north-western part along the western boundary has been deciphered with the help offence diagram (fig 5.1 d) and perusal of strip logs (fig5.1a). Study of lithogs indicates that the 30 to 62m thick aquitard layer exists at the top and it consists of clay and sandy clay capping from the ground level. Its depth in the south western part is about 30m and at Maner in north of the area is 62m bgl. In the western part, this top aquitard is dominated by sand and sandy clay.

The thickness of the 1stprincipal aquifer consisting of fine to medium and coarse sand is 50m. This aquifer occurs under semi-confined to confined condition. The maximum thickness has been found as 62 m at Simri. At Moriyama, a19 m thick clay occurring at 69mbgl breaks the continuity of this aquifer; however, on a regional scale the lateral continuity of this aquifer remains undisturbed. The thickness of this aquifer decreases from south to north.

Vertical downward continuity of the first principal aquifer is hindered by 9 to 40 m thick persistent clay bed which exists below this principal aquifer and separates it from the underlying aquifer. The thickness of this clay zone gradually decreases from 40m at Bikram in the south to 9m at Maner in the north. At Bikram, there is a 10m thick sand lens within this clay bed. At Moriyama, this zone is sandy in nature.The top of this zoneis comparatively shallow in the southern part at Bikram (84m bgl). At Maner in the northen part, it occurs as 7 m thick between 111 and 118 mbgl.

The 2ndprincipal aquifer is comparatively much thicker aquifer and consists of sands of various grades occurs below the confining layer. This aquifer is laterally continuous and in general starts from 118 m bgl. The average thickness of this aquifer is more than 100m and at places it reaches upto 144m as at Bihta in central part of the this section.

As in previously discussed section the 2nd aquifer here also is underlain by a mixed zone of clay and sandy clay occurring at depth of 225-241 m bgl. At Moriyawan, the thickness of this clay layer is upto 70 m upto at Moriyama, with about 10m thick sand lense occurring at depth of 235m.

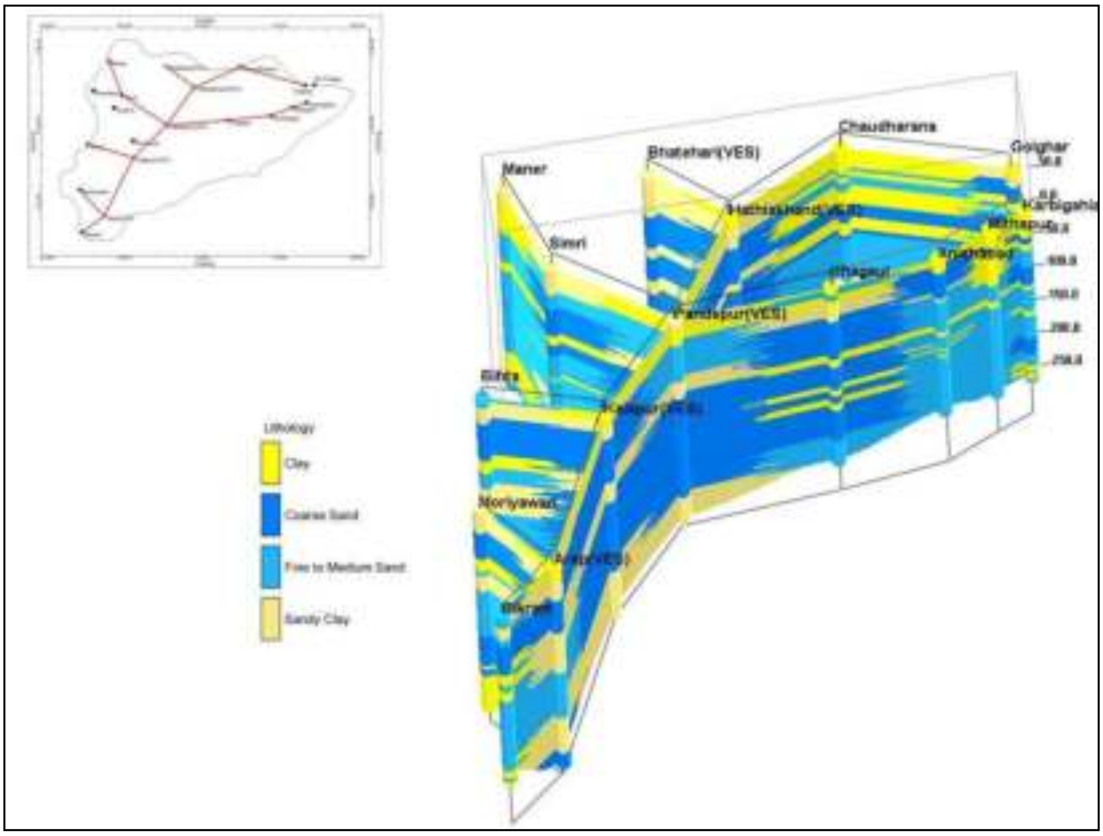


Fig 5.1(d) Fencediagram showing aquifer disposition of the area

5.1.1(D) Aquifer disposition along Bikram- Arap- Kalapur-Pandepur-Hatiakhand- Chaudhrana-Golghar (from SW to N & NE direction in the central part of the area)

This section depicts the disposition along the central part from Bikram- Arap-Kalapur-Pandepur-Hatiakhand-Chaudhrana-Golghar extending from the extreme south-western part to the north and the north-eastern part (fig 5.1 e).In this section the top aquitard layer has been found to range from 30 to 84 m in thickness with thickness increasing towards the north. In the southern part sandier facies dominate in the aquitard layer in comparison to the northern part- closer to River Ganga- where clayey facies are dominant.

From this section the existence of the two prinicipal aquifers is apparent except at Arap in the SW part where a thin third aquifer has also been detected. The 1st principal aquifer of semi-confined to confined nature consists of fine to medium and coarse sand with an average thickness of 50m. This aquifer is comparatively thicker in the southern part.

The 1st principal aquifer is underlain by a 14 to 60 m thick impervious layer consisting of clay and sandy clay. At Arap, this intervening layer is sandy clay in nature. Exploratory drilling at Moriyawan, due west of Arap also indicates its nature as sandy clay.

In this section also the second principal aquifer has been found to be much thicker than the 1st principal aquifer. The presence of a thick impervious layer ranging in thickness from 41 m at Pandepur to 70m at Kalapur forms the base of the 2nd principal aquifer. Except at Arap, this impervious layer continues up to depth of 300m.At Arap, a 24 m thick sand zone occurs below this impervious layer upto 300m depth indicating presence of another aquifer.

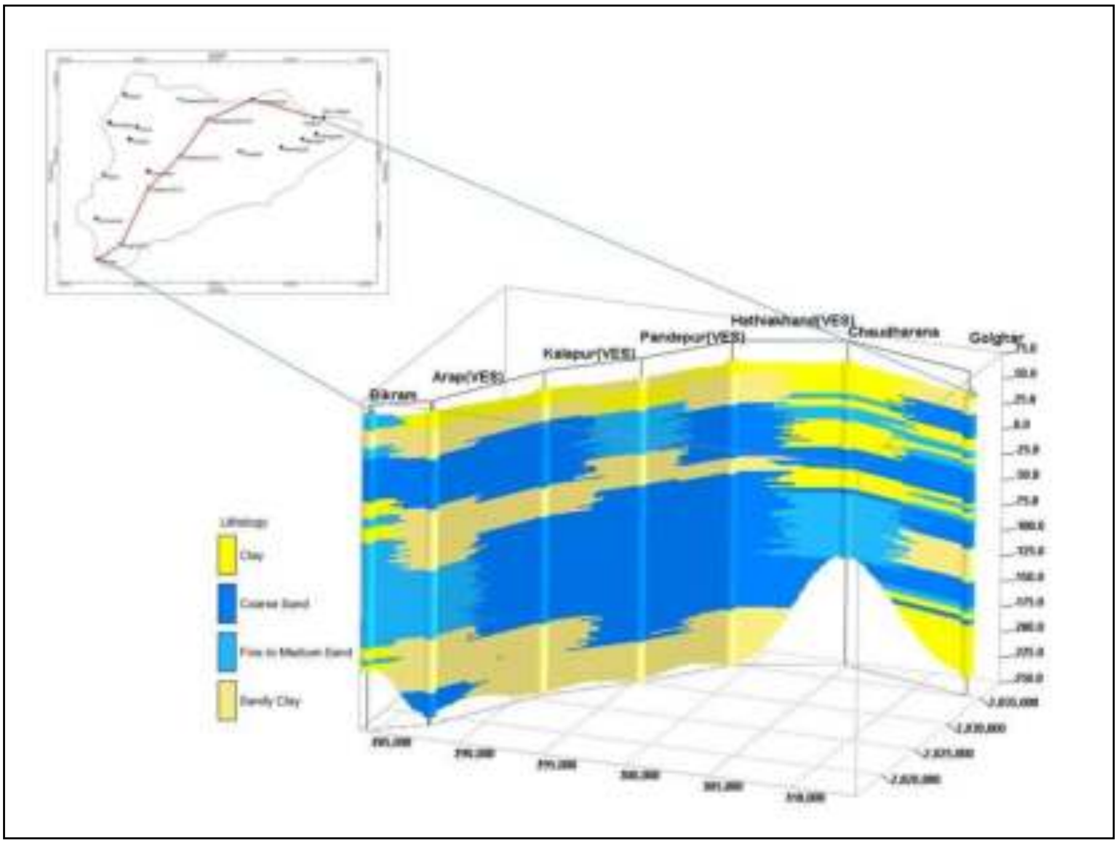


Fig 5.1 (e): Lithological section along north and north-eastdirection in the central part of the area

5.1.1(E) Aquifer disposition along Bikram- Arap- Kalapur-Simri-Maner (from SW to NW direction through the west-central part of the area)

Perusal of Section (fig 5.1 f) reveals the aquifer disposition up to 300m depth along Bikram**-** Arap- Kalapur-Simri-Maner running from SW to NW through the west the west-central part of the area. The aquifer disposition in this section is almost similar to the one along the western part which has been discussed under 5.1.1c.

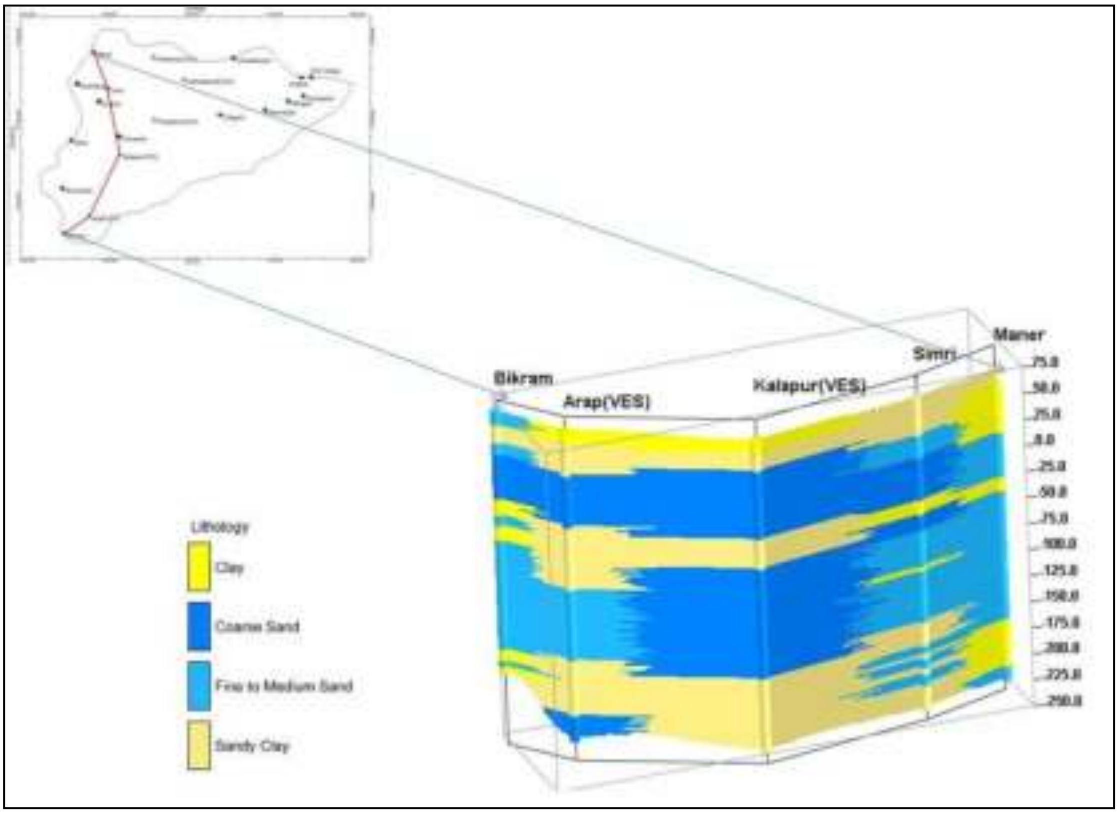


Fig 5.1 (f): Lithological section along SW-NW direction through the west-central part of the area

5.1.1(F) Fence digram showing aquifer disposition in the area

Fence diagram (fig.5.1 g & 5.1 h) has been prepared on the basis of drilling and VES data of CGWB to have the understanding of aquifer disposition of the area up to 300m depth. The fence diagram clearly depicts the existence of two principal aquifer systems below the top aquitard over the project area.

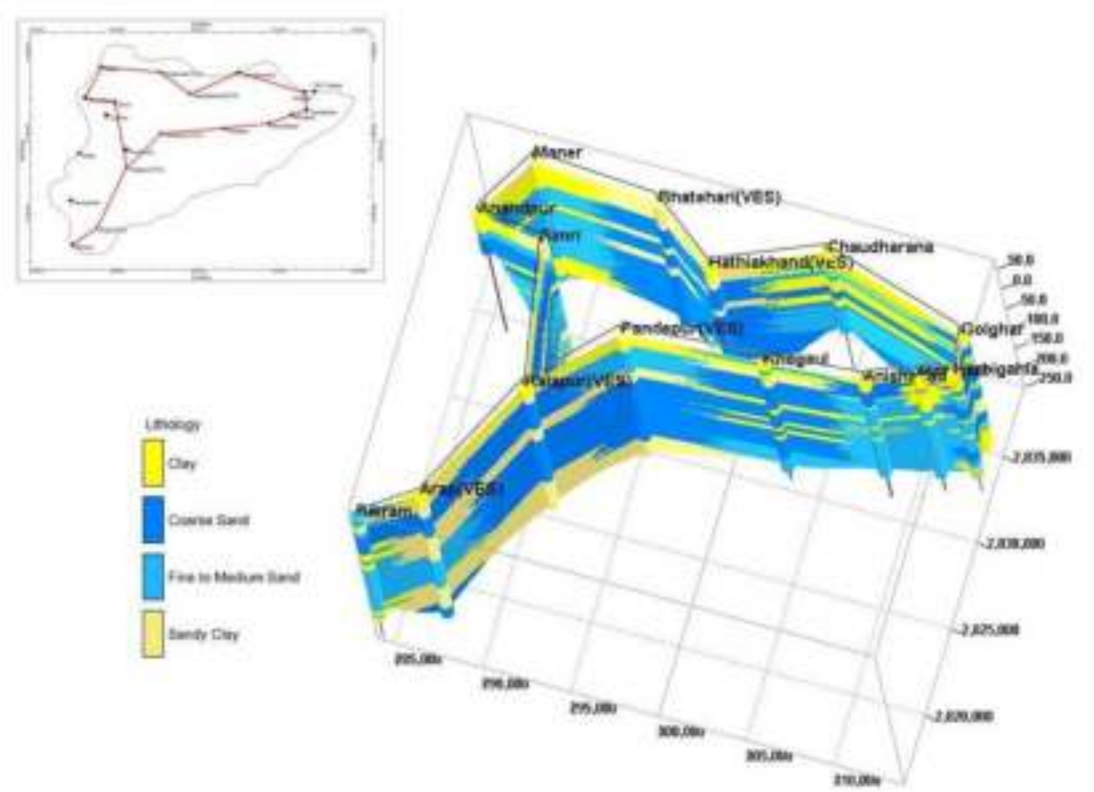


Fig 5.1 (g) Fence digram showing aquifer dispositions in the area

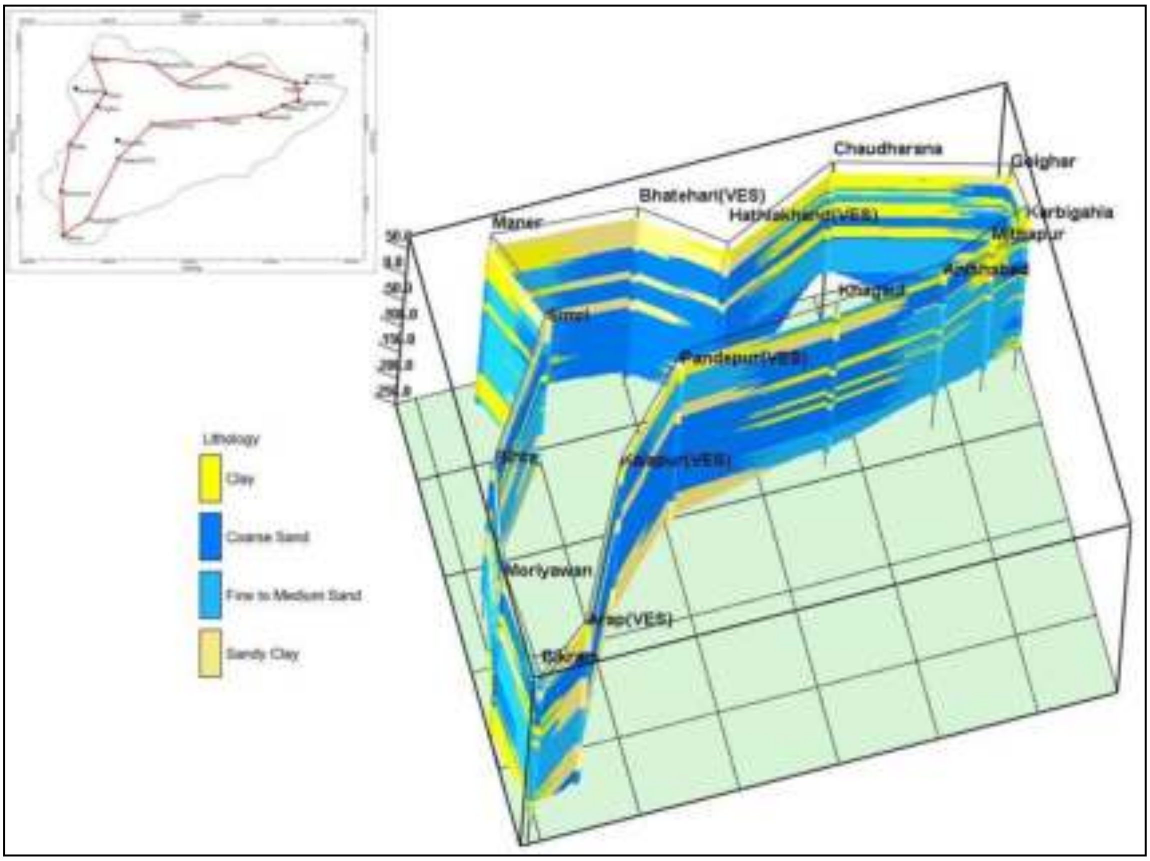


Fig 5.1 (h) Fence digram showing aquifer dispositions in the area

5.2 Aquifer Characterizations

5.2.1 Characterization of Aquifer

Characterization of aquifer upto300 m bgl in the Pilot project area have been arrived at by convergence of the observations from the study of strip logs (fig-5.1 a) different lithological sections (fig.5.1 b ,c,e,&f, fence diagram (fig. 5.1d , g&h), geoelectrical sections(fig 3.5 h &i), sections based on elogs (fig 3.5 j to 3.5 m). All these figures 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 lithological sequence indicates the multiple cycle of deposition (probably three to four) has taken place in the area.

The study of sections, fence diagram and lithological model indicate that there are mainly two principal aquifer systems in the area up to depth of 300m depth below the overlying top aquitard layer.

Isopach map of the individual aquifers have been prepared which provide a clear impression of the spatial variation of aquifer thickness in the area (fig 5.2a &5.2 b). The spatial variation of the thickness of the top aquitard layer lies within 20-30 m in major part of the area. Along the northern its thickness increases upto 40 m and at places even it extends beyond 40 m.

Perusal of the fig 5.2 a reveals that the thickness of the 1st principal aquifer varies from 50 to 80 m. Along the extreme southern part of the area, its thickness decreases to 50m whereas it is more than 80 m thick at places along the north-western and north-eastern boundary.

The 2nd principal aquifer is comparatively much thicker than the 1st principal aquifer. Fig. 5.2 b reveals that the thickness of the 2nd principal aquifer in the nort-central part even extends beyond 140 m. The general thickness of this aquifer is around 100 m in major part of the area.

Perusals of these sections indicate that there are two principal aquifers below the top aquitard layer (water table aquifer) upto 300m depth separated by clay and sandy clay layers. The two principal aquifers have been clearly demarcated while for precise delineation of the extension of the third aquifer, drilling beyond 300 m may be carried out in future as this was not envisaged in the present project.

Aquifer disposition (grid of 2 km x 2 km) obtained from SKY-TEM and ground geophysical survey is given in annexure 3.6 d.

The disposition of aquifers may be summarised as:

(1) Top aquitard layer: The top aquitard layer is highly mixed and is behaves like a low potential aquifer. The presence of sands in the top zones at places renders it semi-pervious in nature. This layer sustains the dug wells and shallow hand pumps of the area. The thickness of this aquitard is more in the north and north-eastern part closer to river Ganga.

(2) First principal aquifer: The first principal aquifer starts from 35-60m and it goes up to 80 - 130m bgl in general. The thickness of the first principal aquifer in general is about 50m.

(3) First impervious layer: The 1stprincipal aquifer is separated by 9 to 60 m impervious layer consisting of clay and sandy clay. This layer is thin in north-esatern part in comparison to the other parts of the area.

PILOT PROJECT ON AQUIFER MAPPING
MANER - KHAGAUL AREA (GNDK013), PATNA, BIHAR

Isopach Map

Aquifer - 1

Depth of occurence: (35-130 m bgl)

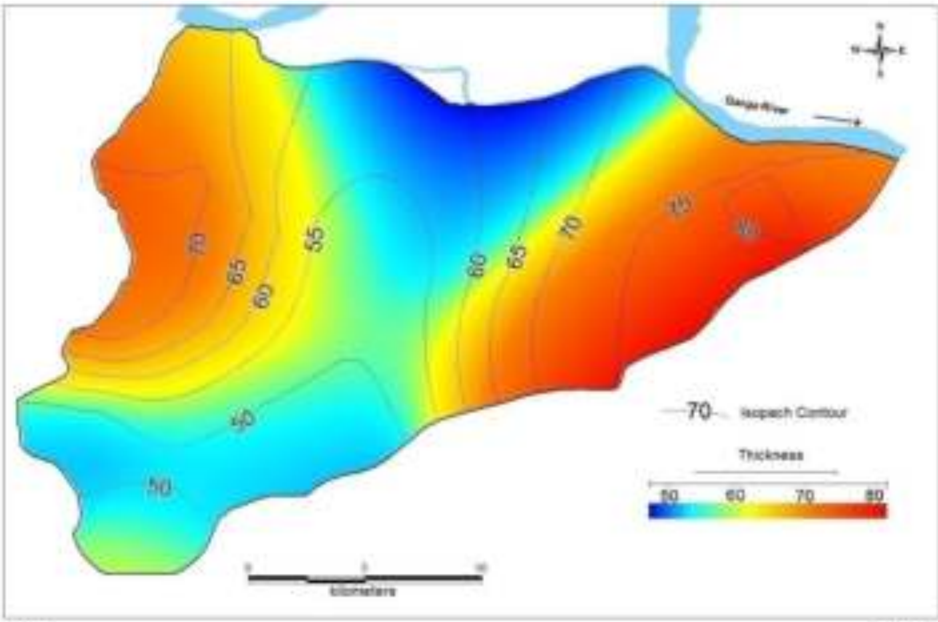


Fig 5.2(a) Isopach map of aquifer -1

PILOT PROJECT ON AQUIFER MAPPING
MANER - KHAGAUL AREA (GNDK013), PATNA, BIHAR

Isopach Map

Aquifer - 2
Depth of occurence: (110-265 m bgl)

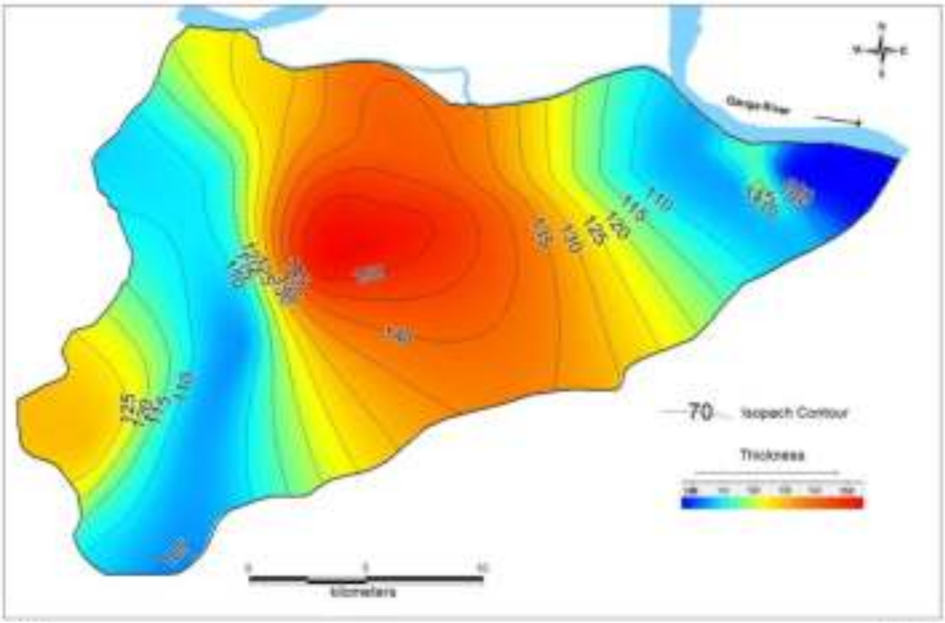


Fig 5.2(b) Isopach map of aquifer-2

(4) *Second aquifer*: Below the first confining layer, there is a 2nd principal aquifer which is much thicker in comparison to the first principal aquifer. At places, this aquifer zone is intercalated with thin lenses of clay and sandy clay.The depth of occurrence of this principal is 110 to 265.

(5) *Second impervious layer*: There is a thick clay and sandy clay bed impervious in nature below the second confining layer. Except at few places, it continues up to depth of 300m, bgl.

Sand beds below the second impervious layer has been detected at places, however, precise delineation of the 3rd aquifer requires drilling even beyond 300m to establish its regional continuity.

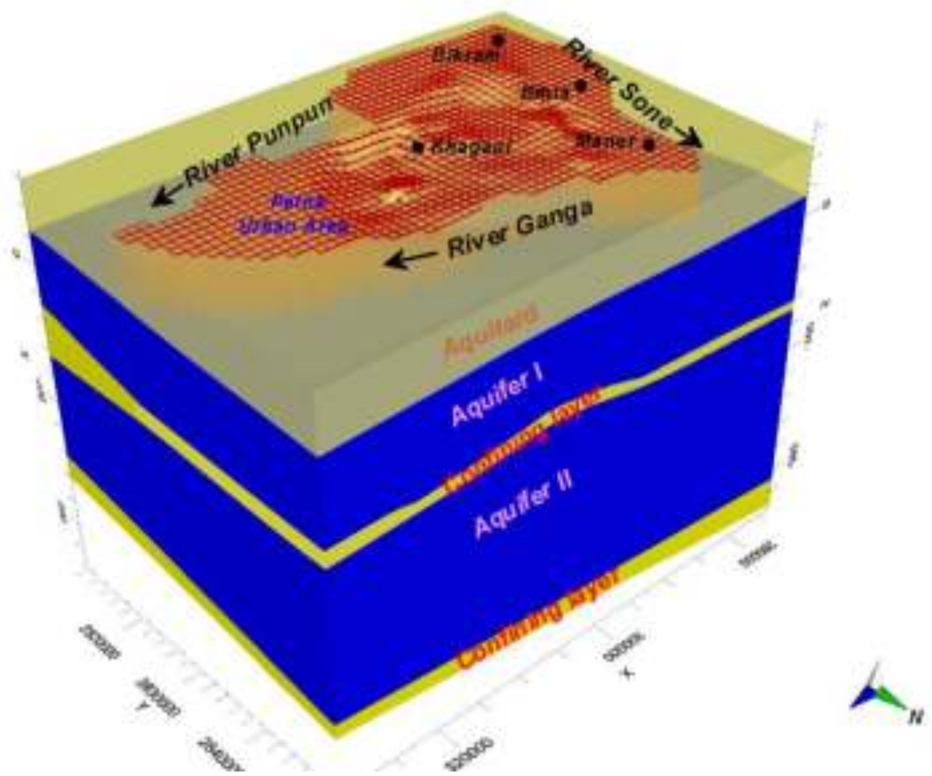


Fig 5.2 c (i): 3D disposition of the aquifers in N-S orientation

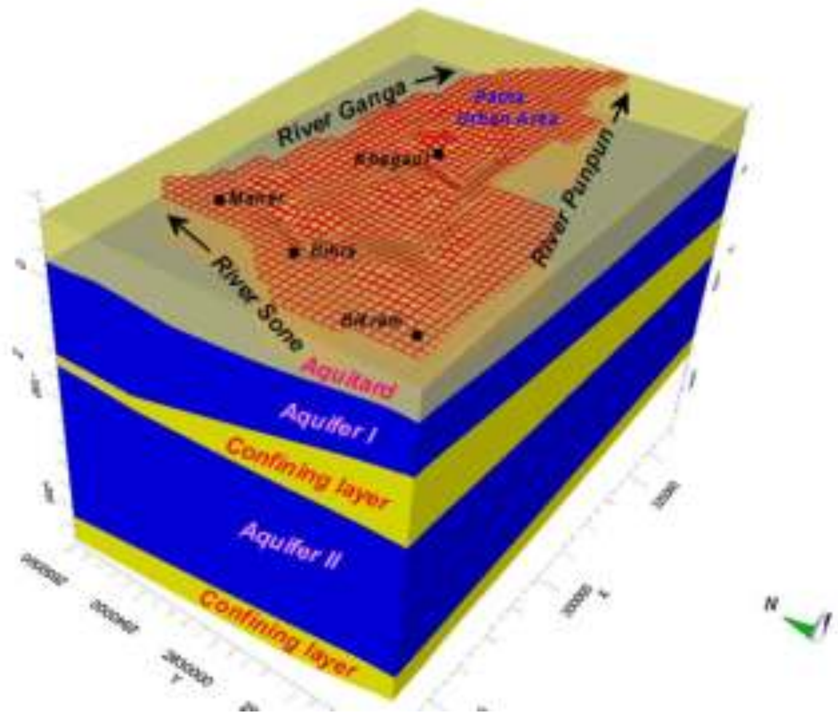


Fig 5.2 c (ii): 3D disposition of the aquifers in E-W orientation

5.2.2 Hydraulic characteristics of Aquifer

5.2.2(A) Hydraulic characteristics of the leaky aquifer (first aquifer)

CGWB has drilled number of wells in the area tapping multiple zones in different aquifers. Pumping test data of CGWB wells have been analysed to arrive at the hydraulic characteristics of the aquifers. Thease apart, the data of the wells constructed by State Government in the western and south-western part of the study area (Bihta,Maner and Naubatpur block) indicate that the yield potential of the tubewell tapping first aquifer (within 110m bgl) (Table-2.8c) varies from 160 m^3/hr to 222 m^3/hr for a maximum drawdown of 3.5 m (fig 5.2 d).

Salient characteristic of the exploratory wells drilled by CGWB in the area is given in table 2.8a & b. Perusal of these data reveal significant potentiality of the aquifer of the area as the transmissivity ranges between 4907and15984 m^2day^{-1} with mean value of 7861 m^2day^{-1}. The specific capacity of the wells ranges from 56 to 100 $m^3hr^{-1}m^{-1}$ and the mean hydraulic conductivity (K) has been found as 113 m/daycorresponding to that of coarse sand mixed with gravel. At two locations, A.N.College and Alamganj the storage coefficient has been found to be 7.7 $x10^{-2}$ and $5.0x10^{-3}$ respectively.

PILOT PROJECT ON AQUIFER MAPPING
MANER - KHAGAUL AREA (GNDK013), PATNA, BIHAR
Yield potential

Aquifer - 1
Depth of occurence: (35-130 m bgl)

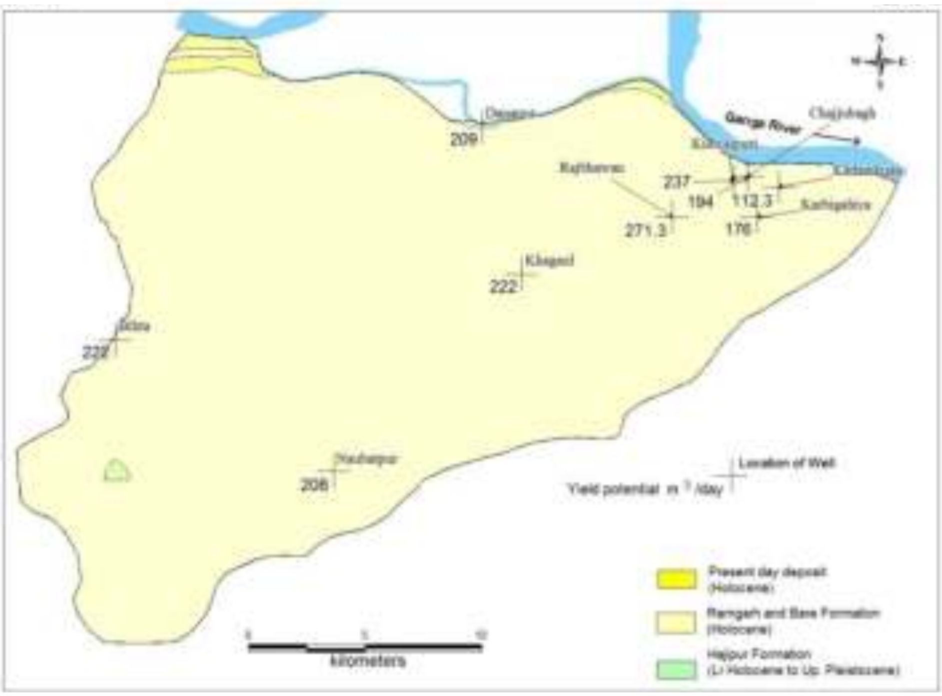


Fig. 5.2d: Yield potential map of aquifer-1

5.2.2(B) Hydraulic characteristics of the confined aquifer (2nd principal aquifer)

Perusal of the salient characteristic of the exploratory wells drilled by CGWB given in table 2.8 (a & b) reveal the hydraulic characteristics of the second aquifer. The transmissivity of this aquifer zone ranges between 5892 and15479 m^2day^{-1} with mean value of 8631 m^2day^{-1}. The mean hydraulic conductivity (K) has been found as 94 m day^{-1} corresponding to that of coarse sand and coarse sand mixed with gravel.

The discharge of tube well tapping 2^{nd} principal aquifer varies from123m^3/hrto224m^3/hr for a maximum drawdown of 4 m (fig 5.2e).

Pumping test result of recently constructed well tapping second aquifer at Naubatpur, Moriyama and Simri indicate the transmissivity value of second aquifer as 9047 m^2/day, 10135 m^2/day and 6323 m^2/day respectively. The storage coefficient has been determinedat Naubatpur and Moriyama as 1.48 x 10^{-5} and 4.98x 10^{-4} respectively indicating the aquifer to be under confined condition.

Table 5.2 (a) Summarized salient characteristics of bore wells drilled by state government department in the area

Name of the Block	Depth of TW	Discharge (m^3)	DD (m)
Bihta	88.39 – 102.11	179 – 222	1.52 – 8
Maner	106.66 – 109.72	208	1.80 – 3.5
Naubatpur	88.39 – 103.63	208	1.52 – 3.65

The aquifer wise hydraulic conductivity map was prepared based on pumping test data of wells constructed by CGWB and are shown in fig 3.10 (a & b). Figure 3.10(c) depicts the variation in the storativity values of the aquifer.

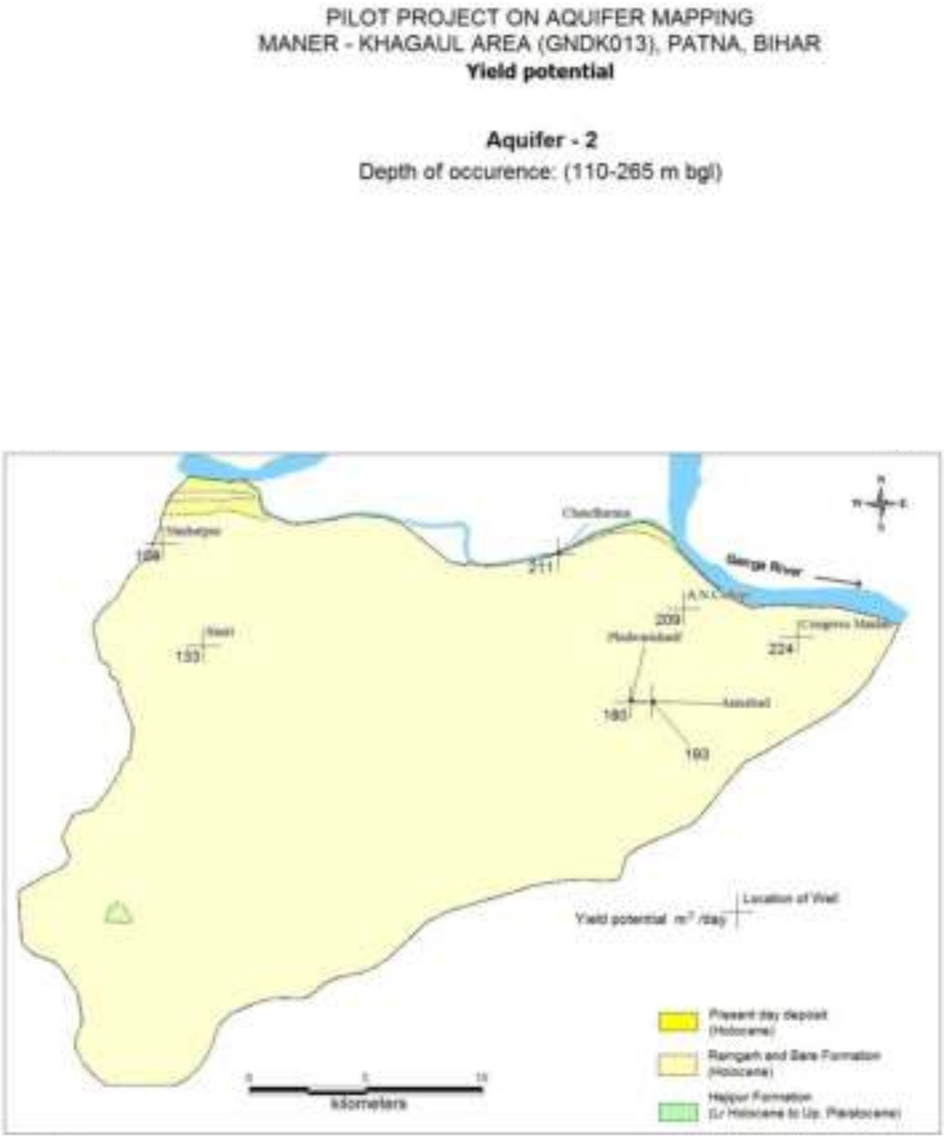


Fig. 5.2e: Yield potential map of aquifer-2

CHAPTER-6

AQUIFER RESPONSE MODEL AND AQUIFER MANAGEMENT PLAN

6.1 Aquifer Response Model

6.1.1 Introduction

Groundwater models are mathematical and digital tools of analyzing and predicting the behaviour of aquifer systems on local and regional scale, under varying geological environments (Balasubramanian, 2001). Models can be used in an interpretative sense to gain insight into the controlling parameters in a site-specific setting or a framework for assembling and organizing field data and formulations of ideas about system dynamics. Models are used to help in establishing locations and characteristics of aquifer boundaries and assess the quantity of water within the system and the amount of recharge to the aquifer (Anderson and Woessner, 2002).

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. Modelling plays an extremely important role in the management of hydrologic and groundwater systems (www.angelfire.com/cpkumar).

Mathematical models provide a quantitative framework for analysing 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 (Mc Donald 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,

K_{xx}, K_{yy}, K_{zz} 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.

The finite-difference computer code Visual MODFLOW (Mc Donald and Harbaugh, 1988) numerically approximates this equation, and were used to simulate the groundwater flow in the study area.

6.1.2 Scope and objective

The purpose of the aquifer response model in the present case is to evaluate the effects of the present and projected ground water withdrawals on the prevailing groundwater level regime in the alluvial aquifer underneath the pilot aquifer mapping area of Bihar state. This report describes the model design, calibration procedures, and results of simulations using the calibrated model on groundwater levels caused by projected groundwater withdrawals. Hypothetical pumpage for 11 years into the future (through 2025) has been computed considering an annual incremental increase @ 2% and the consequent effects on groundwater levels caused by the projected pumping were simulated. In addition, effects of some other possible scenarios like

i. The effects of increasing cropping intensity (CI) from the present 126% to 200%,
ii. Increasing groundwater based irrigation efficiency by 15%,
iii. Reducing groundwater draft in Patna urban area by 50MCM/yr,
iv. Allocating 20 MCM/yr for industrial water requirement ,
v. Possible impacts of draught (-20% deviation from normal rainfall) on the aquifer regime have also been simulated.

6.1.3 Ground water flow pattern

Groundwater flow direction in the study area from south-west to north-east direction.

6.1.4 Range of conductivity/transmissivity and storage parameters

The exploratory wells drilled by CGWB in the area is given in table 2.8a and b. Perusal of these data reveal significant potentiality of the aquifer of the area as the transmissivity ranges between 4907and 15984 m^2/day with mean value of 8302 m^2/day. The specific capacity of the wells ranges from 56 to 100.4 $m3hr^{-1}m^{-1}$ and the mean hydraulic conductivity (K) has been found as 86.9 m/day corresponding to that of coarse sand and coarse sand mixed with gravel. At two locations, A.N.College and Alamganj the storage coefficient has been found to be 7.7 $x10^{-2}$ and $5.0x10^{-3}$ respectively.

6.1.5 2D / 3D Presentation of Aquifer

2D presentation of the aquifer are given below

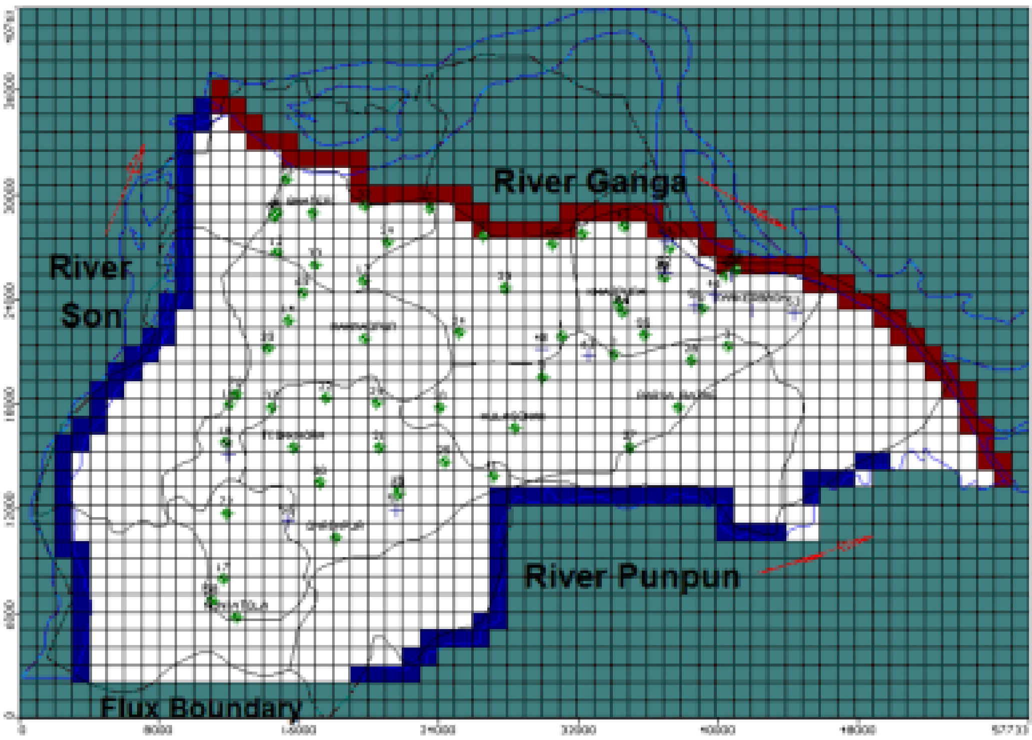


Fig.6.1a: The conceptual model. Green, white, blue and red cells are inactive, active, River boundary, CHB cells respectively.

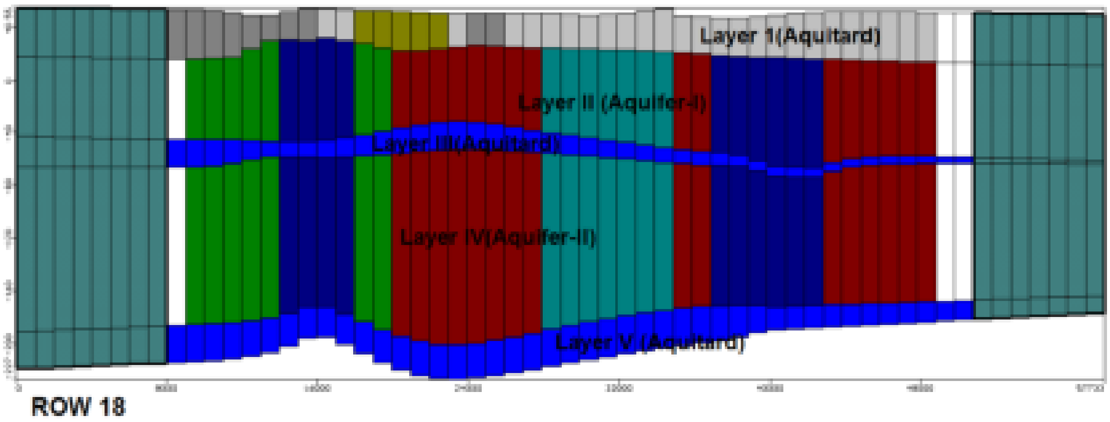


Fig.6.1b: Hydrogeological cross section along row 18 showing five layers system.

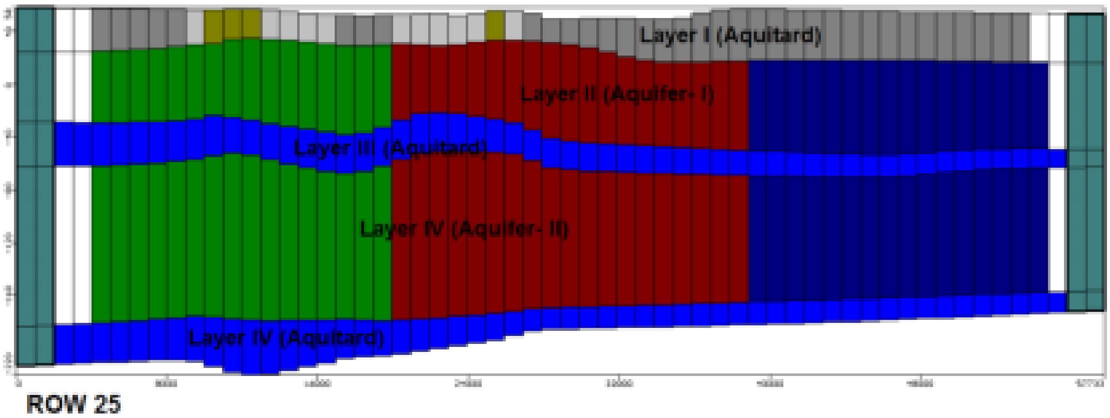


Fig.6.1c: Hydrogeological cross section along row 25 showing five layers system.

3D presentation of the aquifer are given below

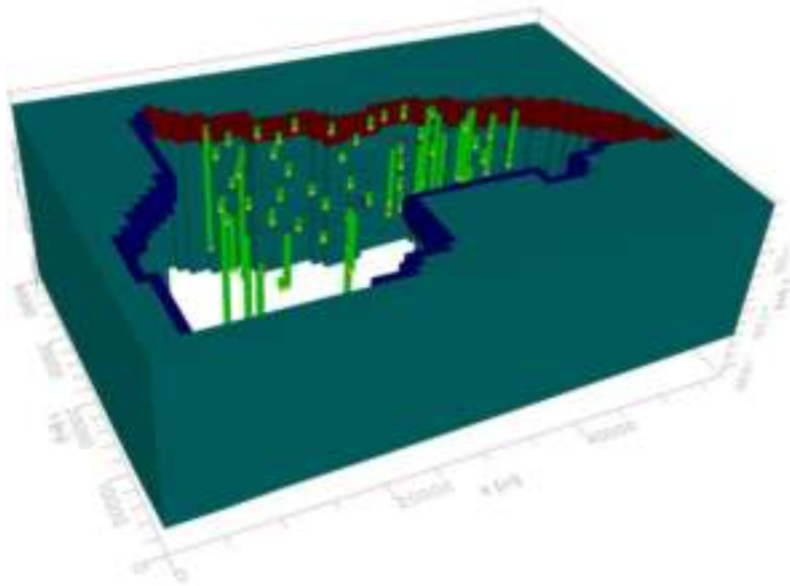


Fig. 6.1d: 3D view of model area with observation well and boundary condition.

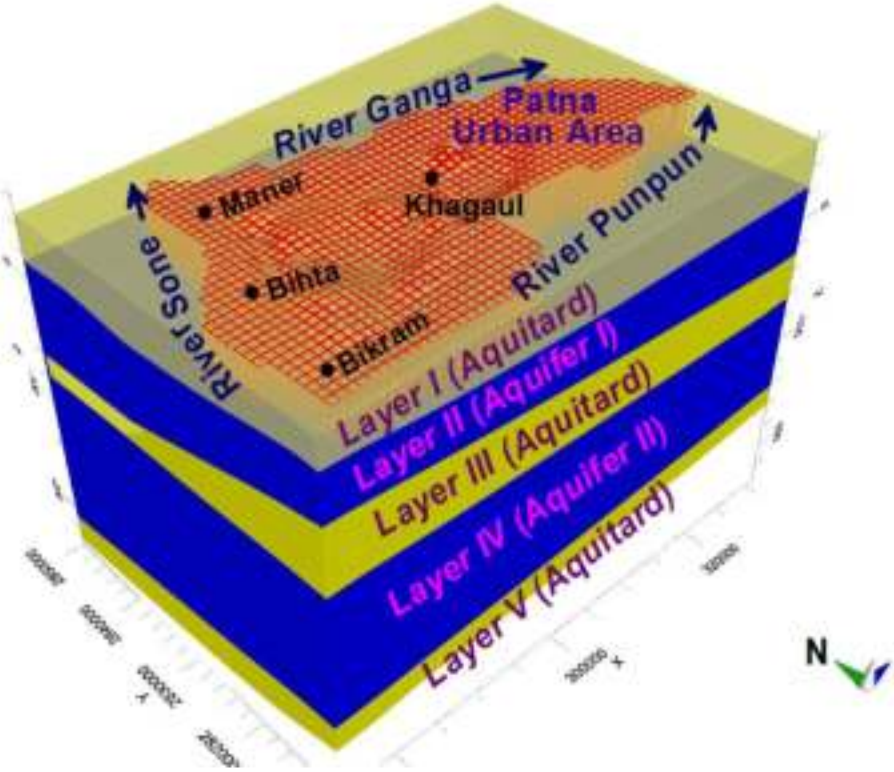


Fig.6.1e: 3D view of model area with layers and boundary condition

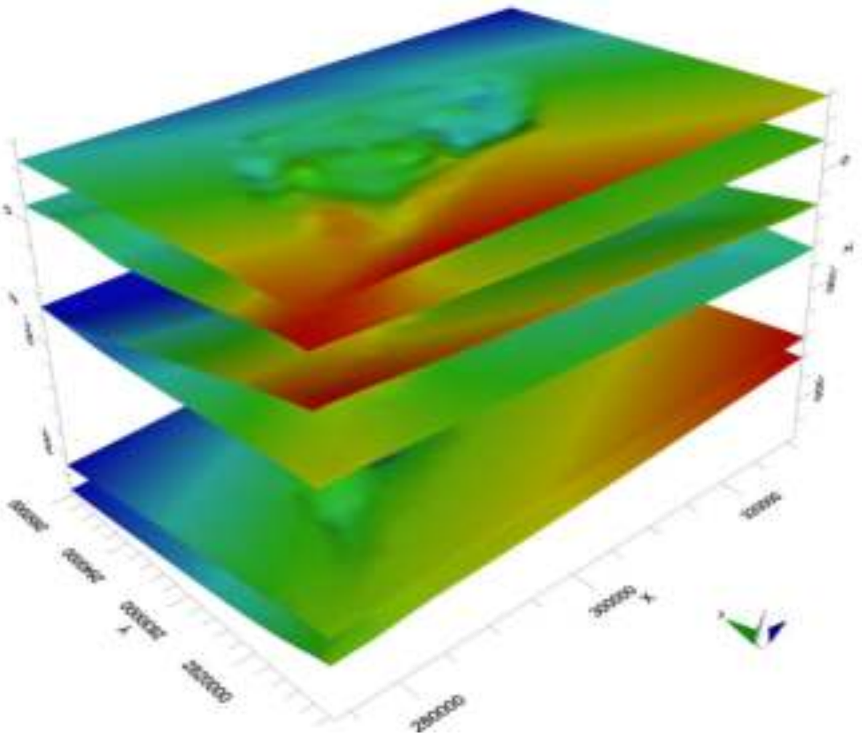


Fig.6.1f: 3D view of model area with horizon type

6.1.6 Numerical model design

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 (Anderson and Woessner, 2002).

6.1.6a Methodology

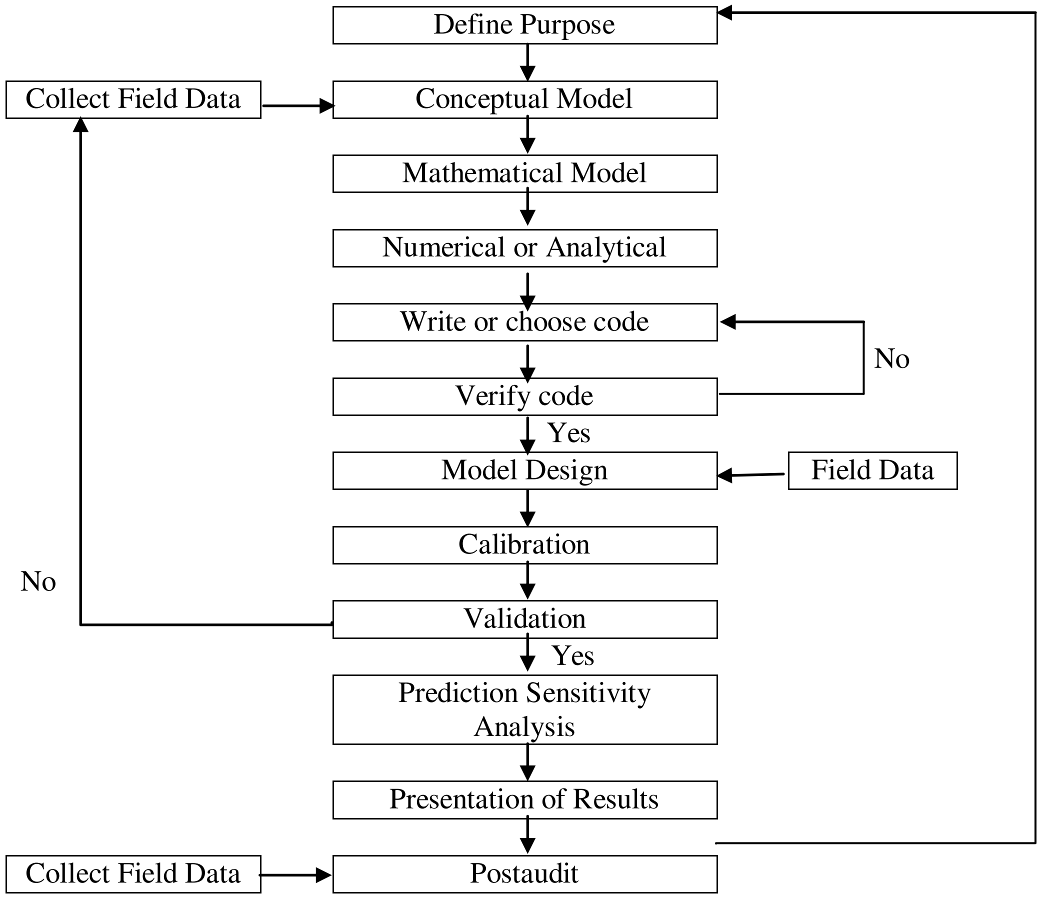


Fig: 6.1g: Flow chart of Aquifer Modelling

6.1.6b Visual MODFLOW

MODFLOW is a versatile code to simulate ground water flow in multilayered porous aquifer. The model simulates flow in three dimensions using a block centred finite difference approach. The ground water 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.

6.1.6c Conceptual Model

Based on the available information as discussed above, a conceptual ground water model has been framed. 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. Simplication is necessary because a complete reconstruction of the field system is not feasible (Anderson and Woessner, 2002). 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 ground water flow model such as a numerical model. Further, it also helps 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).

6.1.6d Grid Design

The area has been divided into 58 columns and 40 rows with a uniform grid size of 1000mX 1000m has been grouped into 5 layers containing 2 main aquifers (Layer 2 and Layer 4 (Aquifer 1 and Aquifer 2). The bottom of layer 5 has been considered as the base of modelling depth. 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 6.1h.

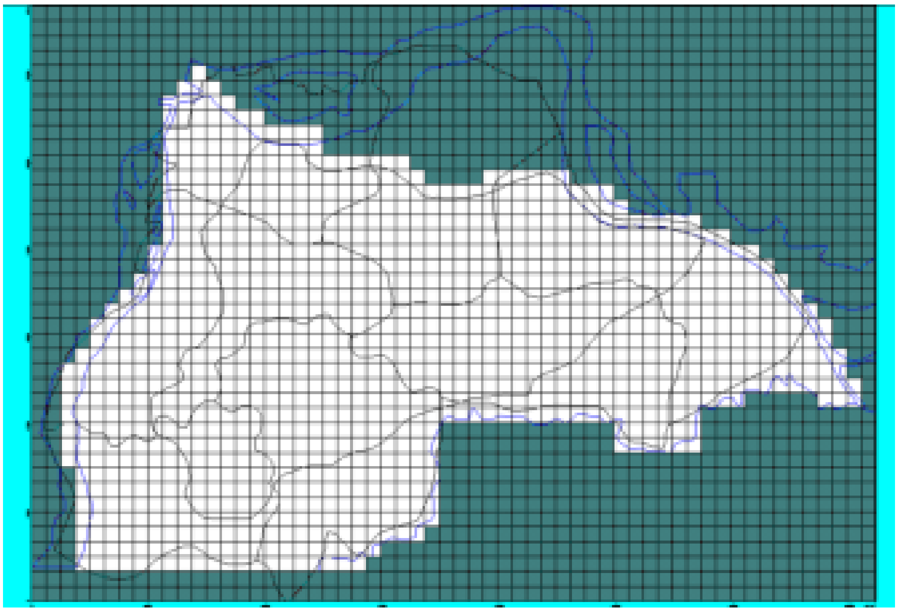


Fig. 6.1h: Model grids with active (white) and inactive (green) cells

The ground elevation data available for 72 stations within the study area have been assigned and these were interpolated for other locations through natural neighborhood technique. In similar manner the elevation for other layers were also assigned for known locations and were interpolated.

6.1.6e Assumptions used in the conceptual model

Some of the major simplifying assumptions in the present modelling study include

1. All pumpage in a model cell has been simulated as coming from the cell center;
2. The pumpage throughout a stress period is applied equally throughout the stress period;

3. Recharge is invariant over large periods of time;
4. Small scale variations of hydraulic conductivity within cells are negligible.

6.1.7 Aquifer geometry and boundary conditions

6.1.7a Aquifer geometry

Geologic information including geologic maps, cross sections and well logs are combined with information on hydrogeologic properties to define hydrostratigraphic units for the conceptual model (Anderson and Woessner, 2002). The Lithological data, VES data, TEM, ERT 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. 6.1b & c).

6.1.7b Boundary conditions

Boundary conditions are defined along the edges of the simulation domain including the top and the bottom. Their main function is to separate the model region from the rest of the world and are required for solution of the ground water flow equation. 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. It can be thus concluded that for obtaining a unique solution it is necessary to know either the head or normal flows all along the boundary. In general there are two commonly used boundary conditions: (a) specified hydraulic head boundaries and (b) specified flow boundaries. 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.

For layer 1, the physical boundary is formed by River Ganga towards the north and north-east. Towards west along the cost of River Son and towards south along the course of River Punpun, River boundary has been assigned. The model boundaries are depicted in Fig 6.1 i.

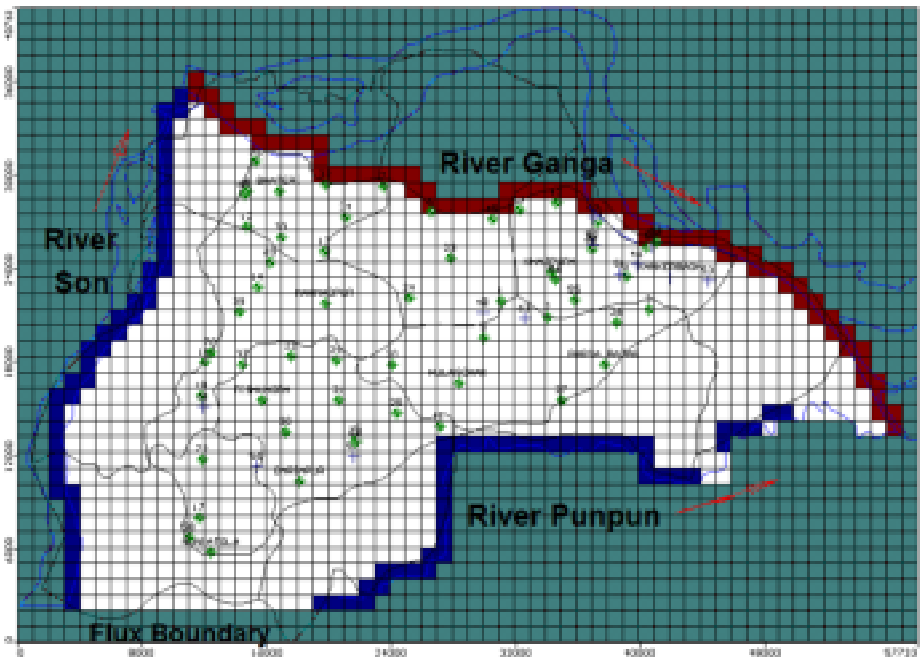


Fig. 6.1(i): Model boundaries: the southern (PunpunR.) and the western (Sone R.) boundary are the River boundaries respectively. NW-SE flow of the river Ganga (maroon cells) forms the northern and the eastern boundary.

6.1.7b (i) River boundary condition

The western and southern boundary has been assigned as River Boundary along the present course of River Son and Punpun. The present course of river Punpun is believed to be occupying the eastern most abandoned channel of the River Sone. The Punpun and the Sone Rivers are presumed to have a good hydraulic connection with the aquifer as these are adequately incised into the aquifer and have sandy river banks. Also the groundwater level in the aquifer adjacent to the river in general corresponds to the river stage.

The river boundary condition is used to simulate the influence of a surface water body on the groundwater flow. The required data for assigning this boundary condition includes data pertaining to the river stage, river bed bottom (i.e the elevation of the bottom of the seepage layer of the surface water body), and thickness of the riverbed and river width. The flow of water through riverbeds is dependent on the transmissive properties of the riverbed and the difference between the head in the aquifer and the river stage. The data obtained from the river gauging station of Central Water Commission (CWC), Govt.of India for River Son at Koelwar and Maner and River Punpun at Sripalpur pertaining to the period under calibration and validation, river stage has been assigned. For the period under the projected scenario, the decadal mean monthly stage of River Sone and Punpun has been assigned.

6.1.7b (ii) Constant head boundary

The northern and the north-eastern boundary along the course of the River Ganga have been assigned as Constant Head Boundary. River Ganga within this segment is effluent in nature. The data obtained from the river gauging station of Central Water Commission (CWC), Govt.of India at Dighaghat and Gandhighat pertaining to the period under calibration and validation, river stage has been assigned. For the period under the projected scenario, the mean monthly stage of River Ganga for the pre-monsoon and post-monsoon period has been assigned.

For layer 2 and 4, the northern boundary has been taken as no-flow boundary and flux has been assigned along the southern and south-western part. The flux to the layers has been estimated using the *TIL* equation for different segments in layer 2 (aquifer 1) and Layer 4 (aquifer 2). The estimated flux has been assigned by adding recharge wells along the boundary.

6.1.7c Distribution of conductivity values

The hydraulic conductivity data obtained from pumping test were utilized in the preparation of model. Vertical hydraulic conductivity has been taken as 10% of the horizontal hydraulic conductivity.

The hydraulic conductivity of first layer has been estimated through grain size analysis. The range of hydraulic conductivity for this layer varies from 5 m/day to 25 m/day. The value of the K for this layer as obtained through grain size analysis has been contoured for the entire layer. For layer 2 which constitutes the first principal aquifer, the hydraulic conductivity distribution map has been prepared based on the available pumping test results. For this layer it varies from 80 to 115 m/day. For layer 3 which separates the aquifer 1 (layer 2) and aquifer 2 (layer 4) and layer 5, K has been taken as 0.087 m/day (Bear 1972). Hydraulic conductivity map for Layer 1 and 2 is given in Fig 6.1j &k.

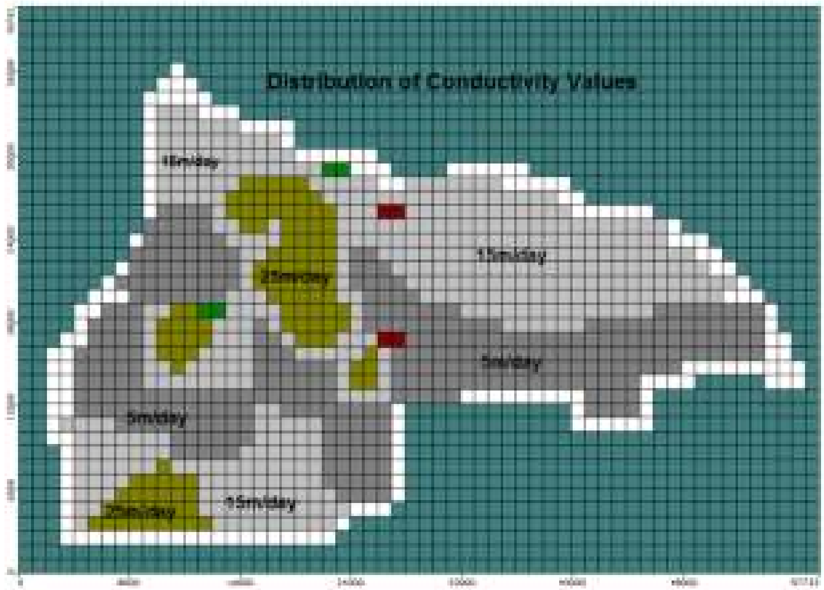


Fig. 6.1(j): Zone wise distribution of hydraulic conductivity in the study area (for Layer I)

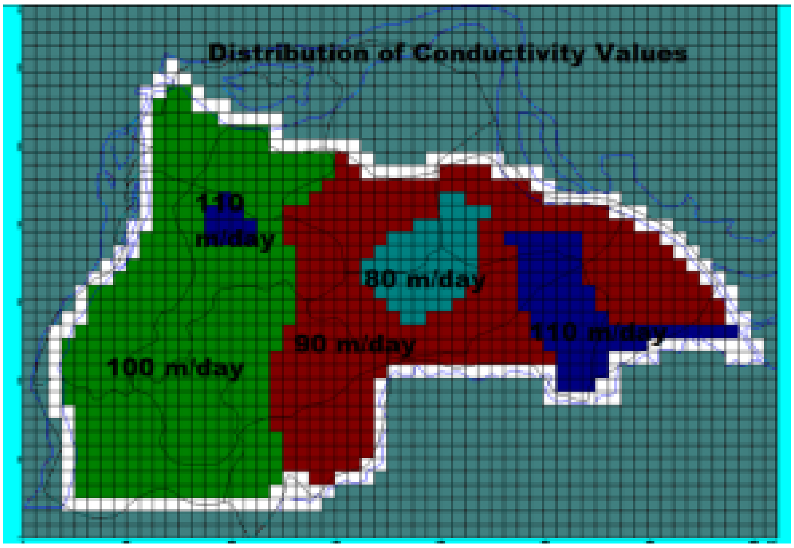


Fig. 6.1 (k): Zone wise distribution of hydraulic conductivity in the study area (for Aquifer I)

6.1.7d 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 limited in the study area, an attempt has been made to estimate the specific storage based on the lithology (Younger 1993). The specific storage of the aquifer 1 and 2 has been worked out using the relationship Ss = ρwg (α + θβ) where ρw = density of water, g = acceleration due to gravity, α = compressibility of aquifer skeleton, θ = porosity of aquifer material and β = compressibility of water (Fig. 6.1l). Where the predominant lithology is of fine to medium sand, the Ss has been considered as 9.82 x 10^{-2} while for the predominant lithology of medium to coarse sand and fine gravels, Ss has beem considered as 1.05 x 10^{-5} (Younger 1993). The specific storage has been found varying over 3 orders of magnitude in the study domain between 10^{-4} and 10^{-7}.

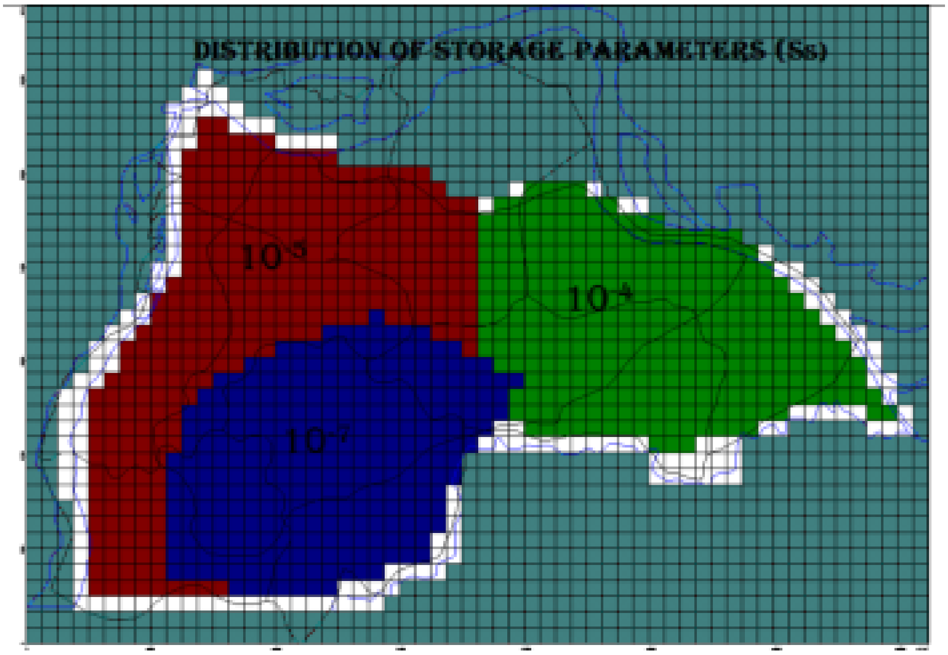


Fig. 6.1(l): Zone wise distribution of specific storage in the study area (for Aquifer I)

6.1.7e Recharge

This package is used to simulate surficially distributed recharge to the groundwater system. Annual precipitation within the study area averages about 1051 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, surficial geologic units are likely to represent a reasonable initial distribution of recharge. Three recharge zones have been demarcated considering the nature of the surficial material. At the extreme southern and the western domain of the model monthly recharge considering rainfall infiltration factor of 20% has been assigned. For the central part of the model, monthly recharge considering rainfall infiltration of 10% and for the core urban areas the recharge rate has been considered as 2% of rainfall as these are the most urbanised part with less of open space and the nature of the surficial material here is also more clayey.

6.1.7f 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 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 besides insights gained from sample draft survey draft survey made during the present study have been used to arrive at the pumping estimate for a grid area of 1 sq km from the different aquifers which have been assigned in the model. The abstraction assigned in different blocks falling in the study area has been summarized in Table 3.11c

6.1.8 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.

6.1.8.1 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 data of river Son and Punpun for pre-monsoon 2008 was considered. In present study steady state model was calibrated for the hydraulic conductivity values to achieve the observed heads.

The calibration was made using 19 observation wells monitored during June 2008.

Figure-6.1n show observed and computed heads of June 2008. The computed groundwater level of June 2008 (steady state) indicate prevailing trend of groundwater flow in the interfluves region.

The computed groundwater 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 -0.981 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 1.843 m (Figure-6.1 n). The absolute residual mean is 1.509 m.

The absolute residual mean $|\overline{R}|$ is similar to the residual mean except that it is a measure of the average absolute residual value defined by the equation:

$$|\overline{R}| = \frac{1}{n}\sum_{i=1}^{n}|R_i|$$

The absolute residual mean measures the average magnitude of the residuals, and therefore provides a better indication of calibration than the residual mean (Waterloo Hydrogeologic Inc, 2005).

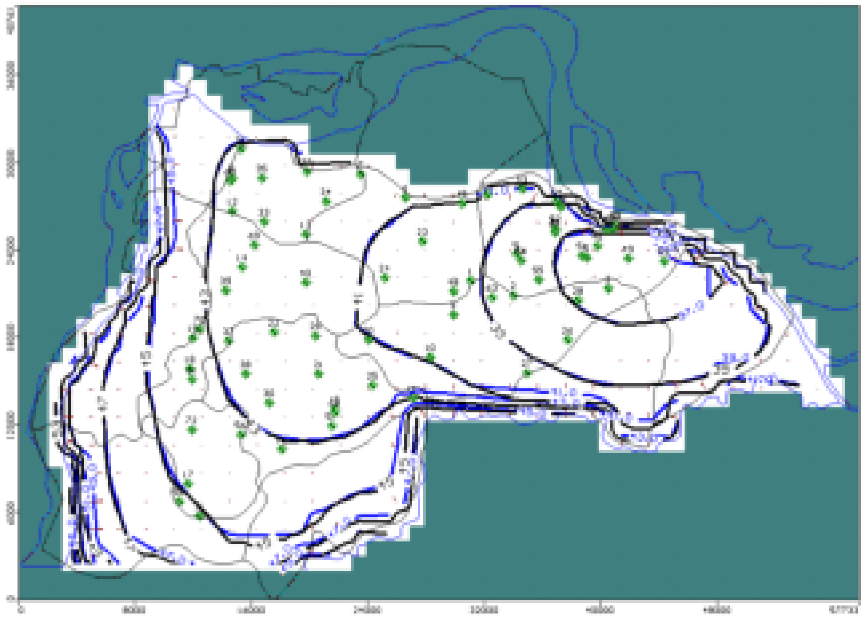


Fig. 6.1(m): Computed heads (black colour) and water table elevation (blue colour) of layer 1 for June 2008.

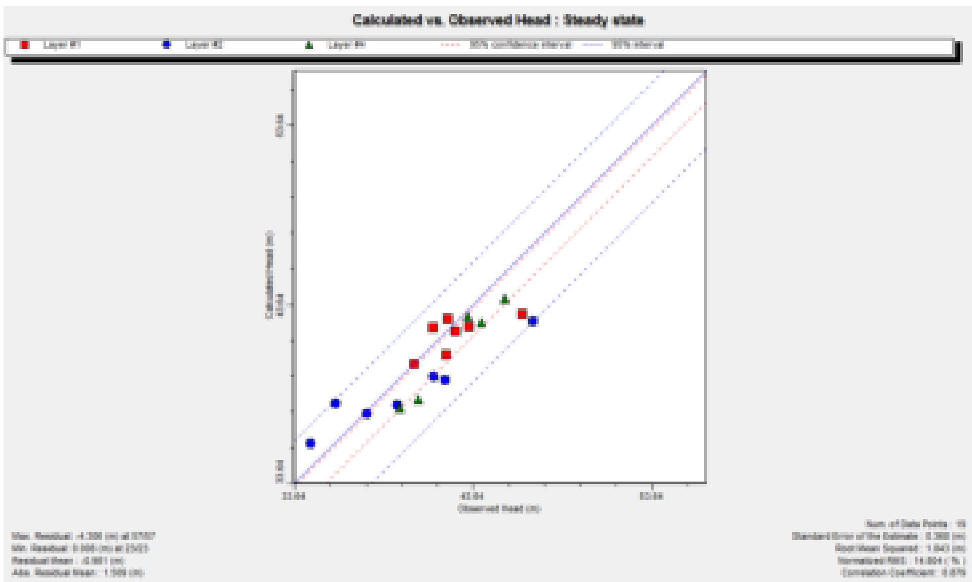


Fig. 6.1 (n): Calculated versus observed heads (June 2008)

6.1.8.2 Transient state

In transient state, head change with time. Transient states are also called time dependent, unsteady, non-equilibrium, or non-steady state problem.

6.1.8.2a Storage values- transient state

The specific storage of the shallow and the deeper aquifer has been worked out from the estimated storativity values obtained for the wells tested in the study area. Further, to augment the data, estimation of Ss was also made using the relationship Ss = ρwg (α + θβ) where ρw = density of water, g = acceleration due to gravity, α = compressibility of aquifer skeleton, θ = porosity of aquifer material and β = compressibility of water. Where the predominant lithology is of fine-medium sand, the Ss has been considered as 9.82×10^{-2} while for the predominant lithology of medium to coarse sand and fine gravels, Ss has beem considered as 1.05×10^{-5} (Younger 1993).

6.1.8.2b Discharge inputs

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 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 besides insights gained from sample draft survey draft survey made during the present study have been used to arrive at the pumping estimate for a grid area of 1 sq km from the different aquifers which have been assigned in the model. The abstraction assigned in different blocks falling in the study area is summarized in Table 3.11c

Evapotranspiration of 1100 mm/yr with extinction depth of 2 m has also been considered. The extinction depth has been considered as 2 m only as the area is mainly a paddy growing region.

6.1.8.2c Recharge inputs

Recharge has been assigned to the first layer as a percentage of rainfall. Based on the hydrogeological characteristics of the layer I, three zones of 20%, 10% and 2% recharge rates has been demarcated and assigned. Low values of 2% recharge has been assigned in the densely urbanized portion of the area and in areas with layer I as predominantly clayey in nature for thickness >10 m.

6.1.8.2d Constant head/variable head

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

6.1.8.2e Transient state calibration

The model was calibrated to transient state from June 2008 to May 2012 and validated for the period under transient state from June 2012 to April 2014.

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 groundwater levels matched fairly reasonably to observed values. The RMS error for the transient state model for layer 2 & 4 at 1614 days (June 2012) is 2.3 m& 2.5m (Figure-6.10 i & ii). The observed pre- and post-monsoon groundwater level for selected observation wells for the period 2008 to 2014 was used for the transient state calibration.

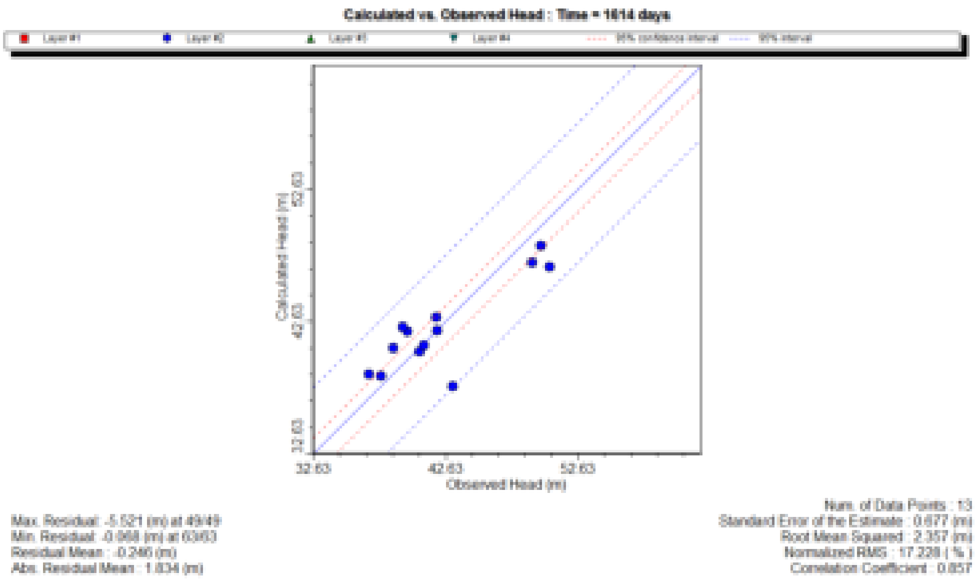


Fig. 6.1o (i): Calculated v/s observed head of aquifer I (for May 2012)

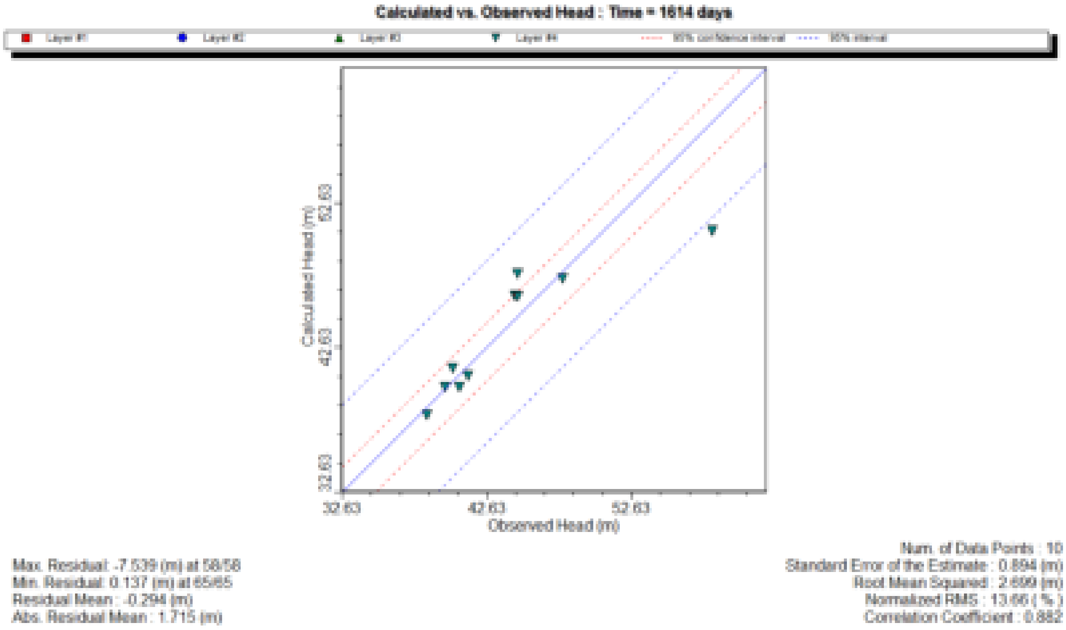


Fig. 6.1o (ii): Calculated v/s observed head of aquifer II (for May 2012)

6.1.9 Sensitivity analysis

Sensitivity analysis is the process to test the effect on the model if one parameter is slightly changed keeping other parameters unchanged (Bihery, 2008). During a sensitivity analysis, calibrated values for hydraulic conductivity, storage parameters, recharge and boundary conditions are systematically changed within the permissible range. The magnitude of change in heads from the calibrated solution is a measure of the sensitivity of the solution to the particular parameters. Sensitivity analysis is typically performed by changing one parameter value at a time (Anderson and Woessner, 2002).

A sensitivity analysis is the process of varying model input parameters over a reasonable range (range of uncertainty in values of model parameters) and observing the relative change in model response. In fact calibration and sensitivity analysis go in tandem. The purpose of the sensitivity analysis is to demonstrate the sensitivity of the model simulations to uncertainty in values of model input data. The sensitivity of one model parameter relative to other parameters is also demonstrated. Sensitivity analyses are also beneficial in determining the direction of future data collection activities. Data for which the model is relatively sensitive would require future characterization, as opposed to data for which the model is relatively insensitive. Model-insensitive data would not require further field characterization.

In the present study the model has been found sensitive to the river stage data of the Punpun and the Sone, values of hydraulic conductivity, specific storage and recharge.

6.1.10 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". The most common history matching scenario consists of reproducing an observed change in the hydraulic head over a different time period, typically one that follows the calibration time period. The best scenarios for model verification are ones that use the calibrated model to simulate the aquifer under stressed conditions. The process of model verification may result in the need for further calibration refinement of the model. After the model has successfully reproduced measured changes in field conditions for both the calibration and history matching time periods, it is ready for predictive simulations.

If validation is done for transient data set with changing boundary conditions and associated stresses and the model is found to produce head distribution that closely matches the observed data set the model is said to be verified. However, if at this stage there is a need to modify any calibrated model parameter, the verification is not complete. Rather, it is another calibration and thus requires a new independent data set for verification. Transient verification offers a better insight into the aquifer responses to time-varying stresses.

To evaluate the validity of the updated flow model, the altitude of groundwater levels simulated by the updated flow model were compared to observed water-level altitudes. The altitude of groundwater level observations for the period of 2012-2014 has been used for validating the model. The scatter plot showing the statistics for 2097 days (April 2014) for aquifer I & II is produced in Fig 10.15a & b. The calibration scatter plot of the validation period at 2097 days (April 2014) exhibits the root mean squared (r.m.s.) of the residuals for aquifer I & II as 2.1m & 2.5m respectively indicating a reasonably good fit of the observed and simulated levels with majority of the data lying close to the 1:1 line. The hydrograph of selected stations for the period under transient calibration & validation are given in Fig. 6.1q i to iv.

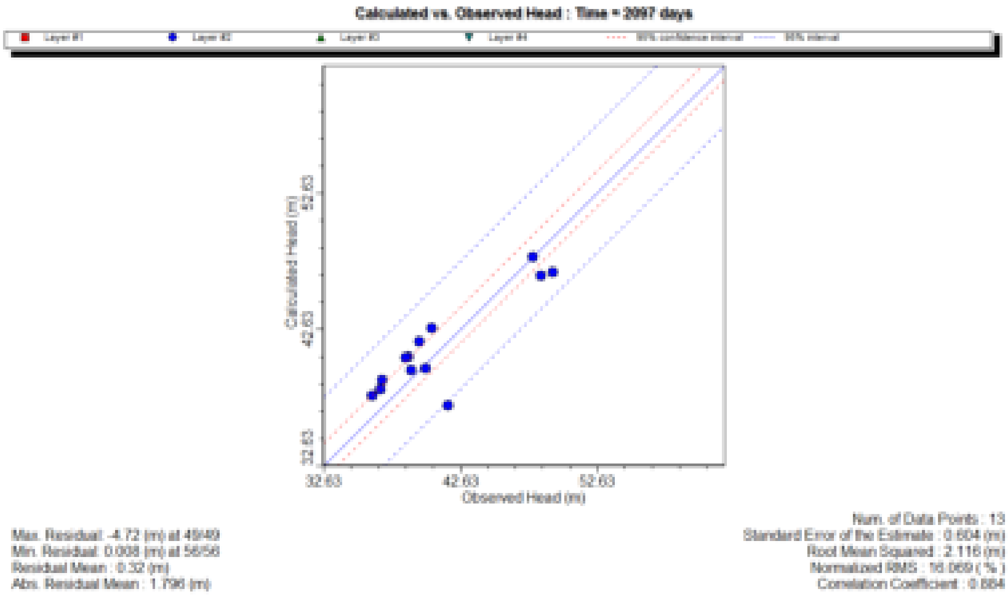


Fig. 6.1p (i): Calculated Vs observed head of aquifer I (for April 2014)

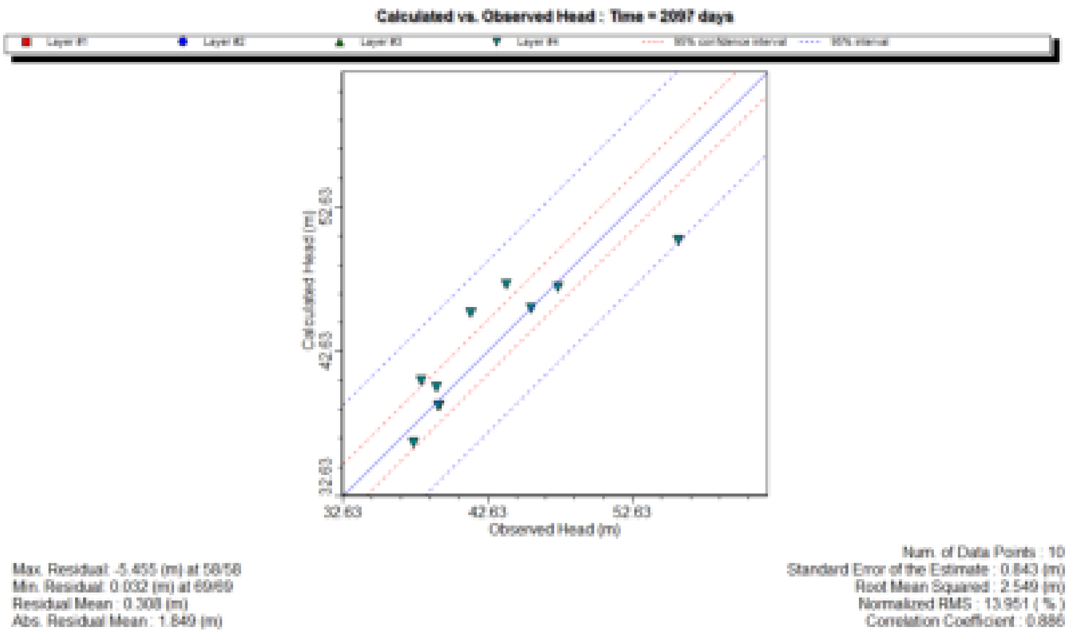


Fig. 6.1p (ii): Calculated Vs observed head of aquifer II (for April 2014)

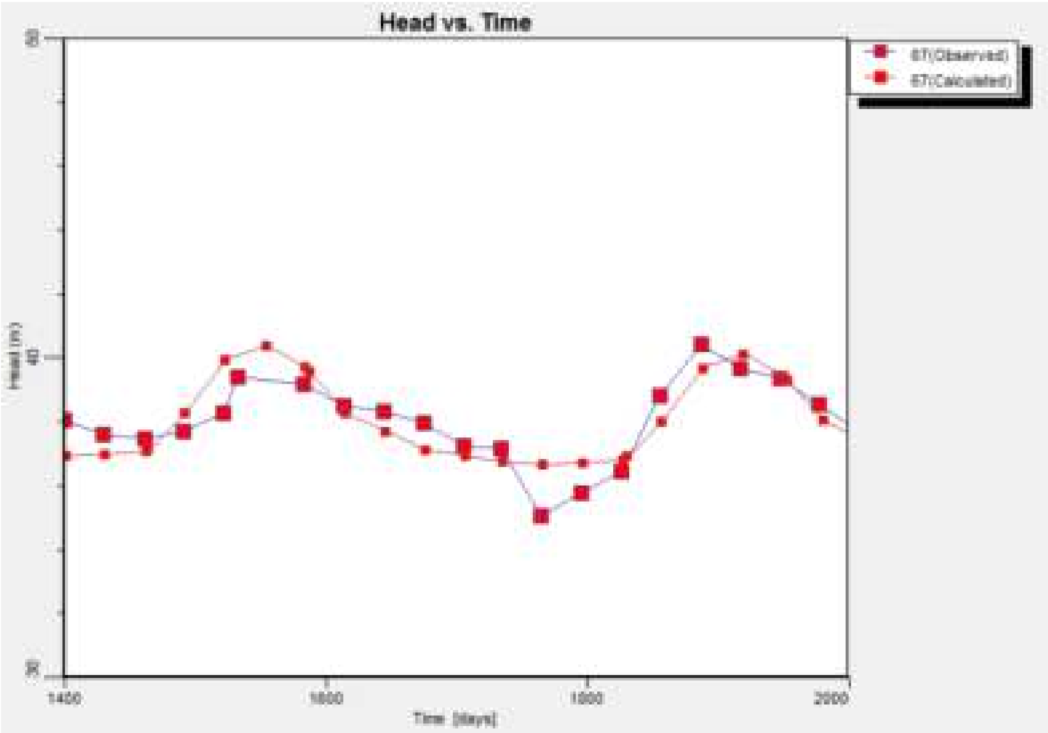


Fig.6.1q (i): Hydrograph of well no. 67.

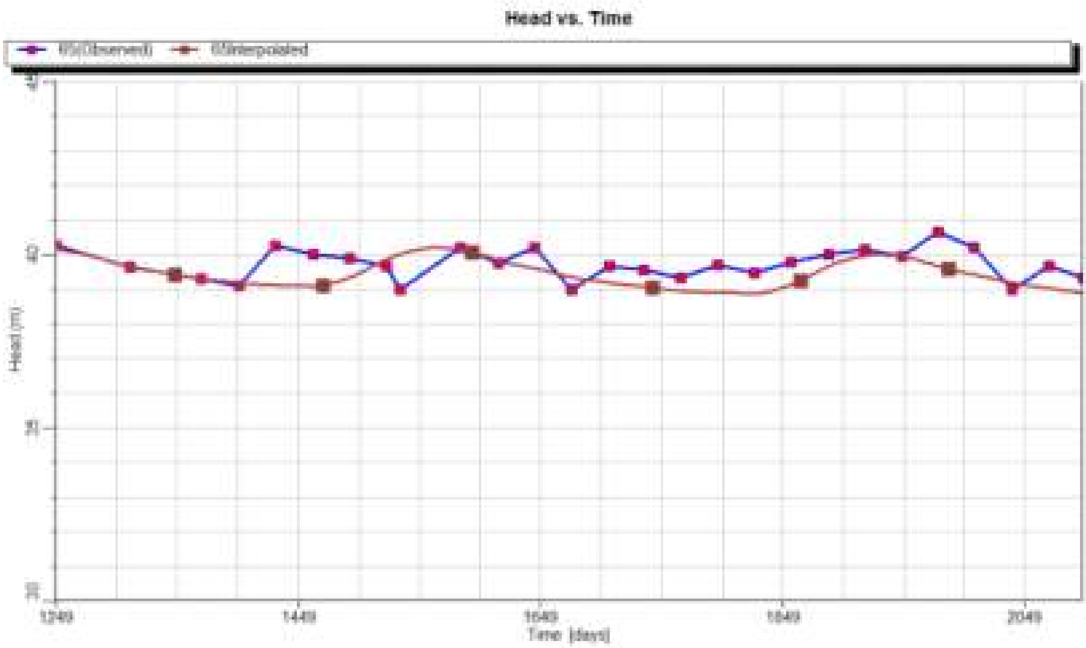


Fig. 6.1q (ii): Hydrograph of well no. 65.

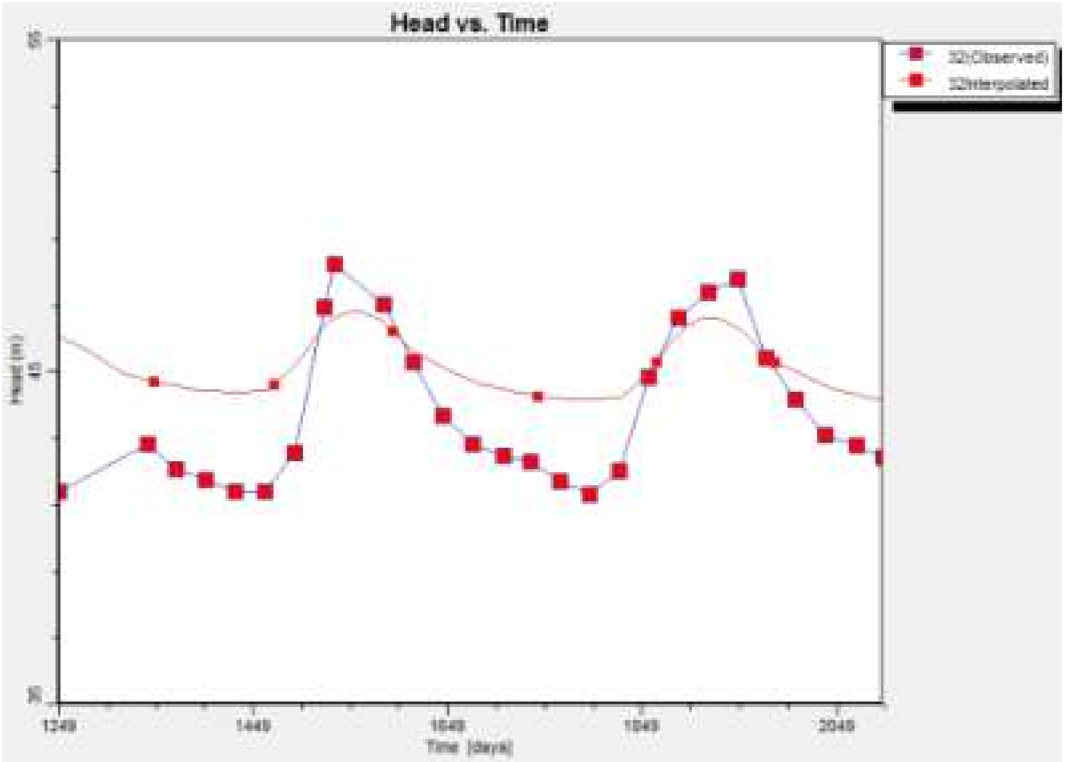


Fig. 6.1q (iii): Hydrograph of well no. 32.

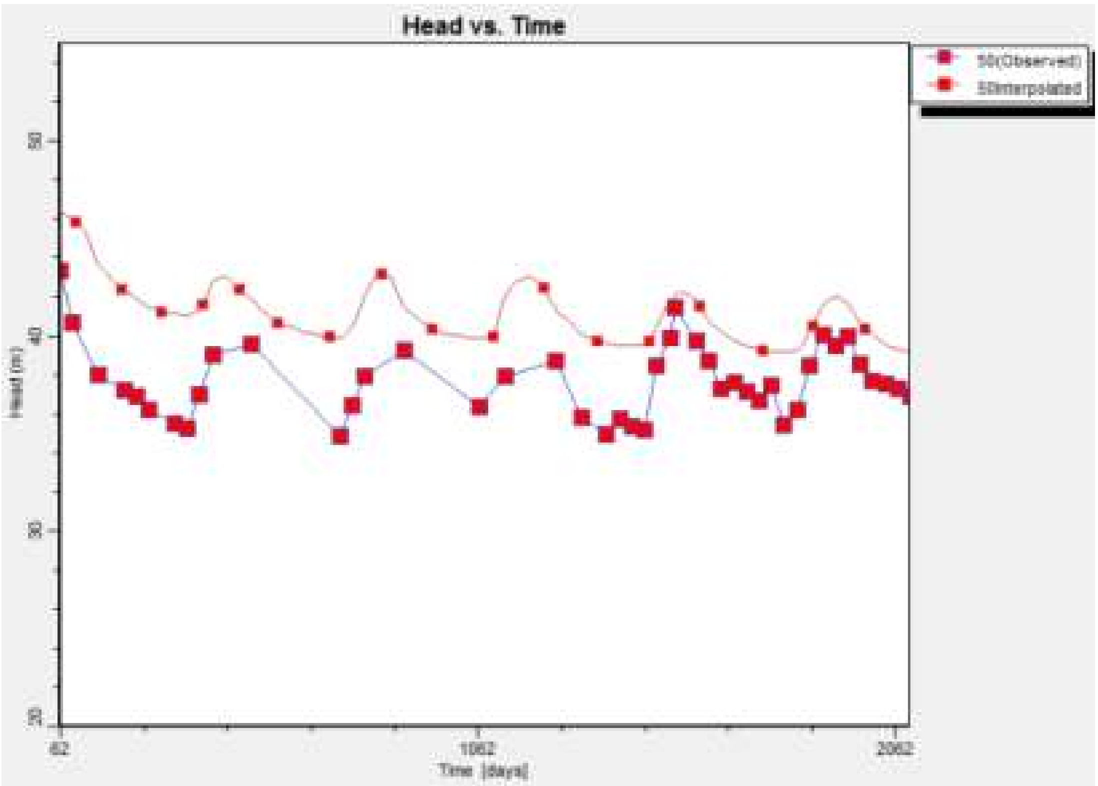


Fig. 6.1q (iv): Hydrograph of well no. 50.

6.2 Aquifer management plan formulation

6.2.1 Introduction

The study area has a mixed land use pattern. While 20 % is densely urbanized and is under residential land use, major part of the remaining 80 % is under agricultural land use. Further, owing to rapid growth witnessed in Patna urban area during the preceding two decades, the city is expanding at a faster rate and is causing change in the land use pattern.

Under the prevailing condition, both in the urban as well as the rural hinterland, the demand for water supply will witness a surge in the days to come. During the past few years there has been an increase in industrial water demand too as owing to groundwater availability in the area and its proximity to the capital city of Patna, water intensive industries like breweries, distilleries and packaged drinking water plants have started coming up.

Considering the above mentioned facts, the calibrated model has been used to assess the impact of future groundwater withdrawal on the groundwater system to examine the projected groundwater withdrawals from the view point of sustainability and the need for possible management interventions.

The following five different scenarios in consonance with the various decisions under consideration by the State Government and few hypothetical scenarios have been simulated. The simulated scenarios are

Scenario1: Increase in cropping intensity (CI) from the present 126% to 200%. This is as per the envisaged road map for agriculture development in the State of Bihar under consideration. The increase in CI has been made @19% /year from 2014 to 2018.

Scenario 2: Increase in groundwater based irrigation efficiency by 15%.

Scenario 3: Reduction in groundwater draft in Patna urban area by 50MCM/yr. This is as per the envisaged plan for reducing dependence on groundwater sources for water supply in Patna Urban area. The State Government is mulling for setting up of two treatment plants with capacity of 50 MCM with source water from Ganga River.

Scenario 4: Under this scenario an allocation of 20 MCM/yr has been made for the industries in the Bihta, Naubatpur and Bikram blocks of the study area located in the south-western part. This has been made considering the surge in the industrial water demand in these blocks in the past few years. This allocation would take care of the demand of 100 industrial units in the area having a demand of 500m^3/day.

Scenario 5: Under this scenario, the impact of draught (-20% deviation from normal rainfall) on the aquifer regime has been modeled. The scenario generated depicts the resilience of the groundwater system to the draught situations.

Scenario 6: In this scenario, the draft has been increased considering the growth in population. The irrigation draft has been increased @2% per year with respect to the prevalent draft during 2008. In this scenario, the normal increase in pumping has been simulated.

6.2.2 Predictive model results of strategies tested

In predictive simulation, the parameters determined during calibration and verification is used to predict the response of the system to future events (Anderson and Woessner, 2002). Faust et al. (1981) suggest that a predictive simulation should not be extended into the future more than twice the period for which calibration data are available. As such, in the present study, the scenarios have been simulated for 11 years into the future i.e upto the year 2025.

Different prediction scenarios were considered to predict the drawdown for the study area during the period of 2008 to 2025. These scenarios are explained below.

6.2.2.1 Scenario wise detailed discussion with relevant outputs

Scenario1: Increase in cropping intensity (CI) from the present 126% to 200%. The increase in CI has been made @19% /year from 2014 to 2018

For increasing the CI, groundwater draft has been increased by 14.6 MCM/yr during the monsoon and 31.65 MCM/yr during the non-monsoon season. The scenarios depict decline at the end of stress period 236 (6210 days) with respect to the in pre-development condition. Under this scenario, irrigation through groundwater would bring additional 7300 ha under cropping during monsoon season and 10,550 ha during non-monsoon season.

Brief description of the aquifer regime under the Scenario 1.

Groundwater regime description for 2008 (Cropping intensity 116%), 2014 (Existing cropping intensity 126%) and 2025 (200% cropping intensity)

2008: Groundwater flow direction is from SSW-NNE. In the northern part, bordering the Ganga, the flow lines turned towards ENE. The effluent nature of the Ganga is clearly seen for its entire length except (a) 6 km stretch near Golghar. The groundwater level varies from >60 m to <44 m above msl (Fig 6.2a). Two groundwater troughs are detected, each of small aerial extent, (i) western part of Patna urban area and (ii) northern part of Punpun River in the eastern half of the study area. The trough (<44 m above msl) together they cover approx. 40 km^2.

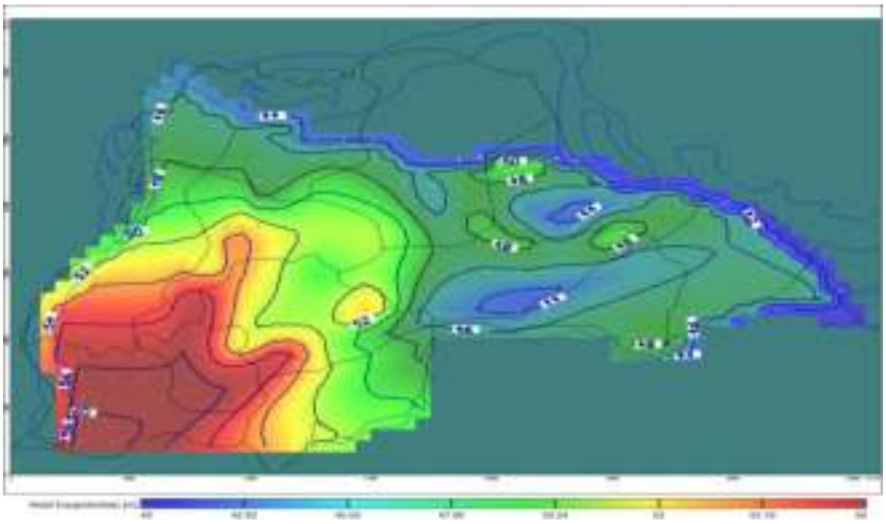


Fig 6.2 (a): Head distribution of Aquifer 1 (June 2008)

2014: Groundwater flow direction remains unchanged. The groundwater level varies from > 56 to < 40 above msl. The Ganga is effluent except for ~ 16 km in the northern part of Patna urban area.

The groundwater trough (<44 m above msl), has widen, covering the entire north eastern part of the study area which includes the Patna urban area, stretching to the northern segment of the central part along the Ganga. A deeper trough with groundwater level<40 above msl is developed in Patna urban area covering about 60 km^2 (Fig 6.2b).

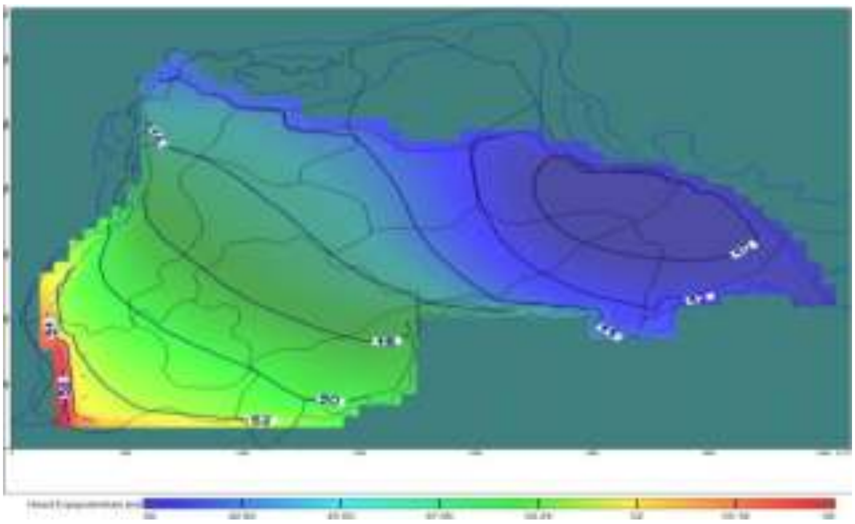


Fig 6.2 (b): Head distribution of aquifer 1 (June 2014)

2025: Groundwater flow regime has been changed considerably. The river Sone has become strongly influent. Significant flow is also entering from the southern part. Considerable length of the Ganga has also become influent contributing the aquifers. For about half of its length, the Ganga (eastern part of Danapur) has become influent for 26 km length.

The groundwater level varies from > 54 to <40 m above msl (Fig 6.2c). The trough of <44 m above msl expands considerably covering about 80% of the study area invading the south western part also. The < 40 above msl trough also expands considerably covering the entire Patna urban, semi-urban and adjoining rural areas (approx. 225 km^2). In this scenario there is no outflow of groundwater from the study area.

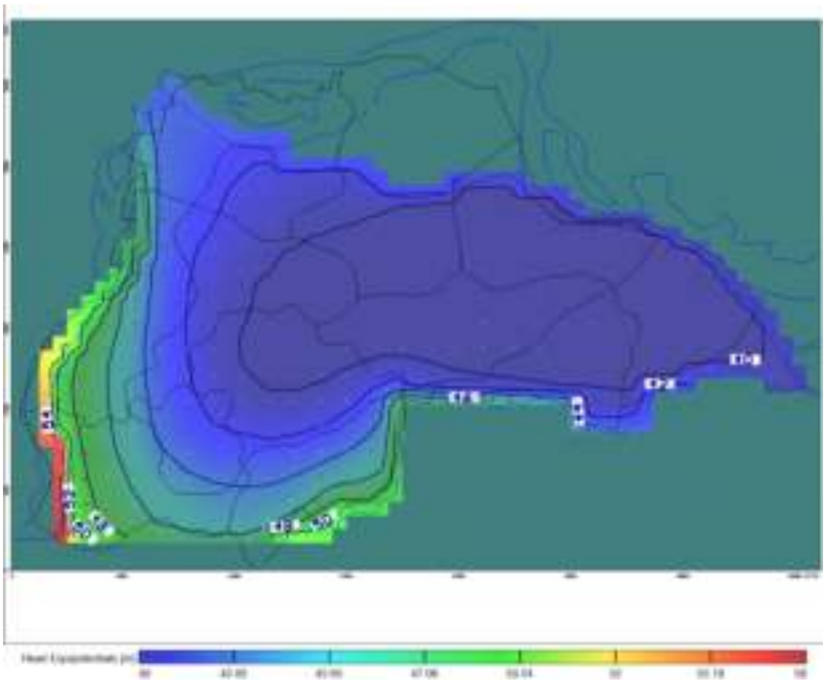


Fig 6.2 (c): Projected head distribution of aquifer 1 (June 2025)

Scenario 2: **Increase in ground water based irrigation efficiency by 15%.**

The scenario depict moderate improvement in ground water decline at the end of stress period 236 (6210 days) in both aquifer I and II as compared to Scenario 1 (Fig 6.2d).

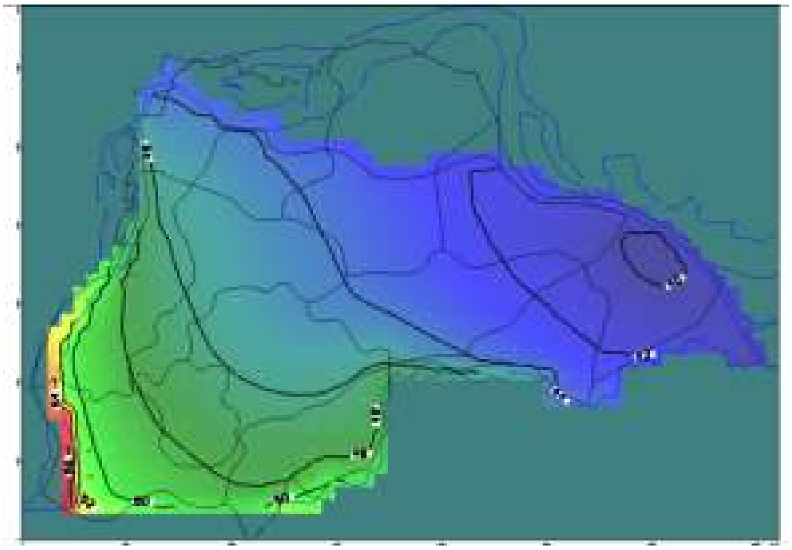


Fig 6.2 (d): Projected head distribution under scenario 2 of aquifer 1 (June 2025)

Scenario 3: Reduction in ground water draft in Patna urban area by 50MCM/yr.

Reduction in groundwater draft in Patna urban area by 50MCM/yr, as per the envisaged plan of PHED Government of Bihar, to supplement water supply in urban area from the Ganga River is considered as scenario 3. The draft has been decreased from layer 4 (aquifer II), as the groundwater draft for Patna Municipal area is presently being met from this aquifer. The modeled scenarios depict the improvement in head for both aquifer I and aquifer II (Fig. 6.2e)

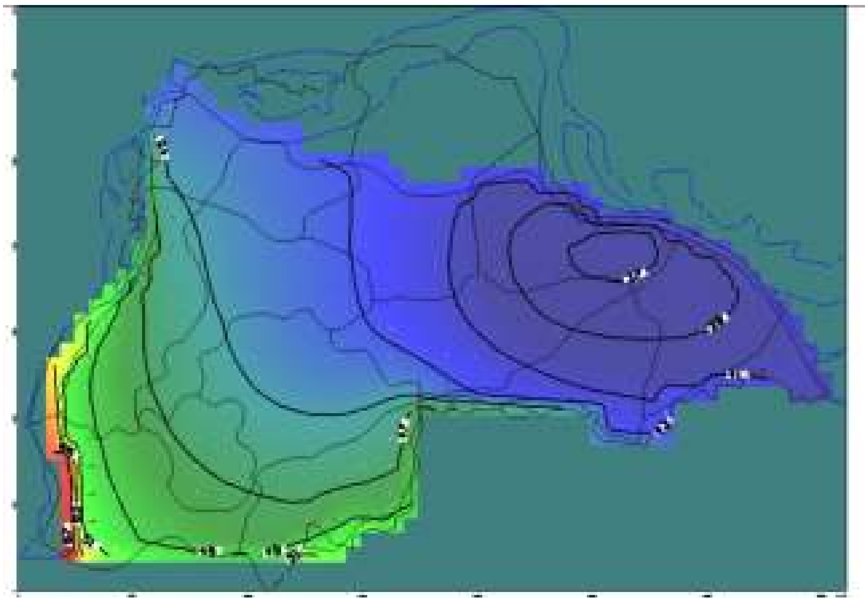


Fig 6.2 (e): Projected Head distribution under scenario 3 of Aquifer 1 (June 2025)

Scenario 4:

Under this scenario an allocation of 20 MCM/yr has been made for the industries in the Bihta, Naubatpur and Bikram Blocks of the study area located in the south-western part. This has been made considering the surge in the industrial water demand in these blocks in the past few years. This allocation would take care of the demand of 100 industrial units in the area having a demand of 500m^3/day (Fig6.2f)

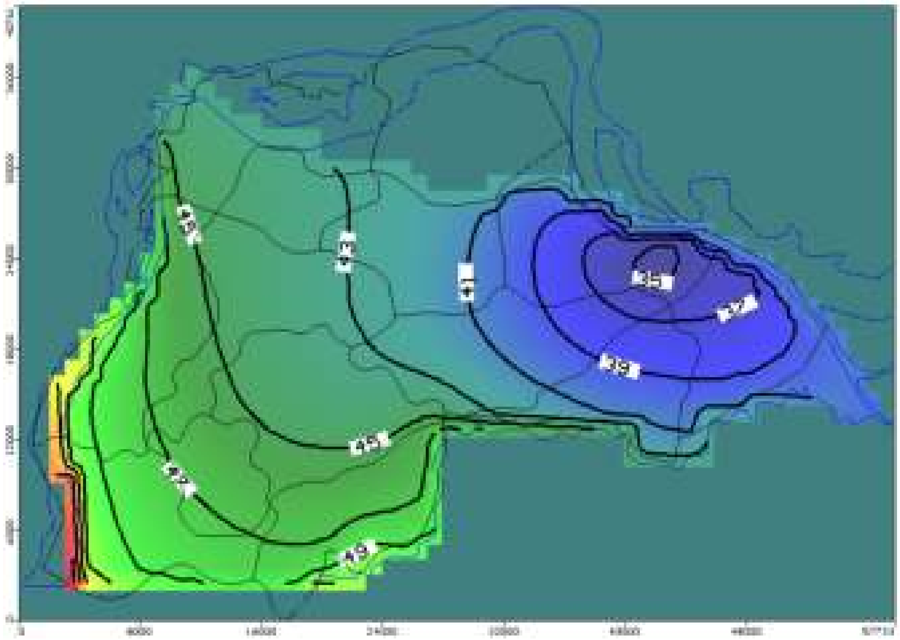


Fig 6.2 (f): Projected Head distribution under scenario 4 of aquifer 1 (June 2025)

Scenario 5:

Under this scenario, the impact of draught (-20% deviation from normal rainfall) on the aquifer regime has been modeled. The scenario generated depicts the resilience of the groundwater system to the draught situations (Fig.6.2g)

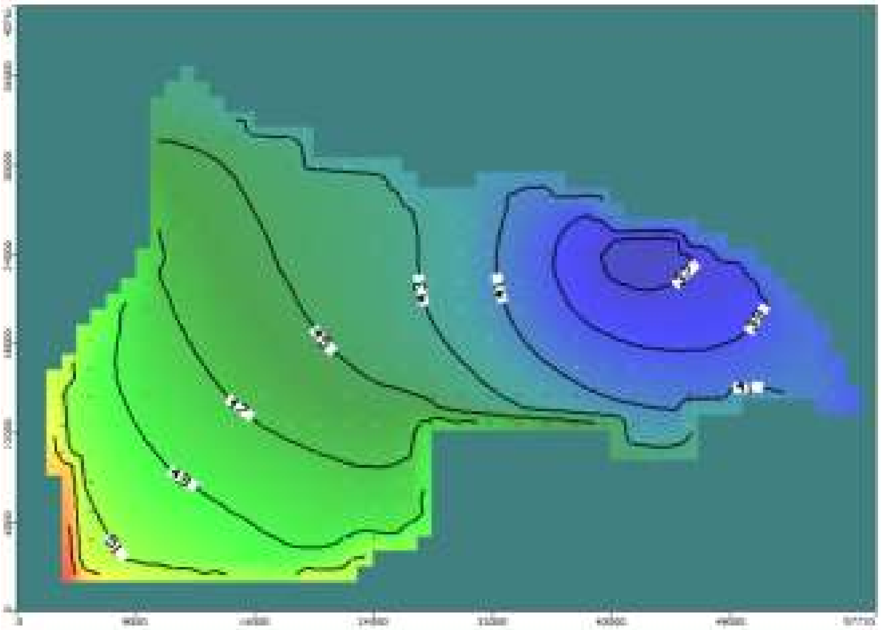


Fig 6.2 (g): Projected head distribution under scenario 5 of aquifer 1 after 3 year of continuous drought.

Scenario 6: In this scenario, the draft has been increased considering the growth in population. The irrigation draft has been increased @2% per year with respect to the prevalent draft during 2008. In this scenario, the normal increase in pumping has been simulated (Fig.6.2h).

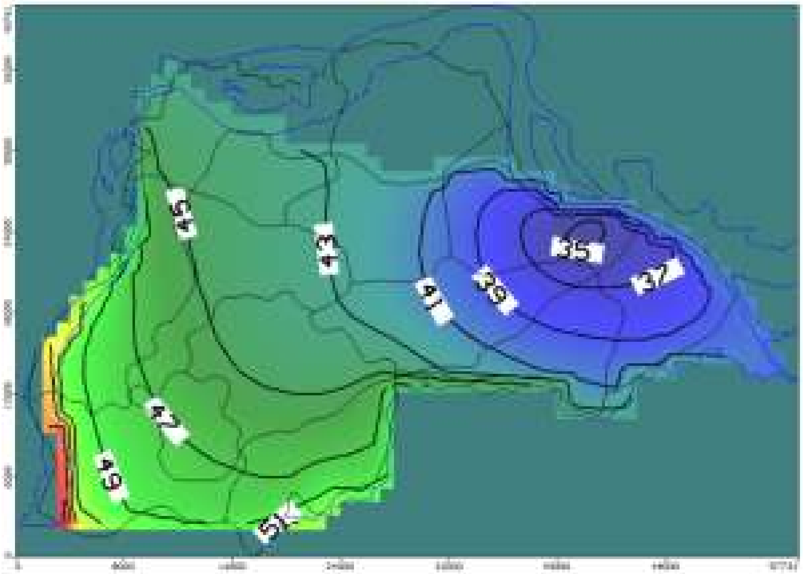


Fig 6.2 (h): Projected head distribution under scenario 6 of aquifer 1 (June 2025)

6.2.3 Hydrogeological consequence of proposed management interventions

To understand the hydrogeological consequences of the proposed management interventions, the predicted change in the piezometric head of a monitoring station in the urban area under the different scenarios is presented in Fig.6.2i

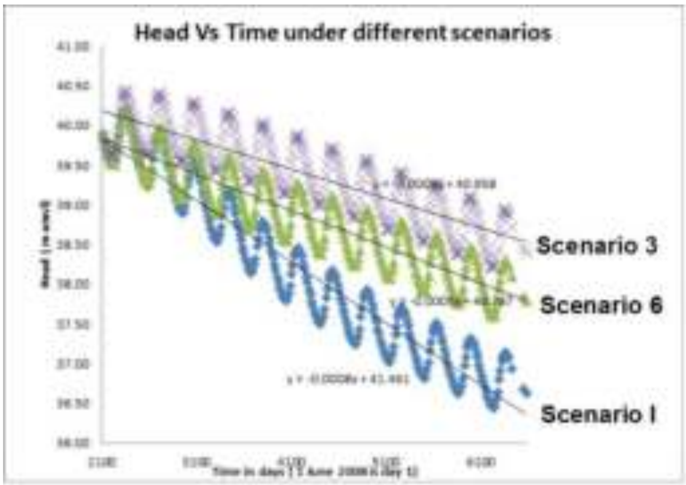


Fig. 6.2(i): Piezometric head of a monitoring station in the urban area under three different scenarios.

Comparison of the rate of annual decline in piezometric head under the projected scenario from the current level reveals that under scenarios 1, 3 and 6, the rate of annual decline would be 0.3, 0.14 and 0.18 m/year. Thus of the various scenarios modeled, the one having the most favourable impact is the one under scenario 3 wherein the effects of the reduction in annual draft from the municipal wells by 50 MCM has been modeled.

The other discernible impact on the aquifer regime is the change in the characteristics of the imposed boundary conditions as made out through the following figures 6.2 j (i to iv) which depict the pre and post-monsoon scenario of year 2008 and 2025 respectively. From the figure 6.2j (i) it is apparent how the River Ganga changes its behavior from predominantly effluent to influent within its flow stretch in the core Patna Urban area. Similarly the Sone and the PunpunRivers also exhibit the change under the simulated scenario.

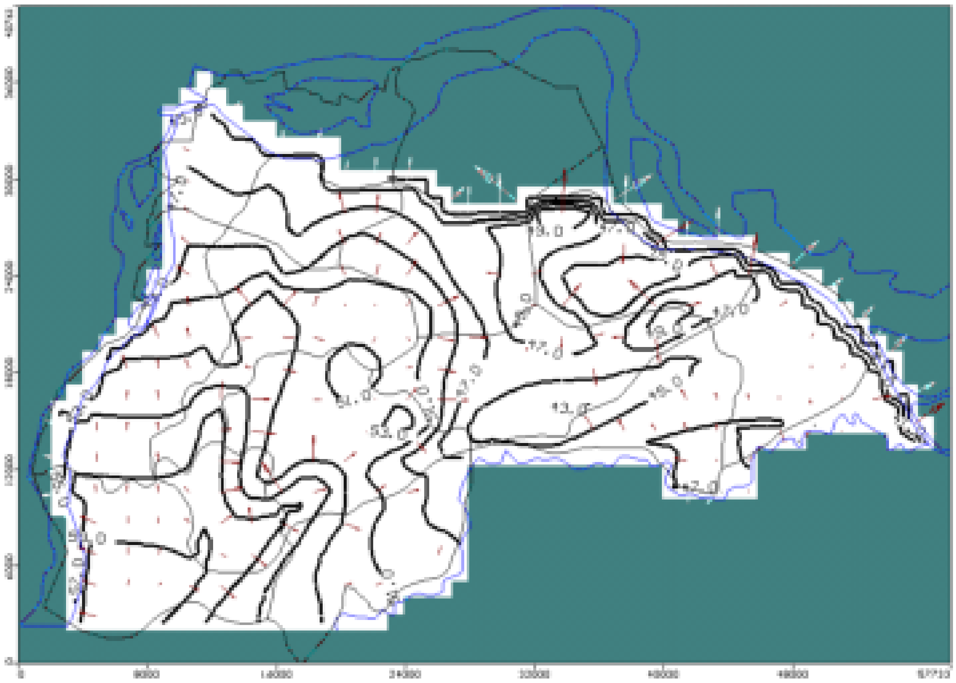


Fig.6.2j (i): Flow regime in aquifer I during pre-monsoon 2008.

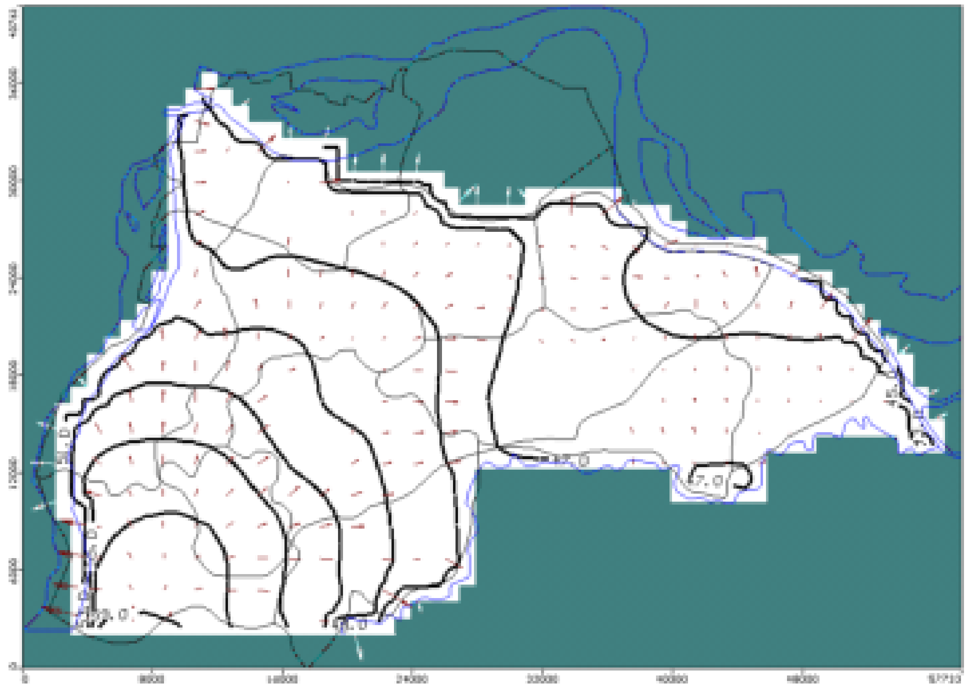


Fig.6.2 j (ii): Flow regime in aquifer I during post-monsoon 2008.

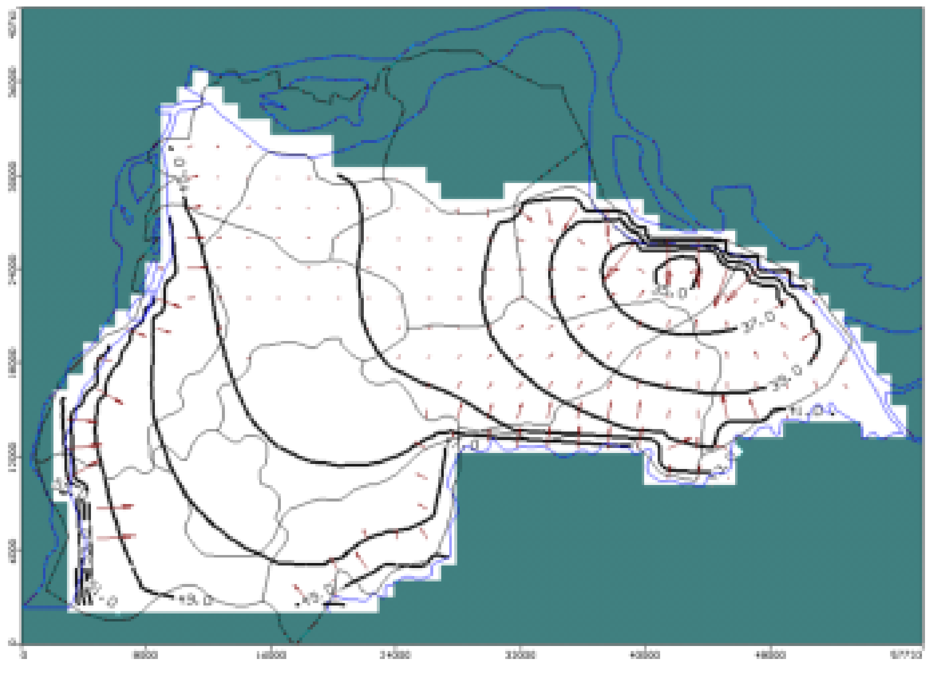


Fig. 6.2 j (iii): Flow regime in aquifer I during pre-monsoon 2025 (model simulated).

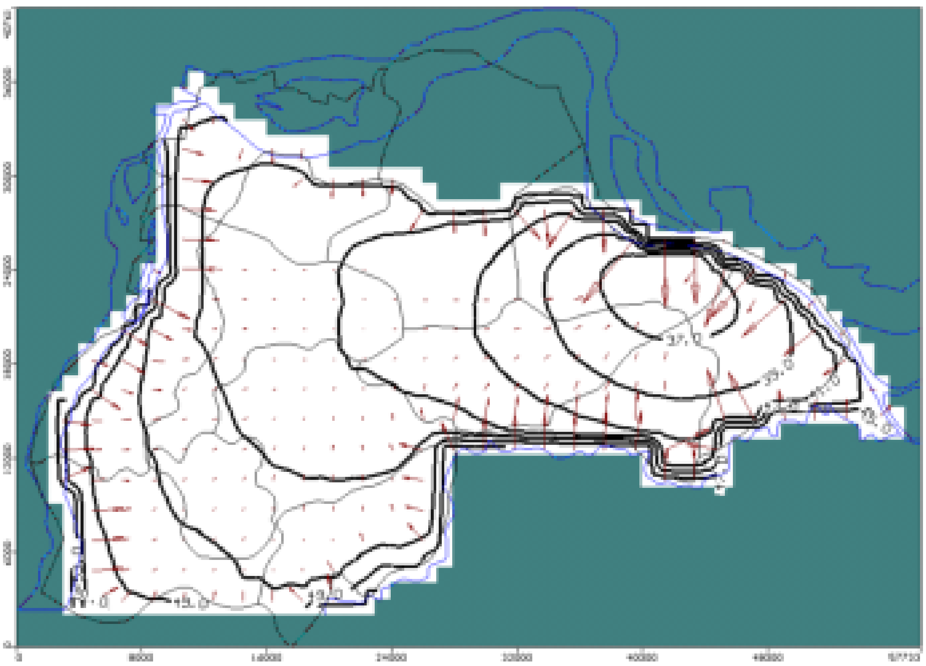


Fig. 6.2 j (iv): Flow regime in aquifer I during post-monsoon 2025 (model simulated).

6.2.4Ground water regime changes in terms of rise /decline of heads /drawdowns

To understand the groundwater regime change in the study area under the different simulated scenarios, an analysis of the drawdown (i.e the difference in the hydraulic head in the year 2025 with respect to that of 2008 i.e the steady state calibration period) is produced for aquifer 1 (the aquifer undergoing intensive ground water draft) for the different scenarios simulated**.**

Visual comparison of the drawdown maps for the year 2025 under the different simulated scenarios is presented in Fig. 6.2k (i to vi). From the drawdown maps generated, one pocket of 10-12 m drawdown in the core urbanized portion of Patna city from the quasi-steady state calibration level of 2008 can be clearly seen in the north-eastern part under scenarios 1, 2, 4 and 5. However, under scenario 3 and 6, the maximum drawdown is to the tune of 6 m only. Thus it can be summarized that reducing the annual groundwater draft in the urban area by 50 MCM is likely to lead to improvement in the hydraulic head in the core urban area. The other prominent drawdown pocket can be seen in the south-western part in the areas falling in Naubatpur, Bikram and Bihta Blocks under Scenario 1, 2, 3 and 4. These Blocks have high agricultural water demand and as such the agricultural water demand for increasing CI to 200% has largely been made from these blocks. Higher drawdown under scenario 4 is because the allocation for industrial water demand has also been made from these blocks. A comparatively lesser drawdown can be seen in all the simulated scenarios in the area lying influence zone of the confluence of Son and Ganga in the north-western part and even extending to north-central part. From the scenario 6 which simulates the behavior under the projected normal increase in pumping @ 2% per annum, the drawdown in the year 2025 remains within 6 m in the urban areas.

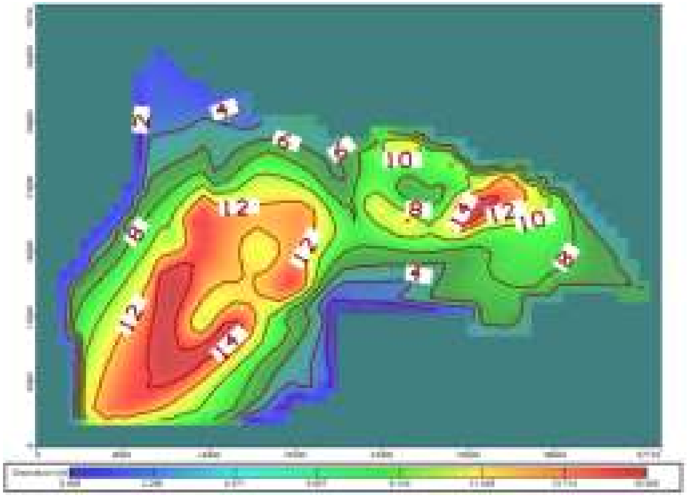


Fig. 6.2k (i): Drawdown map for the year 2025 under scenario 1 (increase in CI to 200%)

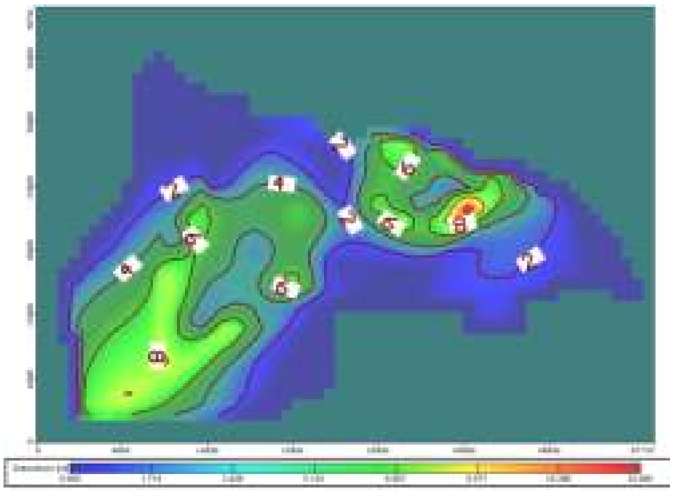


Fig. 6.2k (ii): Drawdown map for the year 2025 under scenario 2 (Increase in groundwater irrigation efficiency by 15%)

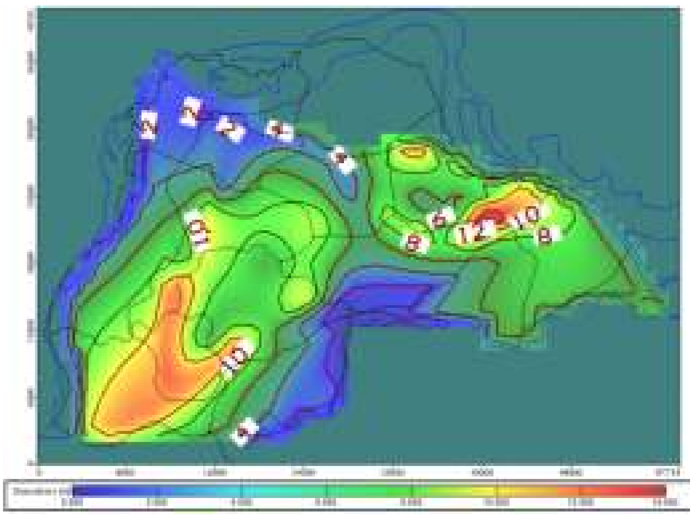


Fig. 6.2k (iii): Drawdown map for the year 2025 under scenario 3 (Reduction in annual urban groundwater draft by 50 MCM)

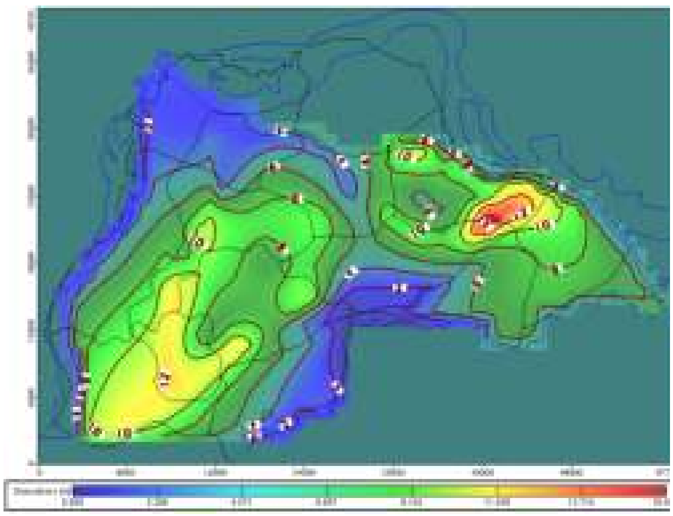


Fig. 6.2k (iv)**:** Drawdown map for the year 2025 under scenario 4 (Allocation for annual industrial water demand of 20 MCM)

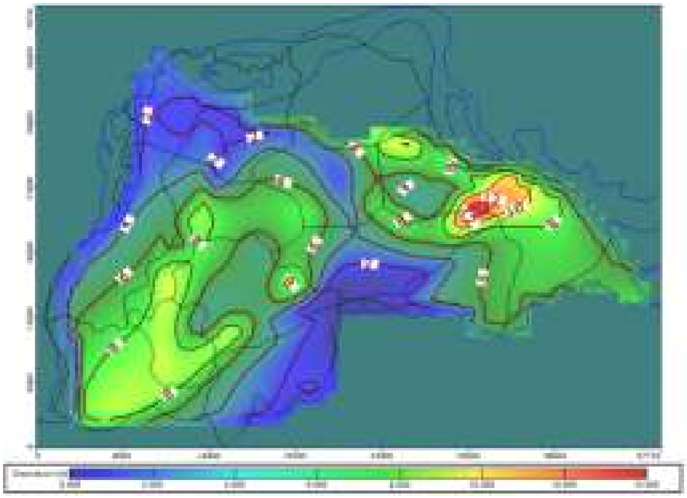


Fig. 6.2k (v)**:** Drawdown map for the year 2018 under scenario 5 (3 years of continuous draught situation)

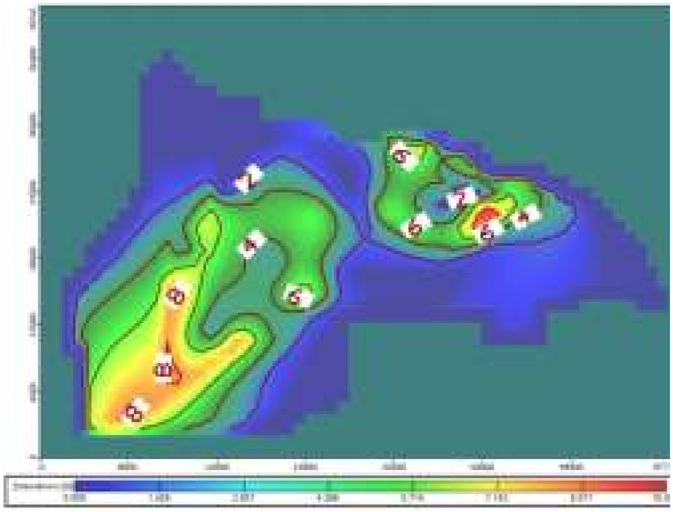


Fig. 6.2k (vi)**:** Drawdown map for the year 2025 under scenario 6 increase in pumping at the normal rate of 2%/annum)

6.2.5 Future prospects of groundwater development for various aquifers/safe yield

The study area is already witnessing an intensive groundwater draft. The current level of groundwater extraction from the area is around 290 MCM. Under the various scenarios simulated except scenario 1, the present draft is projected to increase between 20 and 30% by the year 2025. For scenario 1, the projected draft would increase by 70% from the current level.

Even though the area is blessed with prolific aquifer system, the depletion from aquifer storage owing to the projected groundwater draft is apparent as manifested through the drawdown maps for the year 2025 for aquifer 1 under different scenarios (Fig 6.2 k (i to vi).

Thus any further increase in groundwater extraction from the area should be backed by an appropriate artificial recharge plans for Aquifer 1 and 2.

6.2.6 Quantification of inflows/outflows of various boundary conditions imposed.

One of the main benefits of using the MODFLOW code is that its mass balance calculations provide a very useful way to examine the source of water provided to a system of pumping wells. From the mass balance graph for 1 year and the cumulative mass balance graph for 17th year, the changes in the percentage contribution from various sources have been computed**.** From the table below, it can be seen how the percentage contribution from various sources changes in the projected scenario for year 2025 from that of year 2009. The most important changes are in the contribution from CHB (Ganga River) which contributes 4.3% in 2009 and in the projected scenario for 2025 contributes 18.74% (in cumulative mass balance budget). This reflects upon how the nature of the river which changes its characteristics from net effluent on an annual basis to net influent under the projected scenario. Changes are also apparent in the flow from the river boundaries where the contribution changes from 15.7% in 2009 to 27.2% in 2025 (in cumulative mass balance budget). The inflow and outflow from various sources and sinks for the scenario with normal increase in pumping (scenario 6) are presented in Table6.2 a and b respectively

Table 6.2 a: Inflow from various boundaries in year 1(2009) and year 17 (2025)

Sources	Volume (MCM) 1 year	%	Volume (MCM) 17 year	%
CHB	38.7	4.355656	2036.7	18.74206
Rivers	140.2	15.7794	2965.4	27.28812
Flux	98.2	11.05234	1666.2	15.33266
Recharge	36.5	4.108047	171.3	1.576332
Storage	574.7	64.68205	4027.4	37.06083
Total (In)	888.5		10867	

Table 6.2 b: Outflow from various boundaries in year 1(2009) and year 17 (2025)

Sinks	Volume (MCM) 1 year	%	Volume (MCM) 17 year	%
CHB	71.9	8.09229	455.2	4.188829
Rivers	284.5	32.02026	2156.5	19.84448
Pumping Wells	265	29.82555	5446.5	50.11963
ET	45.9	5.16601	98.5	0.906414
Storage	210.3	23.66911	2710.3	24.94065
Total (Out)	888.5		10867	

The mass balance graphs at the end of year 1 (2009) and for scenario 1, 2 and 3 at the end of year 17 (2015) are shown in figures 6.21 i to iv.

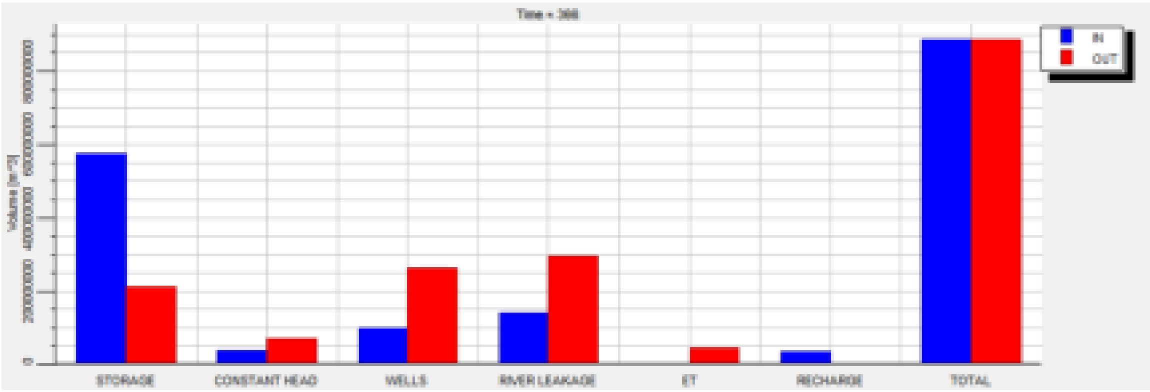


Fig. 6.2 l (i) Scenario 1 (yearly mass balance)

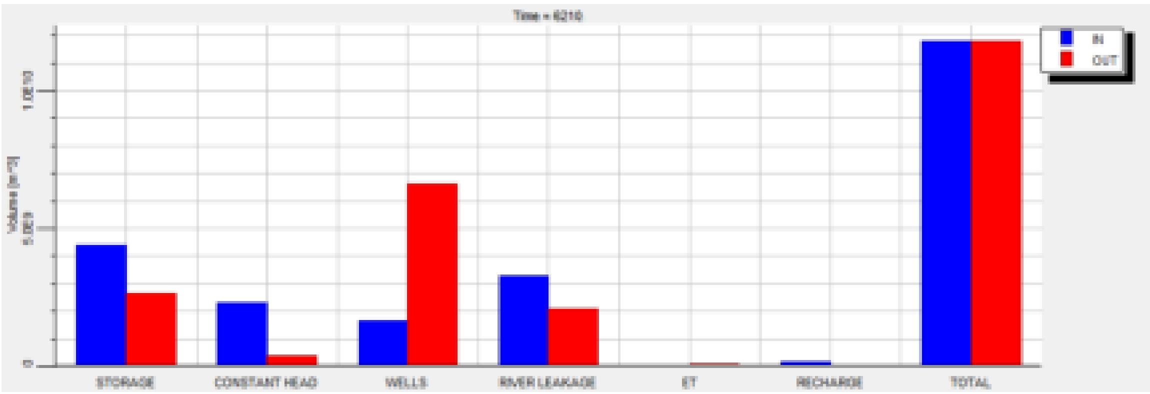


Fig.6.2 l (ii) Scenario 1 (mass balance at the end of year 17)

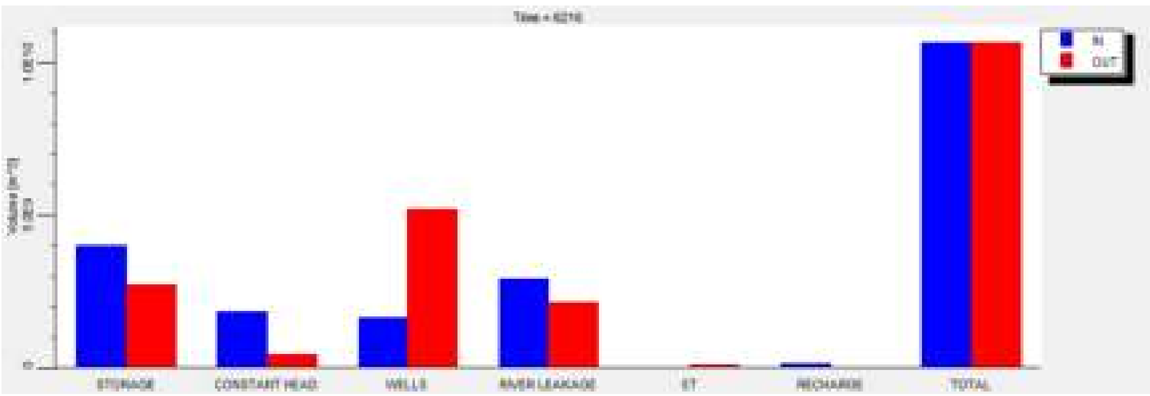


Fig. 6.2 l (iii) Scenario 2 (mass balance at the end of year 17)

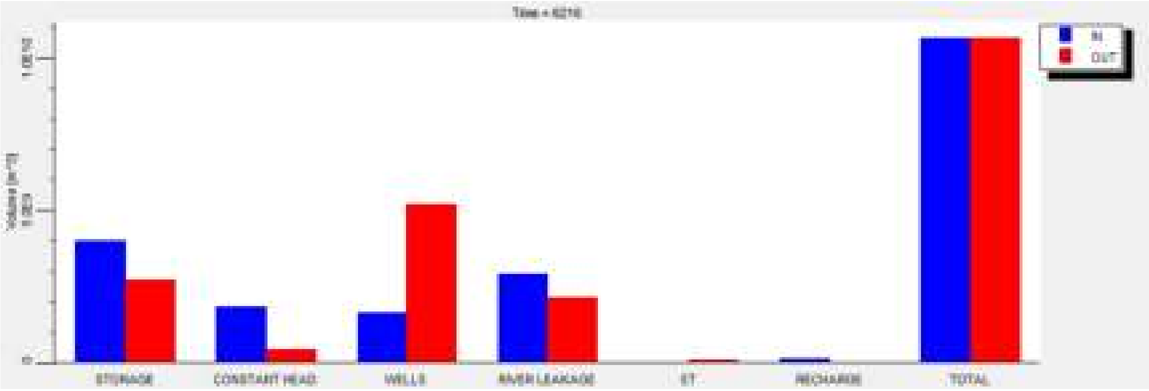


Fig. 6.2 l (iv) Scenario 3 (mass balance at the end of year 17)

6.2.7 Desirable management interventions

Considering the various issues pertaining to groundwater development as emerged from the simulated scenarios, the modeled area has been divided into five zones (Zone A to E, Fig 6.2 m).

Zone A: This zone extends over Bihta, Naubatpur and Punpun blocks where significant demand of groundwater for agricultural use exists.

Zone B: This zone extends over Patna Sadar block characterized by very high population density and significant demand for municipal water supply.

Zone C: This zone extends over Danapur and Punpun block where in most of the scenario simulated the decline in groundwater level has been indicated in moderate range of 4 to 6 m.

Zone D: This zone extends over northern part of Maner block where problem of arsenic contamination of groundwater has been detected in the shallow aquifer.

Zone E: This zone extends over southern part of Naubatpur, Bihta and Bikram blocks where significant decline in groundwater level has been indicated in one of the scenario simulated wherein cropping intensity has been increased from 126% to 200%.

On the basis of the simulated scenarios and the insights into the aquifer dynamics gained through the modeling, it can be concluded that the area is already witnessing intensive groundwater draft both from aquifer 1 & 2. Besides there is extraction from sand layers embedded in the aquitard zone also by dug wells and shallow tube wells. The current draft already exceeds the safe yield limit of the aquifers. However, considering the prolific nature of the aquifer, an allowance for planned depletion from aquifer storage for a drawdown upto 6 m till the year 2025 may be made subject to compliance to the following outlined recommendations (Ref Fig 6.2 m for designated zones for suitable management interventions).

a. Continuation of increase in pumping @ 2% per annum in the study area can be made upto year 2025, however, it is recommended to relocate the heavy duty municipal water supply wells concentrated in zone B (Fig. 6.2 a) to suitable locations in zone C to avoid concentrated extraction (Fig. 6.2 a). Zone B is suitable for recharging of the deeper aquifer through injection wells.
b. Reduction in groundwater draft in Patna urban area by 50MCM/yr, as per the envisaged plan of PHED Government of Bihar, to supplement water supply in urban area from the Ganga River would have a significant positive impact on the aquifer drawdown behavior as such this step is strongly recommended. This would lead to improvement in the hydraulic head for both aquifer I and aquifer II.
c. Increase in cropping intensity to 200% from the current 126% (Scenario 1) would lead to decline in hydraulic head in the agricultural belt by 6 m on an average and even upto 10 m in certain pockets. This scenario may be accepted by sinking additional tube wells for irrigation in zone A, however, a comprehensive artificial recharge plan is desirable in zone E (Fig.6.2 m). The management strategy under scenario 1 is tabulated as under (Table 7.0).
d. Industrial allocation and heavy duty deep tube wells in aquifer 1 should be discouraged in zone D (Fig.6.2m). This is because the arsenic affected blocks are located here and an increase in groundwater draft would lead to lowering of hydraulic head and possible mixing of arsenic safe water with that of the overlying layers with contaminated groundwater.

6.2.8 Ground water development and management plan

To arrive at the holistic groundwater development and management plan for the area, the following considerations are of utmost importance. These include precise demarcation of (i) the feasible areas for groundwater development, (ii) feasible areas for rainwater harvesting and artificial recharge and (iii) areas not only vulnerable to impact of enhanced groundwater extraction but also the quality of groundwater . The answers to the above can best be obtained only by mathematical modeling of the groundwater system. In the present study, the results of mathematical modeling has thrown light on the strategies that need to be adopted in different parts of the study area for invoking sustainable aquifer management plan.

As the economy of the area is predominantly agrarian, emphasis on agriculture is likely to continue. In one of the strategy tested in modeling, it has been found that upon increasing the cropping intensity from the present 126% to 200% by allocating the enhanced water requirement from the aquifer I, groundwater level in Zone A and E (Fig 6.2m) is projected to decline by about 8-12 m with respect to that of the year 2008. The yield potential of aquifer I range from 150- 250 m^3/hr for a modest drawdown of 3-5 m. For placement of screens, the suitable depth zone in aquifer I is from 40- 100m. For aquifer II, the yield potential also varies from 125- 225 m^3/hr for comparable drawdown. Wells in aquifer II can be screened in the depth range of 140-215m bgl.

However, development of ground water in Zone A would require an elaborate artificial recharge plan particularly in Zone E. As the area is rural large scale roof top rainwater harvesting is not a feasible proposition. Artificial recharge in this area can be attempted through on-farm water conservation practices. In an injection well experiment conducted in Patna urban area, it has been found that a tubewell with screen of 6”diameter and slot length of 12m can receive recharge @ 10m^3/hr. Thus one injection well can recharge ~200m^3/day.

Concentration of Municipal water supply wells and their round the year pumpage in Zone B renders the aquifer II in the urban area vulnerable to piezometric level decline even at the present level of pumping. To tide over this challenge, it is suggested to decongest the existing concentration of municipal water supply wells in Zone B to Zone C. Other measures like shifting to surface water supply from the Ganges as mooted by the State Government would also de-stress the aquifer II in the urban area. Groundwater regulation in the urban area particularly to check the unabated extraction by individual housing societies, apartments, commercial complexes also requires consideration.

From the point of groundwater quality, only a small pocket in the extreme north-western and north-central part where arsenic contamination has been detected in the aquitard zone and the upper slice of the aquifer I (Zone D, fig 6.2 m& fig 3.9 p) is vulnerable. For this area, it is recommended that aquifer II should exclusively be used only for drinking and domestic uses. Care should also be taken to restrict any groundwater allocation for industrial requirement from this area. For meeting the agriculture water requirement in this area, blending of groundwater from aquifer I and II in requisite proportion may be attempted to ward off any possible threat of proliferation of arsenic in the food chain.

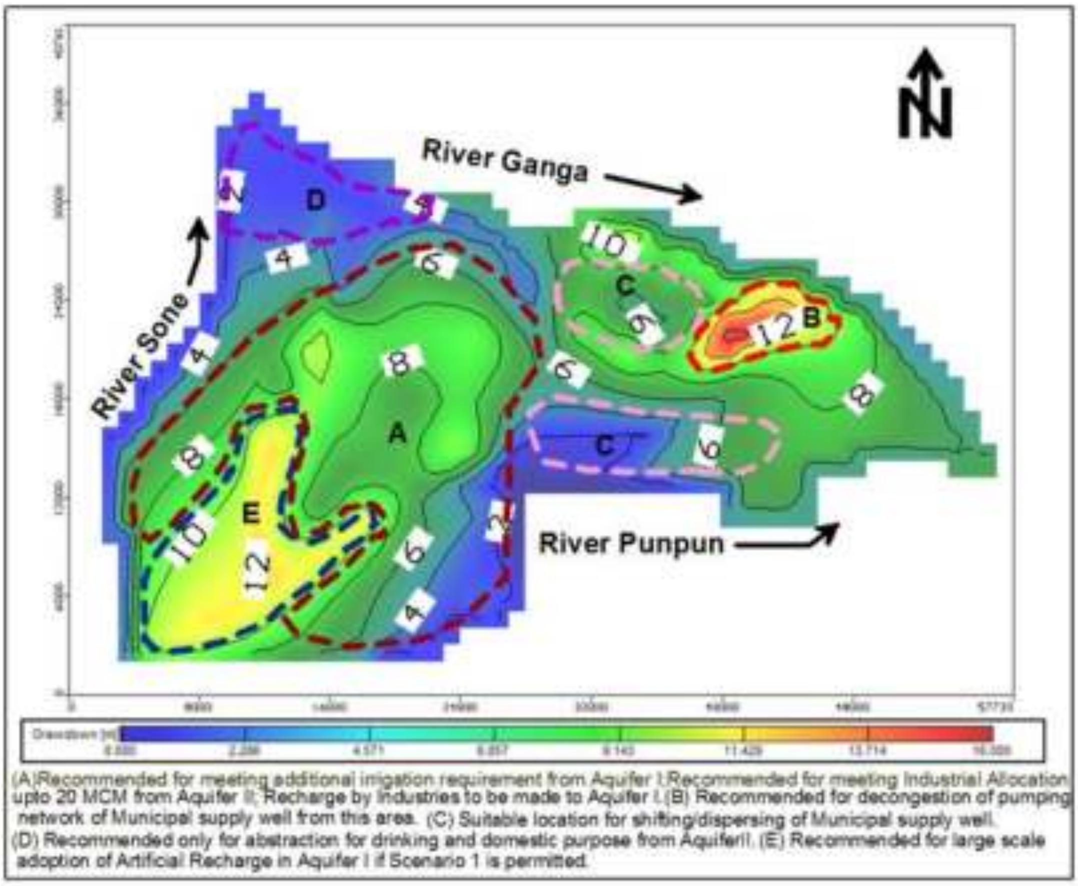


Fig. 6.2(m): Zonation of area for management plan

CHAPTER-7

IMPLEMENTATION PLAN AND RECOMMENDATION

From the detailed study carried out, the following key issues have been identified that need to be addressed

(i) Concentrated groundwater extraction through heavy duty tube-wells in the intensively urbanized part of Patna urban area

(ii) High dependence of agriculture on groundwater and its likely continuance in future

(iii) Projected groundwater decline of 8-12 mby the year 2025 in the agricultural area with respect to that of year 2008 if the cropping intensity is increased to 200% from the current126%.

(iv) Projected decline of 12 mby the year 2025 in the highly urbanized part with respect to that of year 2008 even @ 2% increase in annual groundwater draft.

(v) Arsenic contamination of ground water affecting the aquitard and the upper slice of aquifer I in extreme north-western and north-central part.

On the basis of the simulated scenarios and the insights into the aquifer dynamics gained through the modeling, it can be concluded that the area is already witnessing intensive groundwater draft both from aquifer 1 & 2. Besides there is extraction from sand layers embedded in the aquitard zone also by dug wells and shallow tube wells. The current draft already exceeds the safe yield limit of the aquifers. However, considering the prolific nature of the aquifer, an allowance for planned depletion from aquifer storage for a drawdown upto 6 m till the year 2025 may be made subject to compliance to the following outlined recommendations (Ref Fig 6.2m for designated zones for suitable management interventions).

a. Continuation of increase in pumping @ 2% per annum in the study area can be made upto year 2025, however, it is recommended to relocate the heavy duty municipal water supply wells concentrated in zone B (Fig. 6.2m) to suitable locations in zone C to avoid concentrated extraction (Fig. 6.2m). Zone B is suitable for recharging of the deeper aquifer through injection wells.

b. Reduction in groundwater draft in Patna urban area by 50MCM/yr, as per the envisaged plan of PHED Government of Bihar, to supplement water supply in urban area from the Ganga River would have a significant positive impact on the aquifer drawdown behavior as such this step is strongly recommended. This would lead to improvement in the hydraulic head for both aquifer I and aquifer II.

c. Increase in cropping intensity to 200% from the current 126% (scenario 1) would lead to decline in hydraulic head in the agricultural belt by 6 m on an average and even upto 10 m in certain pockets. This scenario may be accepted by sinking additional tube wells for irrigation in zone A, however, a comprehensive artificial recharge plan is desirable in zone E (Fig.6.2m). The management strategy under scenario 1 is tabulated as under (Table 7.0)

d. Industrial allocation and heavy duty deep tube wells in aquifer 1 should be discouraged in zone D (Fig.6.2m). This is because the arsenic affected blocks are located here and an increase in groundwater draft would lead to lowering of hydraulic head and possible mixing of arsenic safe water with that of the overlying layers with contaminated groundwater.

e. The normal injection rate in aquifer I for a well of 10” housing diameter and 6” screen diameter with a screen length of 12 m has been worked out through injection test in the study area as ~ 11m^3/hr. Considering this rate, one injection well in the urban area is sufficient to accommodate the peak recharge pulse arising out of rainfall intensity upto 40mm/hr from a roof area of ~4000Sq ft.

Table 7.0: Management strategy under scenario 1.

Additional area that can be brought under irrigation during monsoon	Additional area that can be brought under irrigation during non-monsoon (Rabi + Summer)	Increase in ground water draft during monsoon per year	Increase in ground water draft during non-monsoon (Rabi + Summer) per year	No of additional tubewells that may be installed	Projected decline in head upto year 2025 from the current level	Change in ground water regime	Whether acceptable or not
7300 ha	10,550 ha	14.6 MCM	31.65 MCM	198 irrigation tube wells (considering average discharge of 80m^3/hr and 8 hours pumping)	~ 4m	1)Ground water trough area increases by 60% 2) Change in sub-regional flow regime 3) There is no Net outflow from the study area in year 2025 4) Decline in head <5 m	Can be accepted only if backed by artificial recharge plans for Aquifer 1 in zone E (Fig 6.2 m)

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Annexure 2.7 (a): Lithologs of wells drilled by other agencies under Pilot Aquifer Mapping area, Patna

1. Khajpura

Lithology	Depth Range (m bgl)	Thickness (m)
Clay & Kankar	0 -28.4	28.4
Fine Sand	28.4 -39.92	11.52
Coarse Sand	39.92 -67.36	27.44
Sandy Clay	67.36 -70.4	3.04

2. Shekhpura

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -29.26	29.26
Sandy Clay	29.26 -36.89	7.63
Medium Sand	36.89 -45.42	8.53
Clay	45.42 -54.86	9.44
Fine Sand	54.86 -64.92	10.06
Coarse Sand	64.92 -98.13	33.21

3. Dariyapur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay & Kankar	0 -25.95	25.95
Fine Sand	25.95 -29.87	3.92
Medium Sand	29.87 -38.71	8.84
Coarse Sand	38.71 -41.76	3.05
Fine Sand	41.76 -44.81	3.05
Coarse Sand	44.81 -69.8	24.99
Clay	69.8 -99.39	29.59

4. Doghra

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -40.82	40.82
Fine to Medium Sand	40.82 -59.76	18.94
Coarse Sand	59.76 -86.25	26.49

5. Madhopur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay & Kankar	0 -34.12	34.12
Fine Sand	34.12 -51.81	17.69
Medium Sand	51.81 -59.44	7.63
Coarse Sand	59.44 -66.13	6.69
Fine Sand	66.13 -76.2	10.07
Coarse Sand	76.2 -88.7	12.5
Fine Sand	88.7 -92.66	3.96

6. Bahpura

Lithology	Depth Range (m bgl)	Thickness (m)
Clay & Kankar	0 -21.33	21.33
Fine Sand	21.33 -24.38	3.05
Medium Sand	24.38 -32.92	8.54
Coarse Sand	32.92 -38.4	5.48
Clay	38.4 -39	0.6
Coarse Sand	39 -42.98	3.98
Medium Sand	42.98 -54.86	11.88
Gravel	54.86 -88.4	33.54

7. Anandpur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -35	35
Fine to Medium Sand	35 -54	19
Coarse Sand	54 -91.2	37.2

8. Sherpur

Lithology	Depth Range (m bgl)	Thickness (m)
Sandy Clay	0 -38.1	38.1
Medium Sand	38.1 -50.9	12.8
Clay	50.9 -60.96	10.06
Fine Sand	60.96 -65.53	4.57
Coarse Sand	65.53 -93.57	28.04

9. Shadikpur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -51.82	51.82
Medium Sand	51.82 -70.71	18.89
Coarse Sand	70.71 -88.7	17.99

10. Mehdwan

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -39.62	39.62
Sandy Clay	39.62 -42.36	2.74
Clay & Kankar	42.36 -54.85	12.49
Medium Sand	54.85 -61.55	6.7
Fine Sand	61.55 -68.24	6.69
Coarse Sand	68.24 -102.7	34.46

11. Darweshpur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay & Kankar	0 -28.93	28.93
Medium Sand	28.93 -41.14	12.21
Clay	41.14 -56.36	15.22
Medium Sand	56.36 -85.34	28.98
Gravel	85.34 -101.47	16.13

12. Tilhari

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -46.63	46.63
Fine Sand	46.63 -50.27	3.64
Coarse Sand	50.27 -54.55	4.28
Medium Sand	54.55 -70.1	15.55
Coarse Sand	70.1 -94.02	23.92

13. Gonawan

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -22	22
Sandy Clay	22 -25.96	3.96
Fine to Medium Sand	25.96 -33.75	7.79
Coarse Sand	33.75 -75	41.25
Clay	75 -78.5	3.5

14. Daudpur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay & Kankar	0 -30.48	30.48
Fine Sand	30.48 -71.02	40.54
Gravel	71.02 -74.68	3.66
Coarse Sand	74.68 -83.52	8.84
Fine Sand	83.52 -89	5.48
Coarse Sand	89 -96.93	7.93

15. Sarasat

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -1.82	1.82
Sandy Clay	1.82 -29.88	28.06
Fine Sand	29.88 -40.23	10.35
Coarse Sand	40.23 -43.9	3.67
Fine Sand	43.9 -54.25	10.35
Coarse Sand	54.25 -68.88	14.63
Fine Sand	68.88 -71.01	2.13
Coarse Sand	71.01 -73.77	2.76
Fine Sand	73.77 -75.6	1.83

16. Korwan

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -24.98	24.98
Fine Sand	24.98 -39.6	14.62
Coarse Sand	39.6 -46.94	7.34
Medium Sand	46.94 -50.29	3.35
Coarse Sand	50.29 -69.49	19.2
Clay	69.49 -71.62	2.13

17. Amhara

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -18	18
Fine Sand	18 -30	12
Coarse Sand	30 -66	36
Clay	66 -90	24
Coarse Sand	90 -96	6
Clay	96 -102	6

18. Isopur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -7.6	7.6
Clay & Kankar	7.6 -22.9	15.3
Fine Sand	22.9 -35.6	12.7
Medium Sand	35.6 -38.6	3
Coarse Sand	38.6 -78.8	40.2

19. Hasanpura

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -11.3	11.3
Sandy Clay	11.3 -17.1	5.8
Fine Sand	17.1 -31.3	14.2
Medium Sand	31.3 -39.5	8.2
Fine Sand	39.5 -42	2.5
Coarse Sand	42 -55.5	13.5
Gravel & Medium Sand	55.5 -74.2	18.7
Fine Sand	74.2 -81.8	7.6

20. Pakri

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -22.9	22.9
Fine Sand	22.9 -41.6	18.7
Medium Sand	41.6 -44.7	3.1
Coarse Sand	44.7 -78.8	34.1

21. Rajpur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -22.86	22.86
Fine Sand	22.86 -35	12.14
Clay & Kankar	35 -39.62	4.62
Medium Sand	39.62 -42.67	3.05
Coarse Sand	42.67 -77.72	35.05
Clay	77.72 -82.29	4.57

22. Ahiyapur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -25.9	25.9
Clay & Kankar	25.9 -32	6.1
Fine Sand	32 -38.1	6.1
Medium Sand	38.1 -50.29	12.19
Coarse Sand	50.29 -99.06	48.77
Clay	99.06 -102.1	3.04

23. Abhramchak

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -28.95	28.95
Fine Sand	28.95 -38.1	9.15
Medium Sand	38.1 -41.14	3.04
Coarse Sand	41.14 -76.2	35.06
Clay	76.2 -80.77	4.57

24. Arap

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -25.9	25.9
Clay & Kankar	25.9 -35	9.1
Fine Sand	35 -42.67	7.67
Coarse Sand	42.67 -74.67	32
Clay	74.67 -77.72	3.05

25. Jagdishpur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -30	30
Fine Sand	30 -58	28
Coarse Sand	58 -97	39

26. Baliyari

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -13.71	13.71
Clay & Kankar	13.71 -16.76	3.05
Clay	16.76 -28.86	12.1
Clay & Kankar	28.86 -32	3.14
Fine Sand	32 -36.52	4.52
Coarse Sand	36.52 -77.72	41.2
Clay	77.72 -80.77	3.05

27. Kadamkuan

Lithology	Depth Range (m bgl)	Thickness (m)
Clay,	0-21.33	21.33
Fine sand,	21.33-33.52	12.19
Fine to medium sand	33.52-39.57	6.05
Clay,	39.57-51.81	12.24
Fine to medium sand	51.81-68.58	16.77
Clay	68.58-70.10	1.52
Medium to coarse sand,	70.10-90.84	20.74
Clay,	90.84-92.04	1.20
Medium sand	92.04-114-29	22.25
Clay	114.29-114.89	0.60
Coarse to very coarse sand	114.89-150.88	35.99
Gravel, medium to coarse	150.88-161.54	10.66
Fine to medium sand	161.54-306.32	144.78
Coarse sand with admixture of fine and medium sand	306.32-311.49	5.17

28. Ramnagar

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0-5.17	5.17
Medium sand	5.17-7.62	2.45
Coarse sand	7.62-21.33	13.71
Fine sand with clay	21.33-50.89	29.56
Coarse sand	50.89-53.04	2.15
Fine sand	53.04-58.22	5.18
Coarse sand	58.22-70.40	12.18
Fine sand	70.40-73.75	3.55
Coarse sand	73.75-74.35	0.60
Clay,	74.35-83.81	9.46
Coarse sand	83.81-89.01	6.20
Clay	89.01-89.67	0.66

Annexure 3.5 (a): Lithologs of wells (drilled by CGWB) existing and drilled under Pilot Aquifer project, Bihar

1. Bikram

Lithology	Depth Range (m bgl)	Thickness (m)
Fine to Medium Sand	0 -13.54	13.54
Clay	13.54 -15.93	2.39
Sandy Clay	15.93 -31.14	15.21
Fine to Medium Sand	31.14 -42	10.86
Coarse Sand	42 -84.35	42.35
Clay	84.35 -100.39	16.04
Fine toMedium Sand	100.39 -109.92	9.53
Clay	109.92 -124.51	14.59
Fine to Medium Sand	124.51 -228.85	104.34
Clay	228.85 -240	11.15
Fine to Medium Sand	240 -245	5
Clay	245 -252	7

2. Chhajubag

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -60.62	60.62
Medium Sand	60.62 -196	135.38

3. Anishabad

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -14.3	14.3
Coarse Sand	14.3 -52	37.7
Sandy Clay	52 -57	5
Fine to Medium Sand	57 -102	45
Clay	102 -109	7
Fine to Medium Sand	109 -128	19
Clay	128 -131	3
Fine to Medium Sand	131 -136	5
Clay	136 -140	4
Fine to Medium Sand	140 -230	90

4. Golghar

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -3.5	3.5
Sandy Clay	3.5 -19.6	16.1
Coarse Sand	19.6 -43	23.4
Clay	43 -55	12
Fine to Medium Sand	55 -63	8
Clay	63 -68	5
Fine to Medium Sand	68 -75.87	7.87
Coarse Sand	75.87 -107.13	31.26
Clay	107.13 -110.74	3.61
Fine to Medium Sand	110.74 -116.22	5.48
Clay	116.22 -121.94	5.72
Fine to Medium Sand	121.94 -126.39	4.45
Coarse Sand	126.39 -151.3	24.91
Sandy Clay	151.3 -184.6	33.3
Coarse Sand	184.6 -209.12	24.52
Fine to Medium Sand	209.12 -214.65	5.53
Clay	214.65 -221.58	6.93
Coarse Sand	221.58 -226.4	4.82
Clay	226.4 -277.78	51.38

5. Karbigahia

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -32	32
Coarse Sand	32 -42	10
Clay	42 -52	10
Fine to Medium Sand	52 -77	25
Coarse Sand	77 -107	30
Clay	107 -110	3
Fine to Medium Sand	110 -143	33
Clay	143 -150	7
Fine to Medium Sand	150 -185	35
Coarse Sand	185 -208	23
Fine to Medium Sand	208 -225	17
Clay	225 -233	8
Fine to Medium Sand	233 -237	4
Clay	237 -245	8
Fine to Medium Sand	245 -250	5

6. Maner

Lithology	Depth Range (m bgl)	Thickness (m)
Sandy Clay	0 -13	13
Clay	13 -60	47
Fine to Medium Sand	60 -111	51
Clay	111 -119	8
Fine to Medium Sand	119 -241	122
Clay	241 -287	46
Fine to Medium Sand	287 -300	13

7. Khagaul

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -3.5	3.5
Fine to Medium Sand	3.5 -13.2	9.7
Clay	13.2 -25.9	12.7
Sandy Clay	25.9 -45	19.1
Coarse Sand	45 -113	68
Clay	113 -122	9
Coarse Sand	122 -147	25
Clay	147 -156	9
Coarse Sand	156 -167	11
Clay	167 -177	10
Coarse Sand	177 -225	48
Fine to Medium Sand	225 -262.27	37.27

8. Danapur

Lithology	Depth Range (m bgl)	Thickness (m)
Sandy Clay	0 -21.62	21.62
Clay & Kankar	21.62 -30.63	9.01
Sandy Clay	30.63 -33.65	3.02
Clay & Kankar	33.65 -51.62	17.97
Medium Sand	51.62 -78.61	26.99
Gravel & Medium Sand	78.61 -150.58	71.97

9. Kidwaipuri

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -6.64	6.64
Clay & Kankar	6.64 -15.64	9
Medium Sand	15.64 -30.59	14.95
Clay & Kankar	30.59 -48.59	18

Medium Sand	48.59 -66.55	17.96
Gravel & Medium Sand	66.55 -78.56	12.01
Coarse Sand	78.56 -84.56	6
Gravel & Medium Sand	84.56 -108.48	23.92
Fine Sand	108.48 -114.49	6.01
Medium Sand	114.49 -135.53	21.04
Coarse Sand	135.53 -151.52	15.99

10. BN College

Lithology	**Depth Range (m bgl)**	**Thickness (m)**
Clay	0 -9.8	9.8
Fine to Medium Sand	9.8 -26.3	16.5
Clay	26.3 -32.5	6.2
Fine to Medium Sand	32.5 -49.6	17.1
Clay	49.6 -58.5	8.9
Fine to Medium Sand	58.5 -102	43.5
Clay	102 -122	20
Coarse Sand	122-194	72

11.Chaudharana

Lithology	**Depth Range (m bgl)**	**Thickness (m)**
Clay	0 -30.4	30.4
Fine to Medium Sand	30.4 -35.8	5.4
Clay	35.8 -43.81	8.01
Fine to Medium Sand	43.81 -57.53	13.72
Clay	57.53 -84.76	27.23
Coarse Sand	84.76 -104.61	19.85
Clay	104.61 -123.5	18.89
Coarse Sand	123.5 -129.47	5.97
Fine to Medium Sand	129.47 -192.55	63.08

12.Harding Road

Lithology	**Depth Range (m bgl)**	**Thickness (m)**
Sandy Clay	0 -7	7
Clay & Kankar	7 -63.7	56.7
Medium Sand	63.7 -221.2	157.5
Clay	221.2 -245.4	24.2

13.Phulwarisharif

Lithology	Depth Range (m bgl)	Thickness (m)
Sandy Clay	0 -43.82	43.82
Medium Sand	43.82 -118.56	74.74
Coarse Sand	118.56 -137.26	18.7
Medium Sand	137.26 -230.62	93.36

14.Mithapur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -22	22
Coarse Sand	22 -27	5
Clay	27 -77	50
Fine to Medium Sand	77 -104	27
Clay	104 -109	5
Fine to Medium Sand	109 -247	138

15.Kadamkuwa

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -13.3	13.3
Coarse Sand	13.3 -35.5	22.2
Clay	35.5 -54.4	18.9
Coarse Sand	54.4 -57.4	3
Clay	57.4 -63.7	6.3
Coarse Sand	63.7 -70	6.3
Clay	70 -73.5	3.5
Coarse Sand	73.5 -82.6	9.1
Gravel	82.6 -88.9	6.3
Clay	88.9 -95.2	6.3
Gravel	95.2 -101.8	6.6
Coarse Sand	101.8 -191	89.2
Medium Sand	191 -228.8	37.8
Clay	228.8 -251.7	22.9

16.Naubatpur

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 -7.5	7.5
Coarse Sand	7.5 -13.75	6.25
Clay	13.75 -40	26.25
Coarse Sand	40 -77	37
Clay	77 -93.25	16.25
Coarse Sand	93.25 -108.75	15.5
Clay	108.75 -115	6.25
Coarse Sand	115-185	70

17.Simri

Lithology	Depth Range (m bgl)	Thickness (m)
Sandy Clay	0 -37	37
Fine to Medium Sand	37 -59	22
Coarse Sand	59 -99	40
Clay	99 -110	11
Coarse Sand	110 -129	19
Fine to Medium Sand	129 -163	34
Clay	163 -167	4
Fine to Medium Sand	167 -216	49
Sandy Clay	216 -239	23
Fine to Medium Sand	239 -246	7
Sandy Clay	246 -251	5
Fine to Medium Sand	251 -260	9
Sandy Clay	260 -266	6
Fine to Medium Sand	266 -277	11
Sandy Clay	277-300	23

18.Bihta

Lithology	Depth Range (m bgl)	Thickness (m)
Fine to Medium Sand	0 -7	7
Sandy Clay	7 -31	24
Coarse Sand	31 -87	56
Clay	87 -106	19
Fine to Medium Sand	106 -129	23
Sandy Clay	129 -175	46
Fine to Medium Sand	175 -250	75

19.Moriyama

Lithology	Depth Range (mbgl)	Thickness (m)
Sandy Clay	0- 30	30
Coarse Sand	30-69	39
Clay	69-88	19
Fine to Medium Sand	88-94	6
Sandy Clay	94-118	24
Fine to Medium Sand	118 – 185	67
Coarse Sand	185-230	45
Clay	230-235	5
Coarse Sand	235-245	10
Clay	245-300	55

20.A.N.College Campu,Patna

Lithology	Depth Range (m bgl)	Thickness (m)
Clay	0 - 39	39
Fine to Medium Sand	39 -47	8
Sandy Clay	47 -52	5
Fine to Medium Sand	52 -67	15
Sandy Clay	67 -71	4
Medium to Coarse Sand	71 - 87	16
Sandy Clay	87 - 92	5
Medium to Coarse Sand	92 -100	8
Sandy Clay	100 -104	4
Medium to Coarse Sand	104 -124	20
Sandy Clay	124-129	5
Medium to Coarse Sand	129-134	5
Sandy Clay	134 - 137	3
Medium to Coarse Sand	137 - 143	6
Sandy Clay	143-147	4
Medium to Coarse Sand	147-174.56	27.56

21. Goriyasthan (Jibrakhantola)

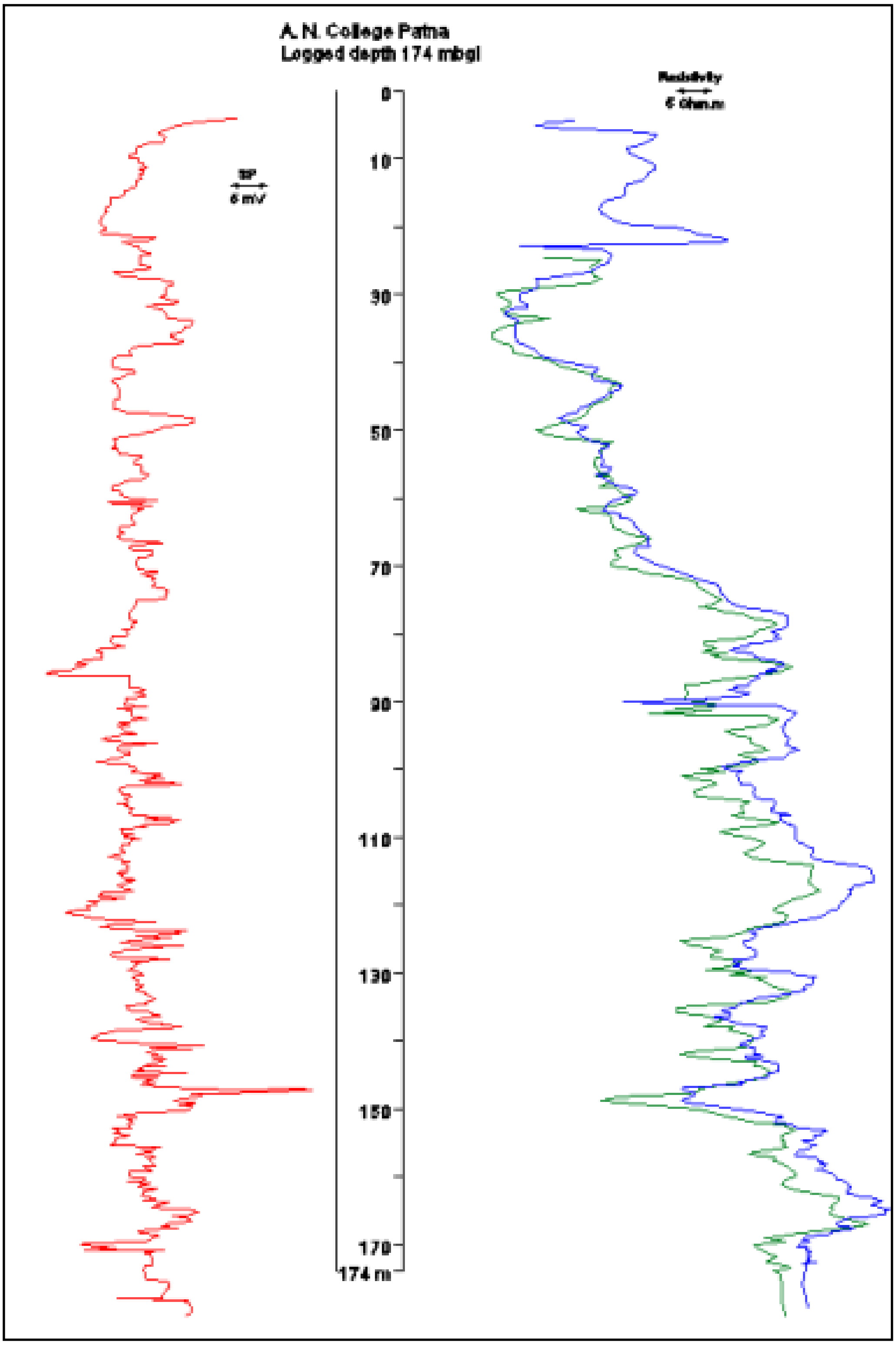
Lithology	Depth Range (mbgl)	Thickness (m)
Surface soil mixed with sandy clay	0.000 – 7.50	7.50
Clay	7.5- 23	15.5
Clay mixed with fine sand.	23- 87	64
Fine to medium sand	87- 107	20
Clay	107-112	5
Fine to medium grained sand.	112 -125	13
Cay	125- 127	2
Medium grained sand	127- 147	20
Clay	147-152	5
Medium grained sand.	152 – 188	36
Clay	188- 193	5
Fine to medium grained sand	193- 209	16
Clay	209-213	4
Fine to medium grained sand	213-216	3
Clay	216- 218	2
Fine to medium grained sand	218-223	5
Clay	223-262	39
Fine to medium grained sand	262-281	19

Annexure 3.5 (b): Interpreted VES data (CGWB) of Pilot Aquifer Mapping areas, Patna

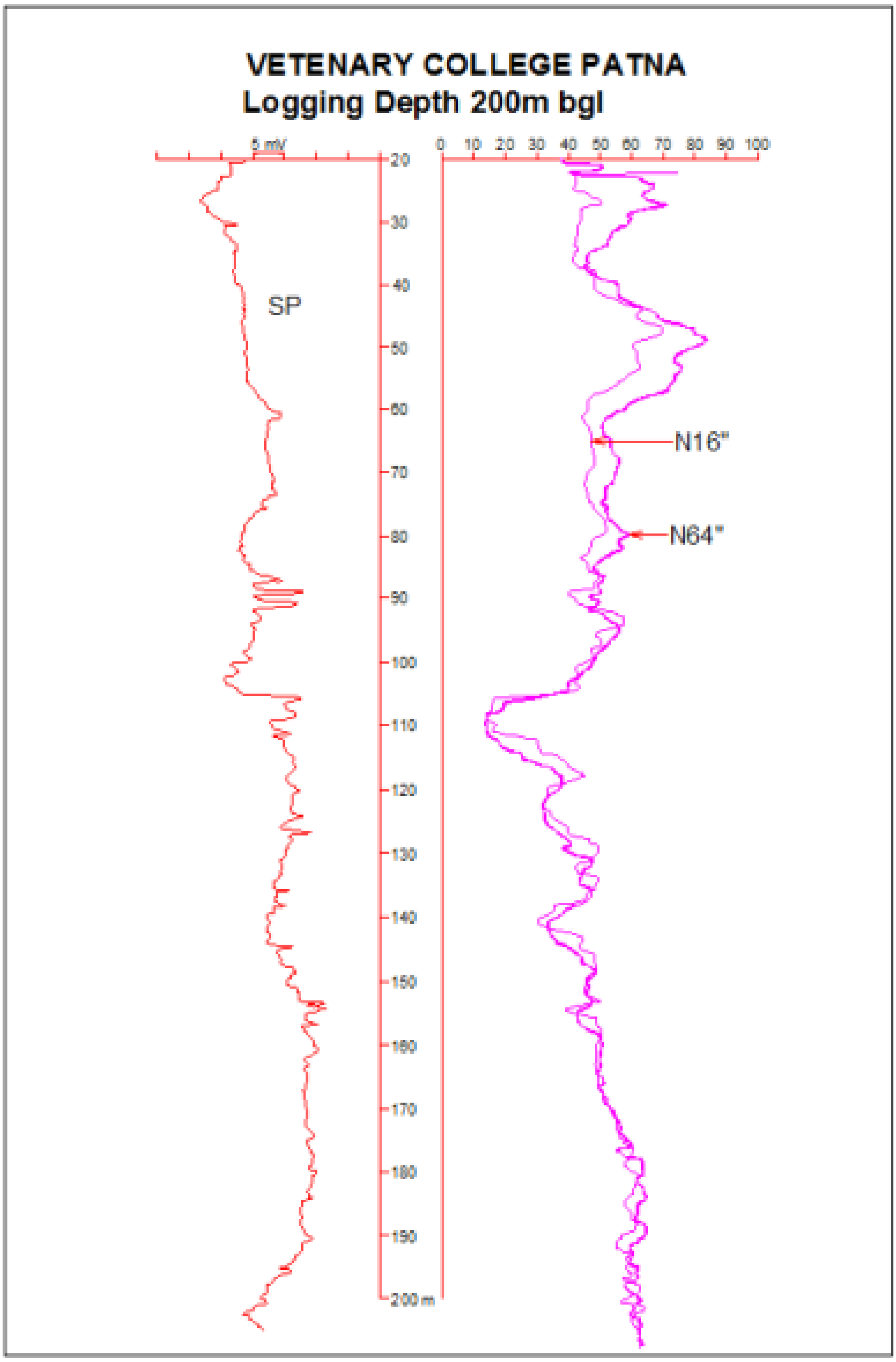
VES. No.	Location	Long	Lat	Resistivity's of individual layers in Ohm -m									Thickness of individual layers in metres								
				ρ1	ρ2	ρ3	ρ4	ρ5	ρ6	ρ7	ρ8	ρ9/ρ10/ρ11/ρ12	h1	h2	h3	h4	h5	h6	h7	h8/ h9/ h10/ h11	H Depth (m)
1	HathiaKhand	84.99711	25.61767	11	9	33	57	31	62	39	-	-	1.6	6.56	32.8	50	10	143	-	-	243
2	Bhagwatipur	84.92511	25.57353	18	23	10	46	31	41	-	-	-	2.7	5.67	21.15	35.38	125	-	-	-	189
3	Bishunpur	84.89833	25.56625	88	9	58	25	81	22	270	-	-	3.2	24	12.5	5	60	168	-	-	272
4	Bihta	84.86953	25.59806	19	12	20	61	30	62	18	-	-	2.6	8.84	25.3	57	40	61	-	-	197
5	Hiramanpur	84.92667	25.59478	24	10	23	100	42	96	17	-	-	1.6	6.88	39	82.8	44	85.8	-	-	259.7
6	Purushottampur	84.90692	25.60242	44	9	22	85	33	90	31	82	39/72/42	1.8	10.5	34.5	28	60	18	40	35/26/90	300
7	Bahpura	84.89639	25.62169	20	10	24	100	42	92	30	81/29	-	1.7	5.78	34.8	51	37	71	32	33/67	333
8	Gopalpur	84.93944	25.60606	10	7	15	80	24	51	31	67	29/53/40/93	1.8	4.14	19.98	44.08	23	27	13	22/27/52/40	272
9	Singhwara	84.94536	25.62842	11	22	48	29	85	35	140	20	-	3.7	17.76	73.5	23.4	56	61.1	87	-	322
11	Bhatehari	84.96	25.64178	37	19	60	31	58	37	-	-	-	1	52	100	23	140	-	-	-	313
12	Pandepur	84.96228	25.57322	30	20	10	45	31	55	23	67	-	1	7	20.2	64.8	13	100	60	-	320
13	Gorhan	84.97431	25.58369	8.4	29	15	58	29	60	38	92	-	1.4	7	30	65	10	199	123	-	427
14	Sattar	84.98963	25.60295	22	11	22	60	28	63	34			1	9	26	54	10	256	-	-	356
15	Gonwa	84.92494	25.55044	19	24	9	50	30	47	34	50	30	1	2.4	21.7	80.9	27	40	7	185	364
16	Raunia	84.94436	25.54525	7	14	65	30	53	29	64	-	-	1	25	75	72	93	50	-	-	316
17	Azwan	84.95519	25.53206	21	11	35	25	65	15	-	-	-	1.6	19.2	88	21.2	110	60	-	-	300
18	Kalapur	84.92114	25.53442	7	6	15	57	33	50	26	80	-	1	7.5	16.8	70.2	29.5	101.9	77.1	-	304
19	Sarasat	84.90969	25.50442	18	9	14	40	29	58	27	85	-	1	8	21	60.3	10	146	77.3	-	324
20	Arap	84.88511	25.46619	28	7	22	56	38	64	39	53	-	1.3	11.7	32.5	50	60	66.5	54	-	276
21	Raghopur	84.86333	25.54892	12	5	37	5	20	52	-	-	-	1.8	2.9	8	25.2	76	-	-	-	113.9
22	Amhara	84.85006	25.52511	160	400	136	45	145	32	-	-	-	1	8	60	86	18	60	-	-	233
23	BITmesra	85.08543	25.59649	9.9	69	36	140	-	-	-	-	-	1	25	135	-	-	-	-	-	161
24	Maner	84.88524	25.64459	19	61	21	30	130	-	-	-	-	1	50	154	21	-	-	-	-	226
25	GandhiMaidan	85.1452	25.61893	32	9	35	18	118	-	-	-	-	1.5	9.3	40	29	-	-	-	-	79.8
26	Darbeshpur	84.94569	25.65286	39	63	32	52						1	2.3	29.8						33.1
27	Mahadeva	84.9024	25.64795	16	69	17	59						5.2	5.7	37						47.9

Annexure 3.5 (c): e-logs and Gamma logs of bore wells under Pilot Aquifer Mapping areas, Patna

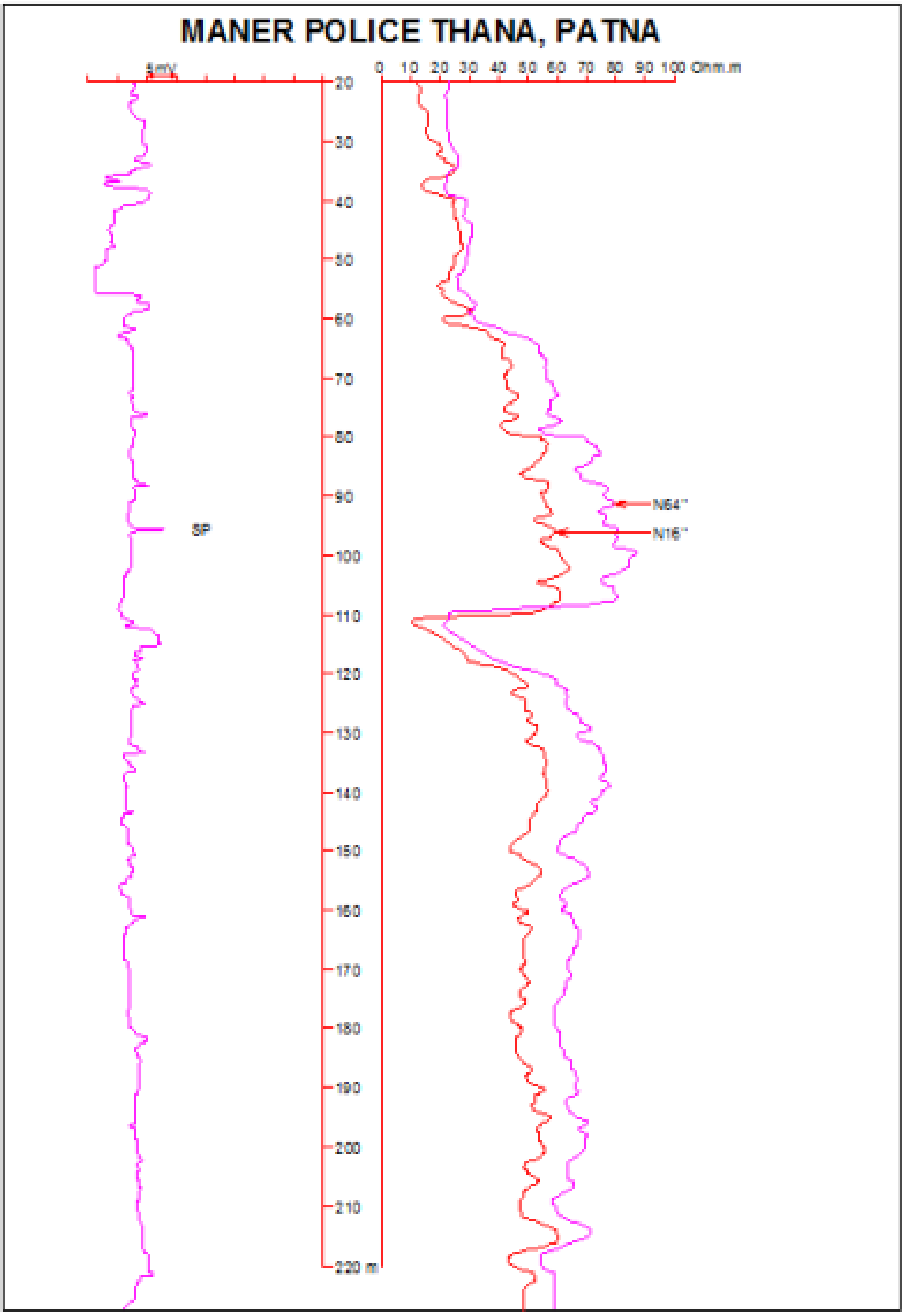
1. Electrical Log of A.N.College, Patna



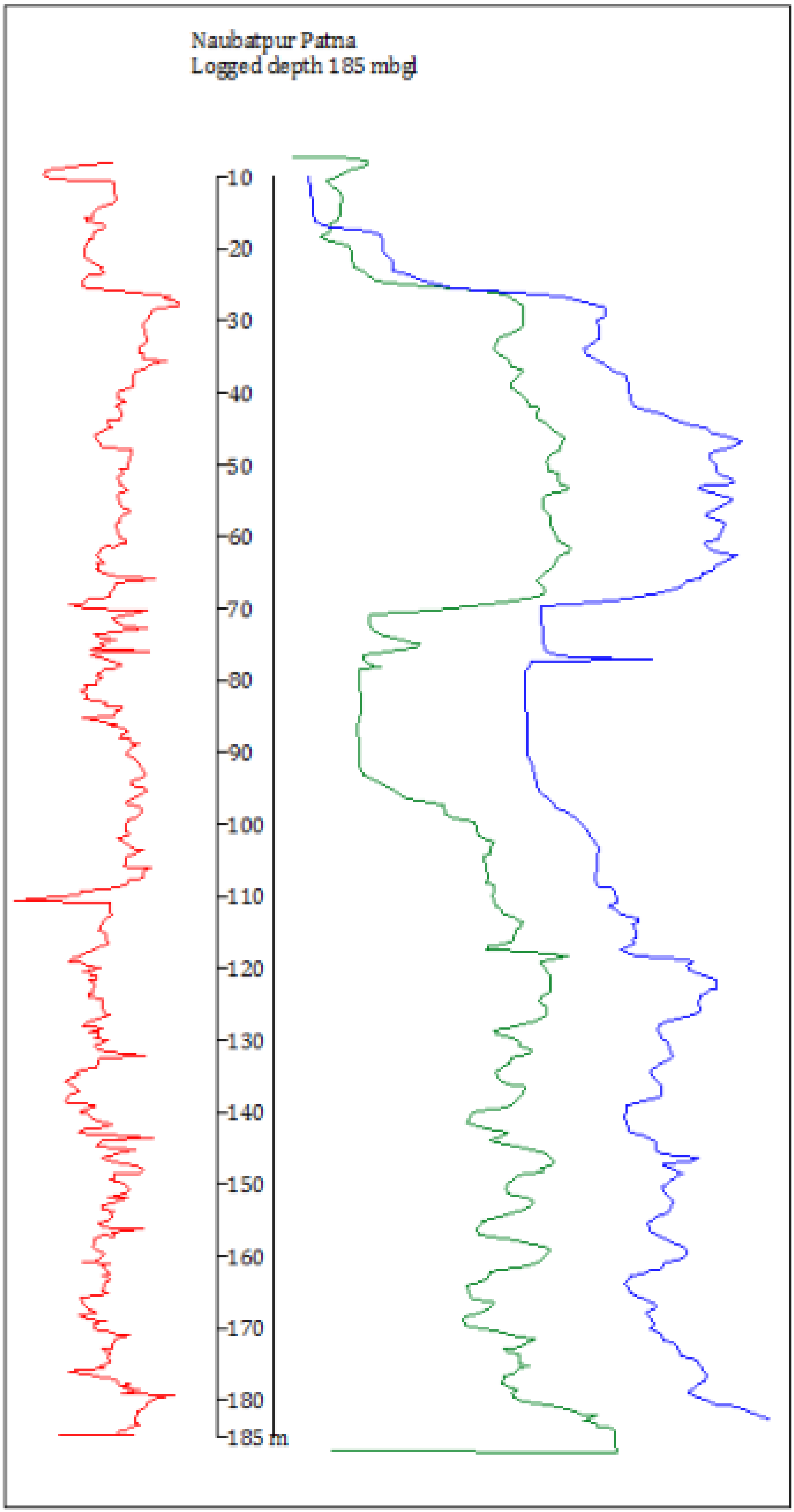
2. Electrical Log of B.V.College , Patna



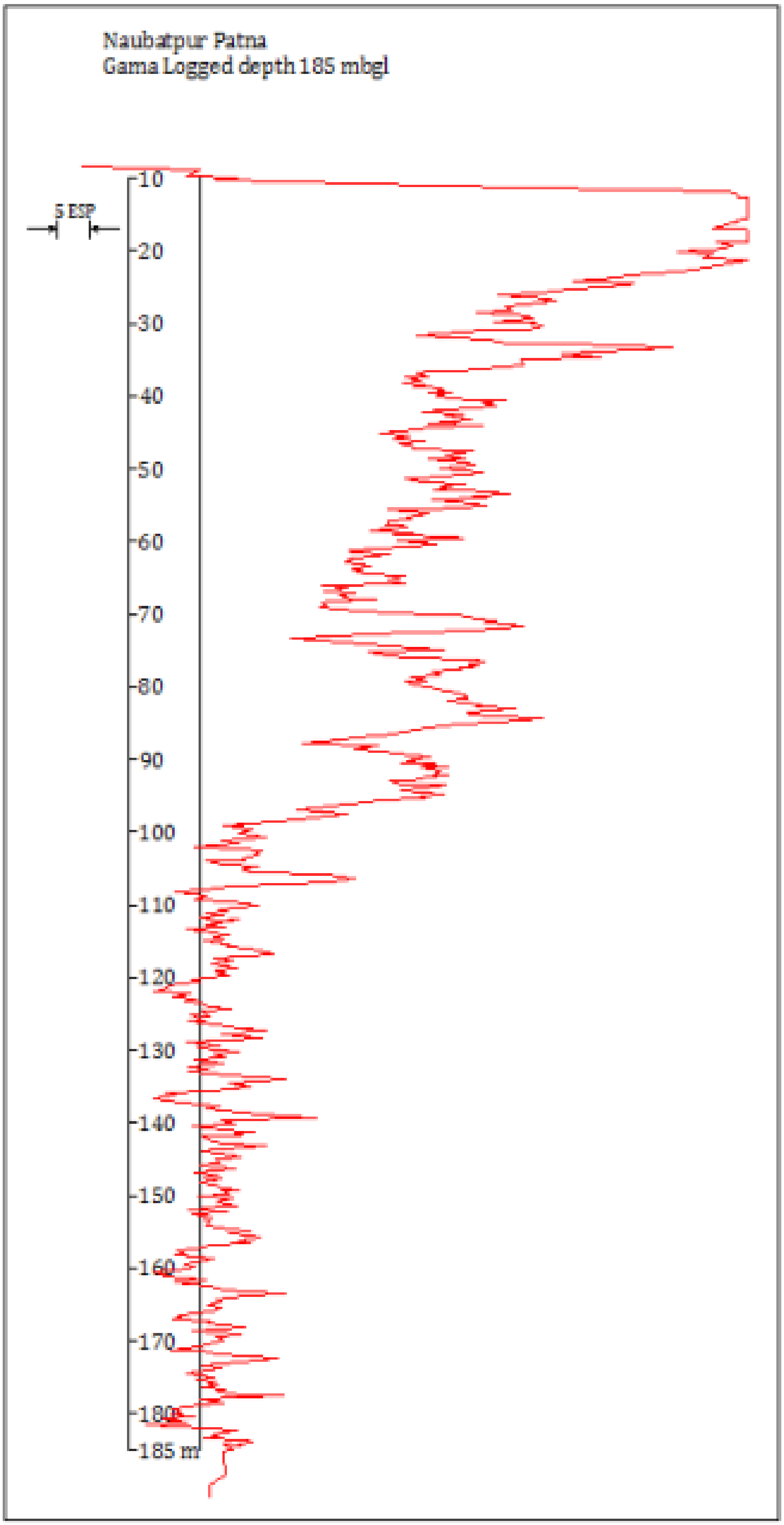
3. Electrical Log of Maner Police thana , Patna



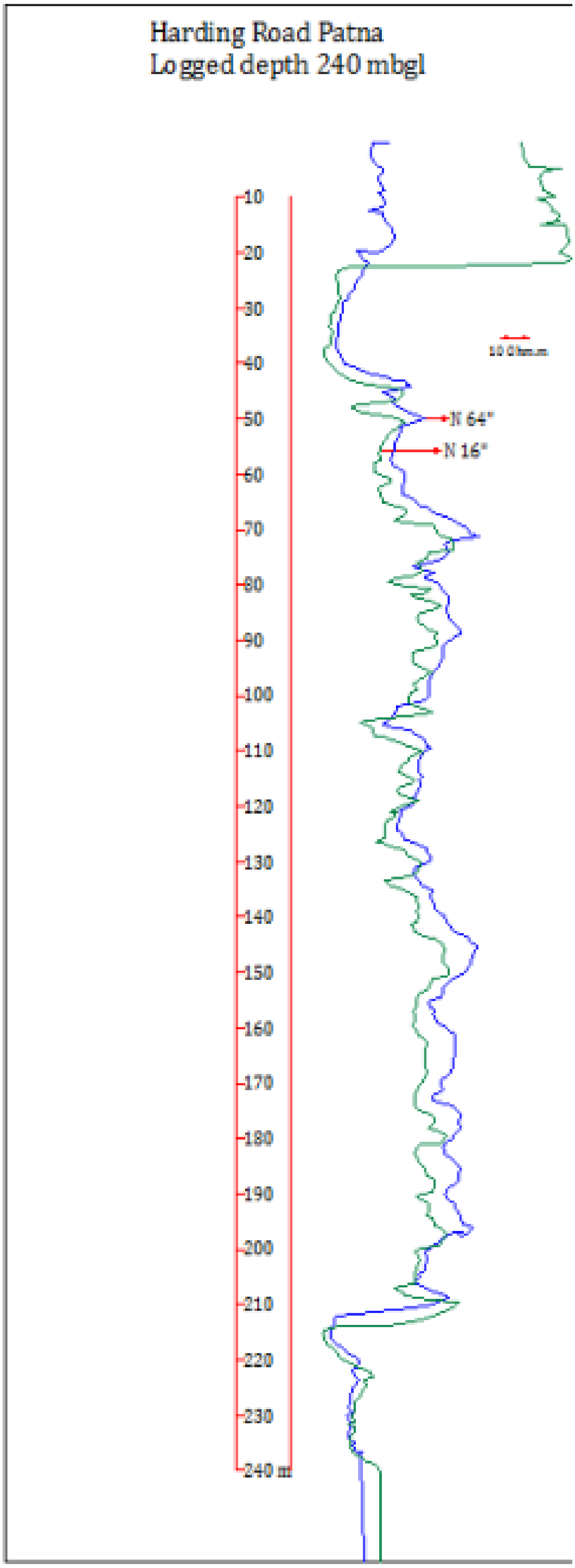
4. Electrical Log of Naubatpur, Patna (carried out by NGRI, Hyderabad)



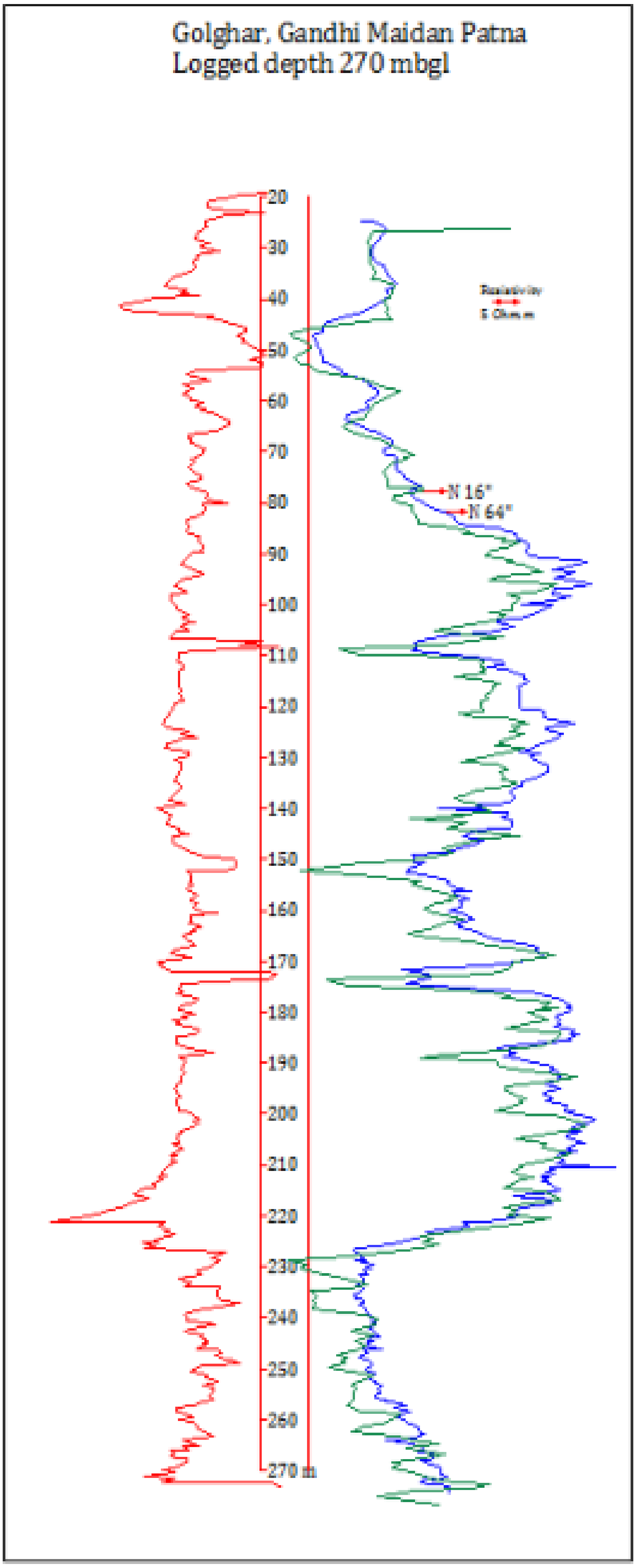
5.Gamma Log of Naubatpur, Patna(carried out by NGRI, Hyderabad)



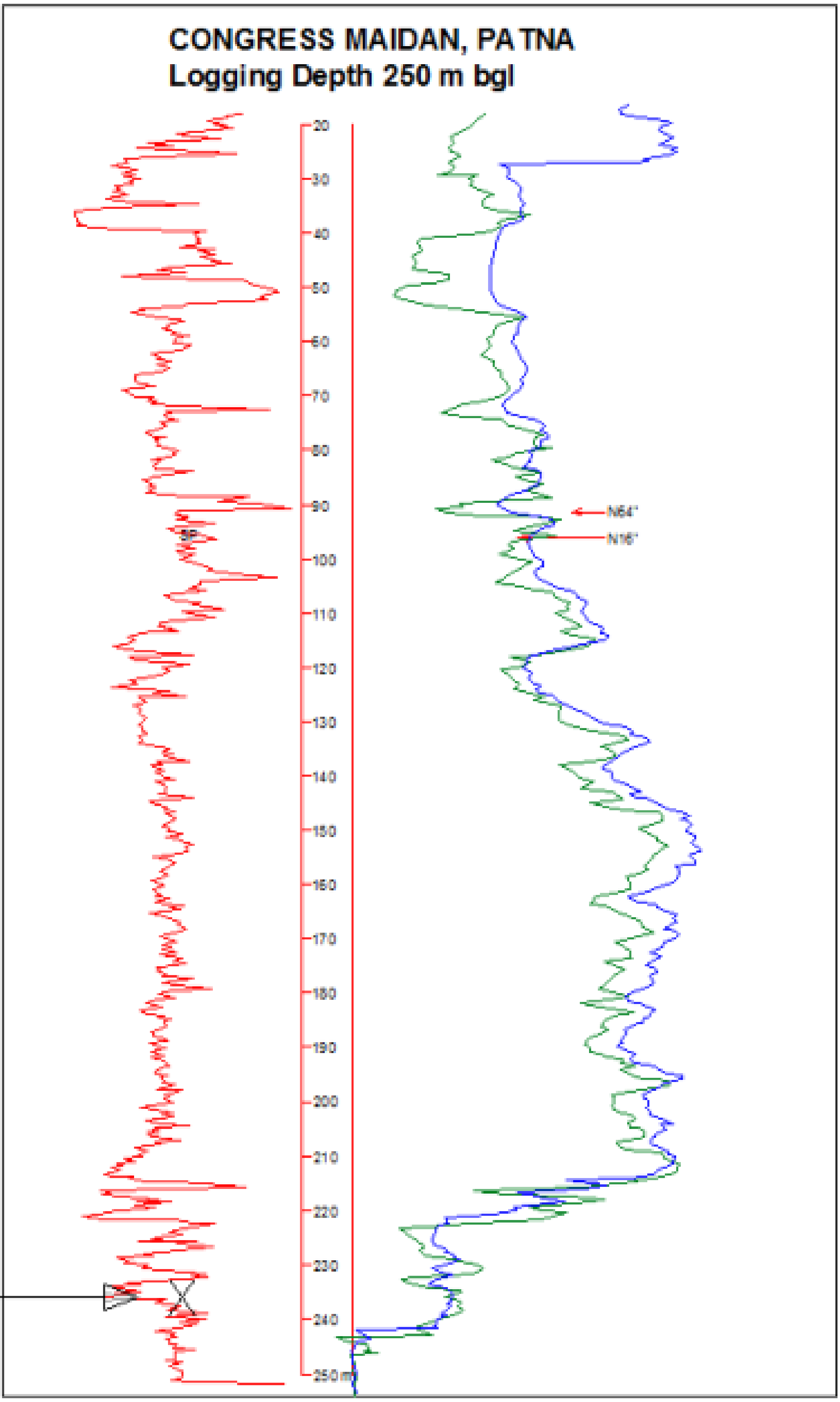
6.Electrical log of Harding road, Patna



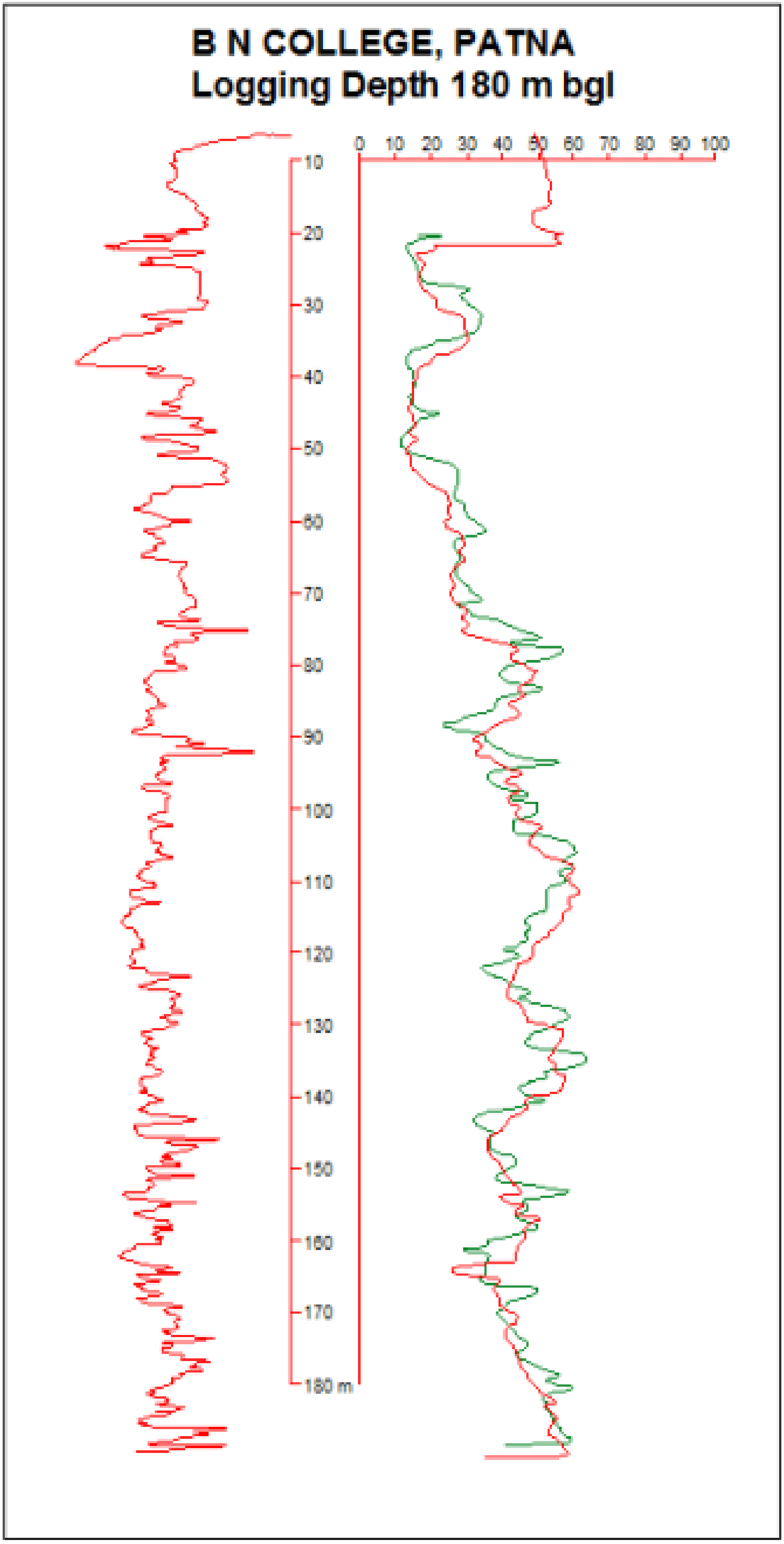
7.Electrical Log (Resistivity) of GolgharGandhiMaidan , Patna



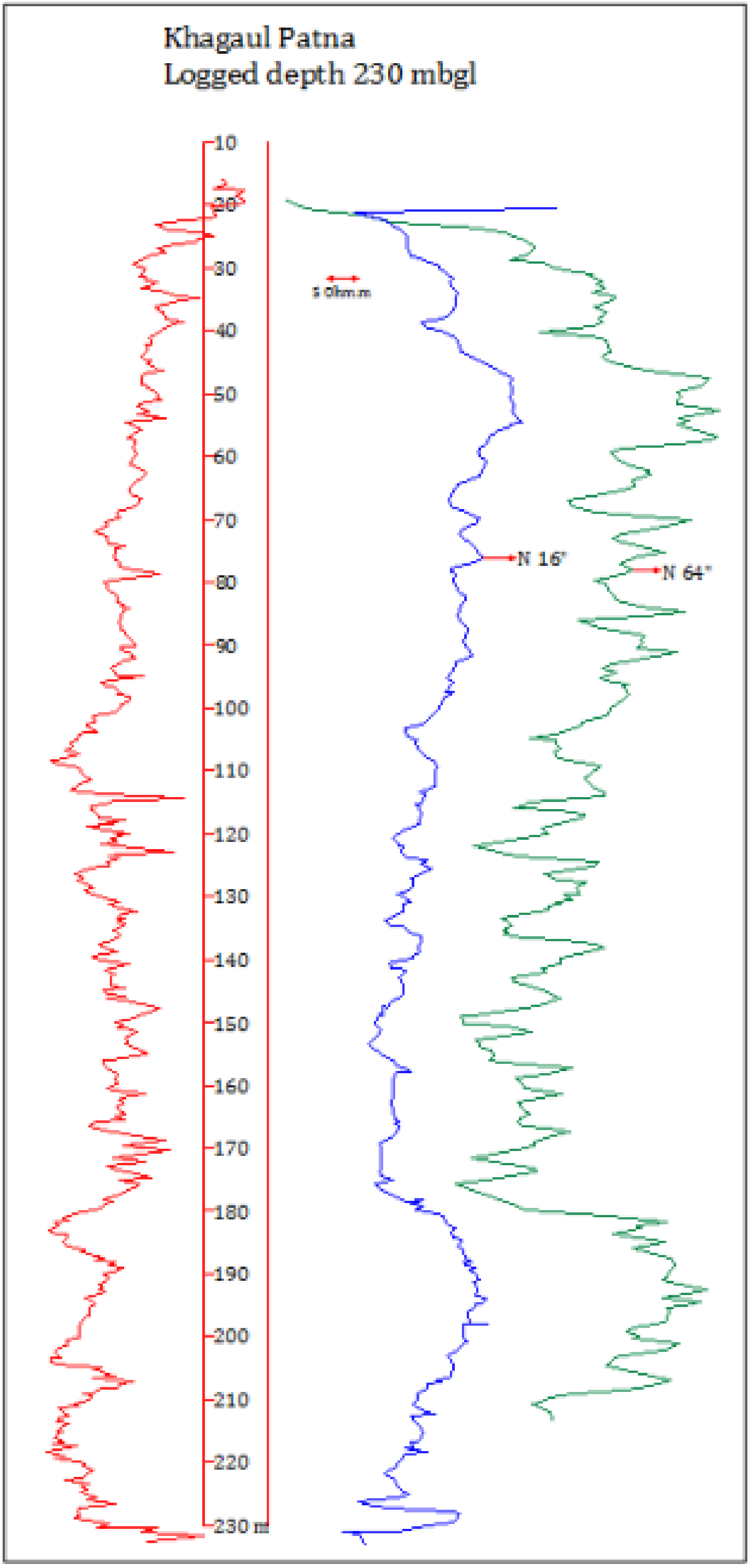
8.Electrical Log of Congress Maidan , Patna



9. Electrical Log of B.N.College, Patna

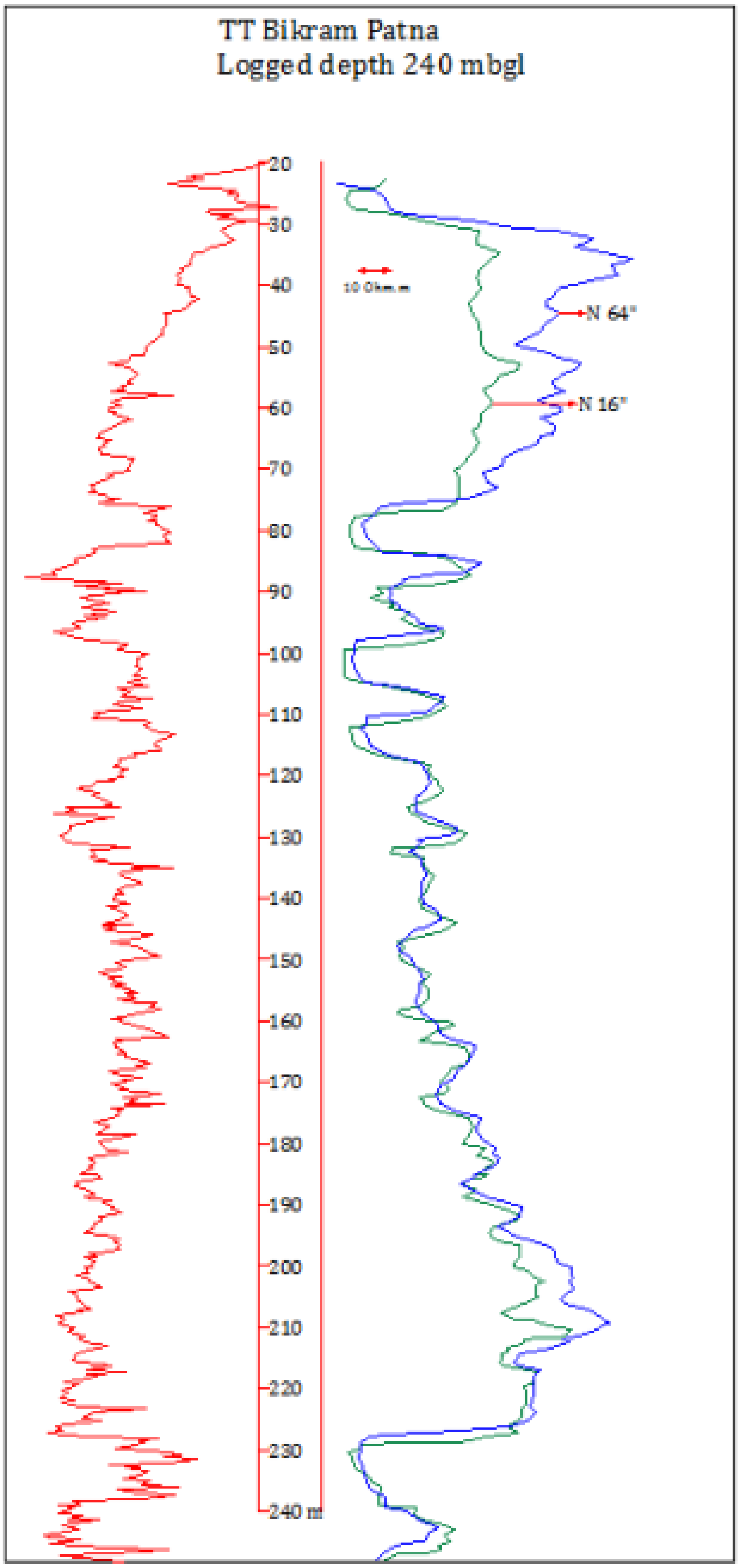


10. Electrical Log of Khagaul , Patna

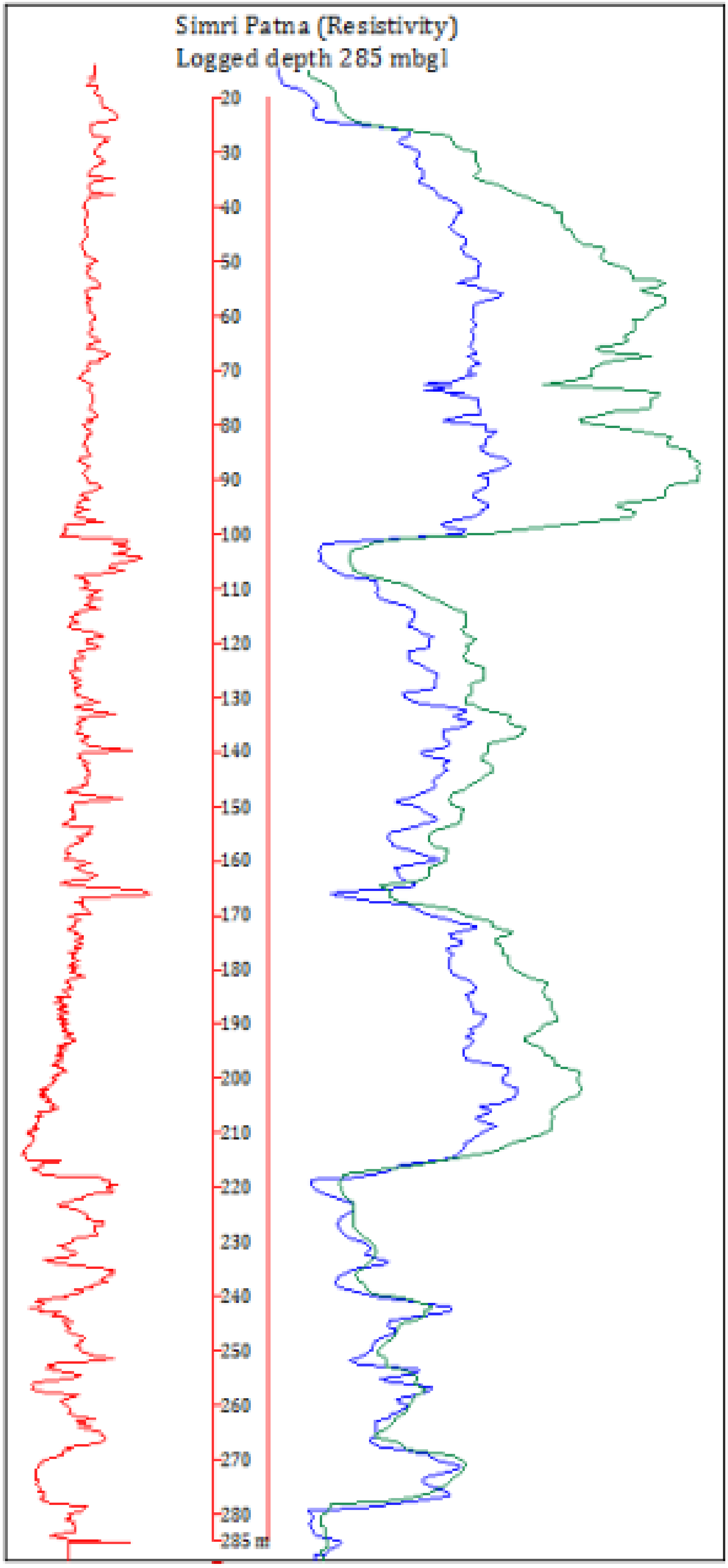


z

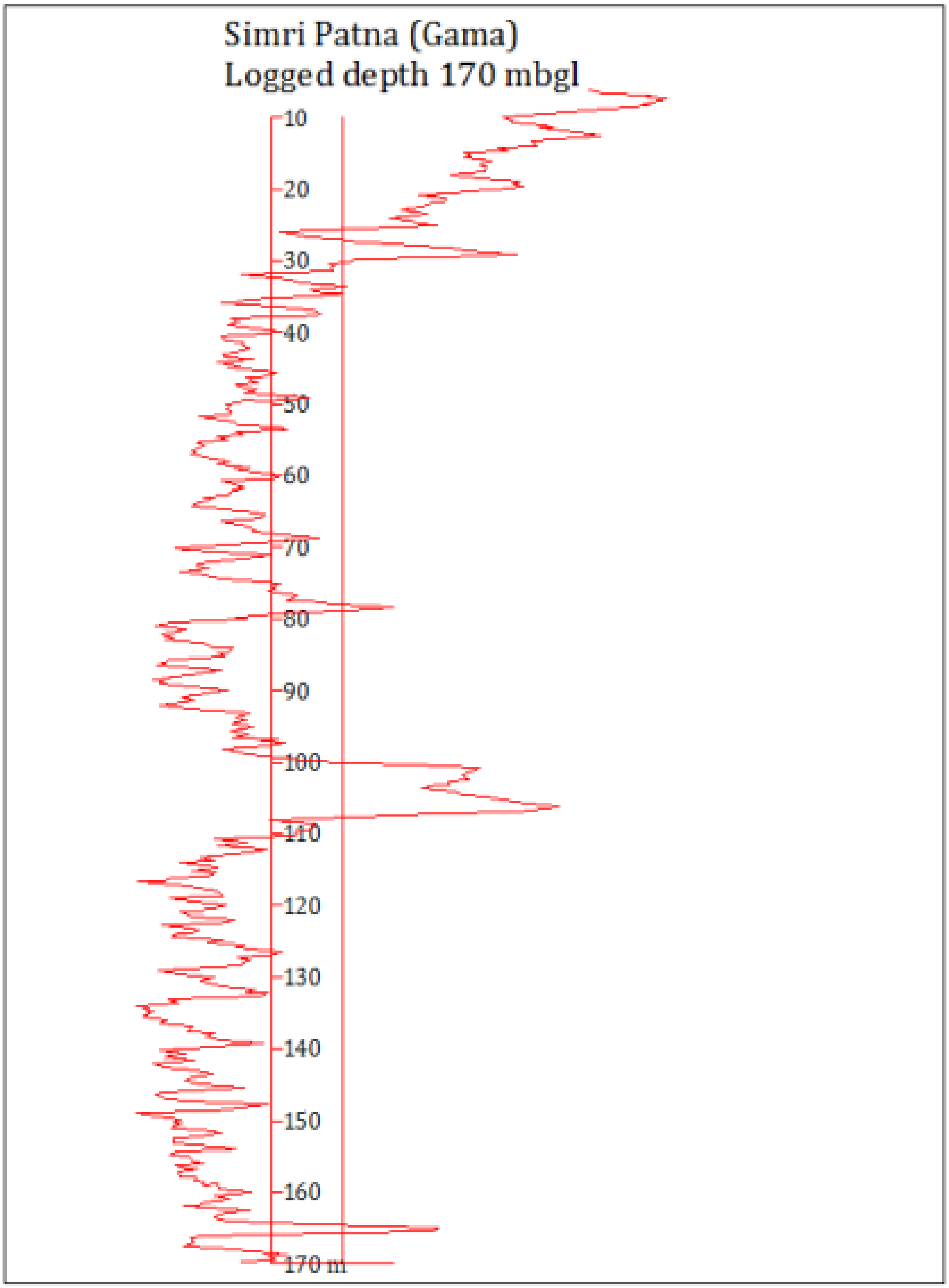
11. Electrical Log of Bikram , Patna



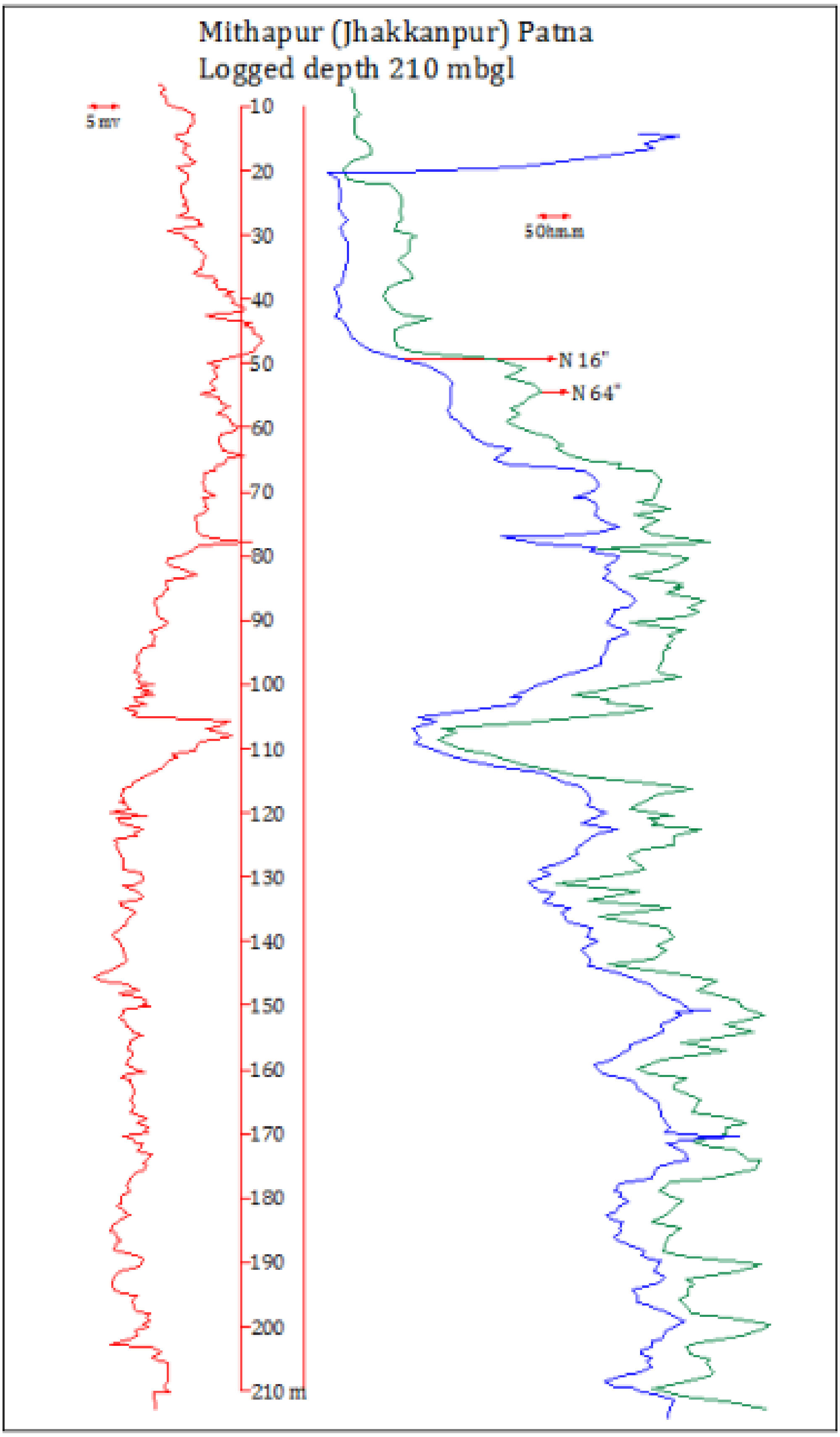
12. Electrical Log of Simri, Patna(carried out by NGRI, Hyderabad)



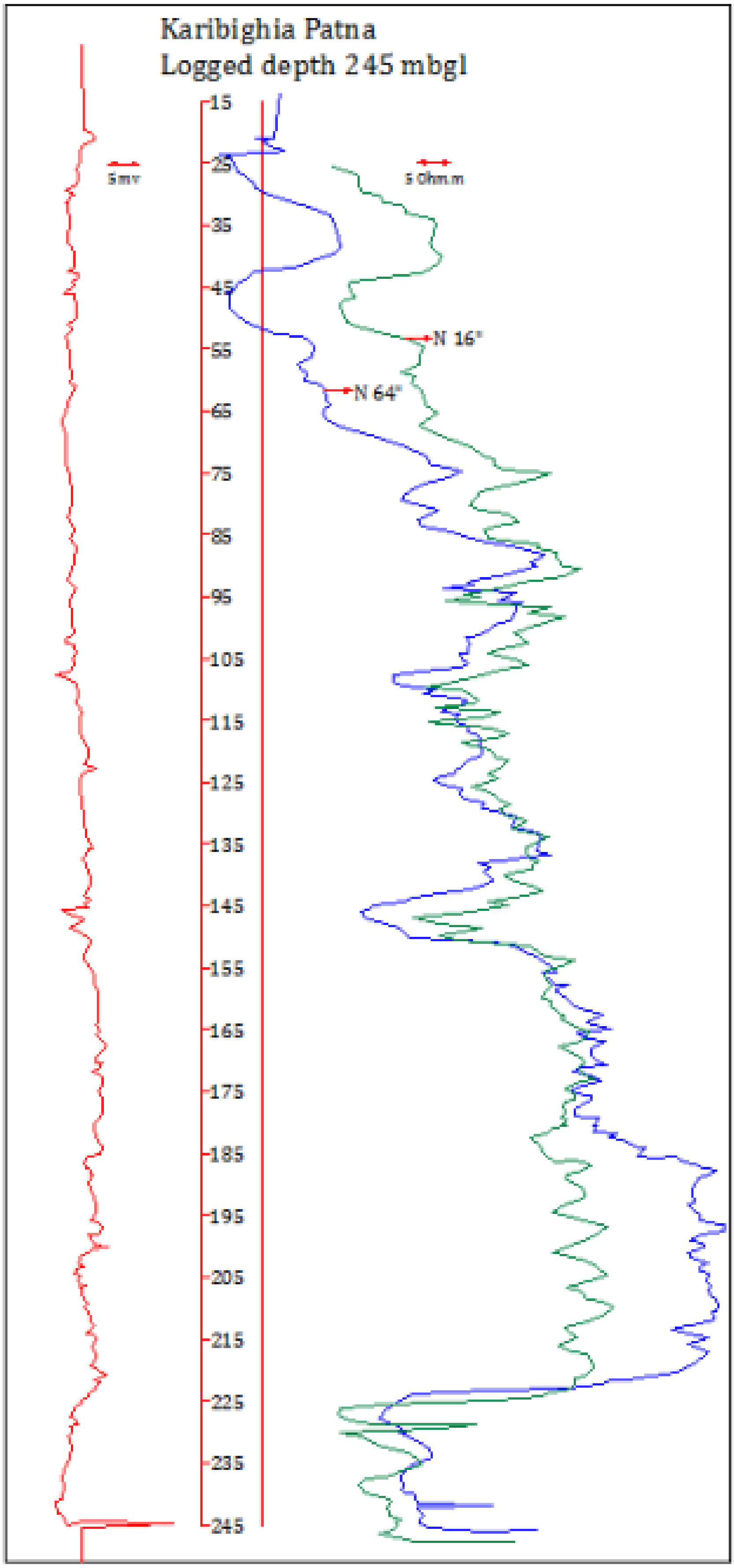
13. Gamma Log of Simri, Patna(carried out by NGRI, Hyderabad)



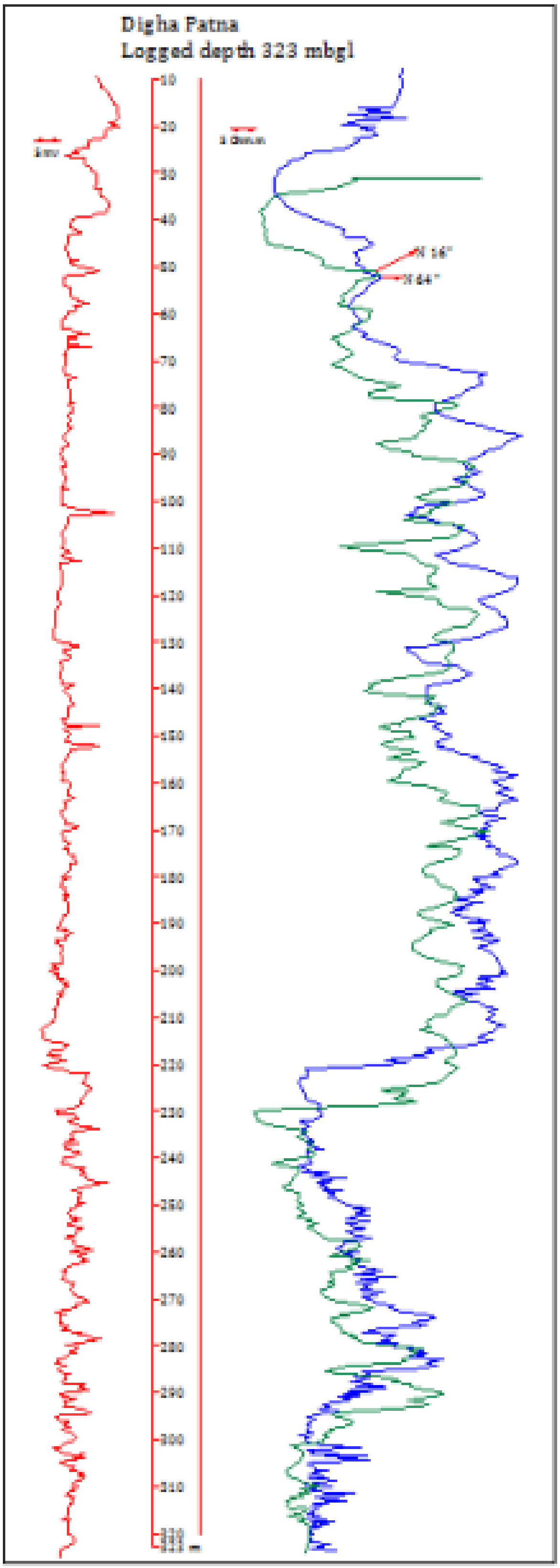
14. Electrical Log of Mithapur, Patna



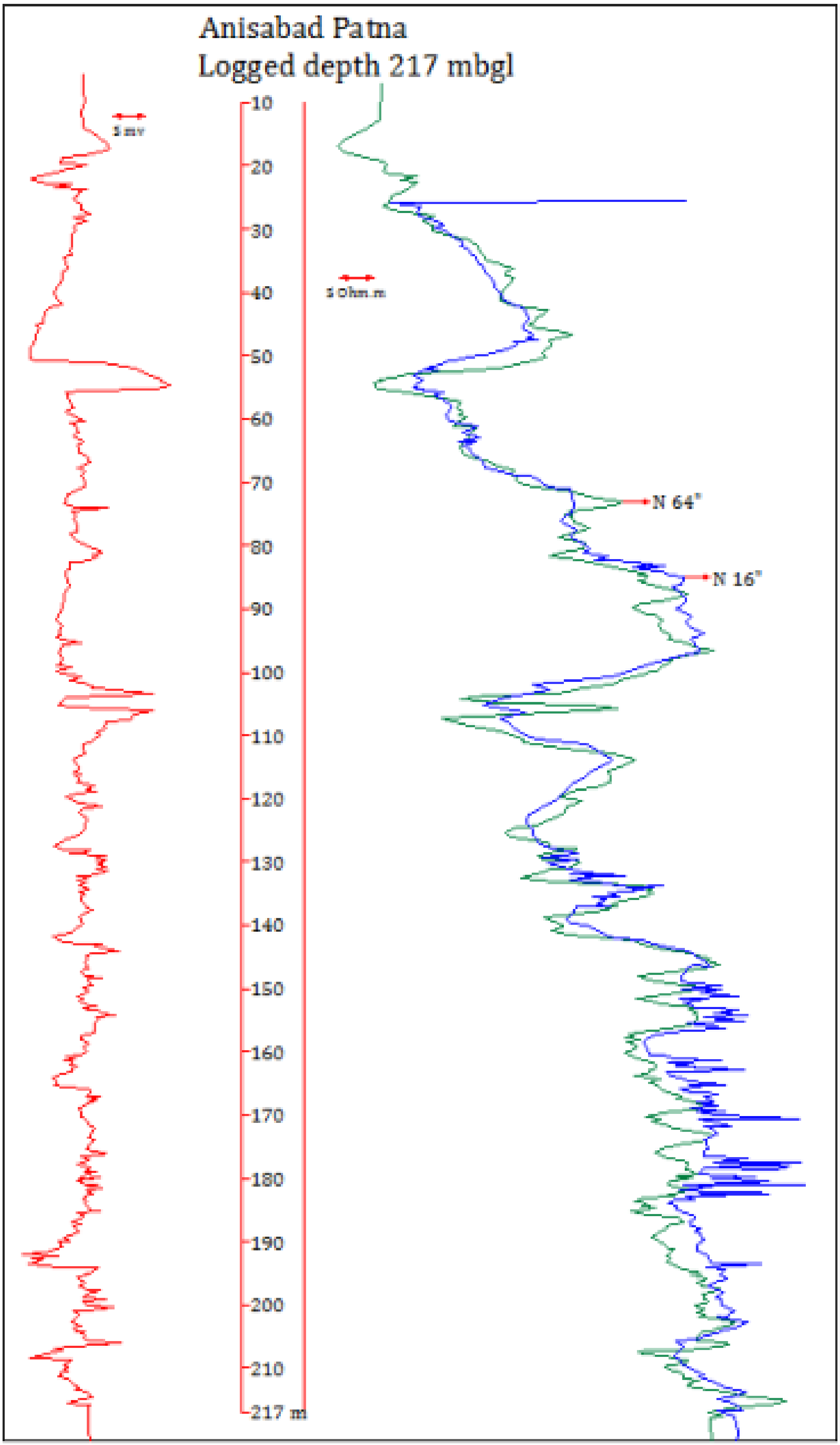
15. Electrical Log of Karbighaia, Patna



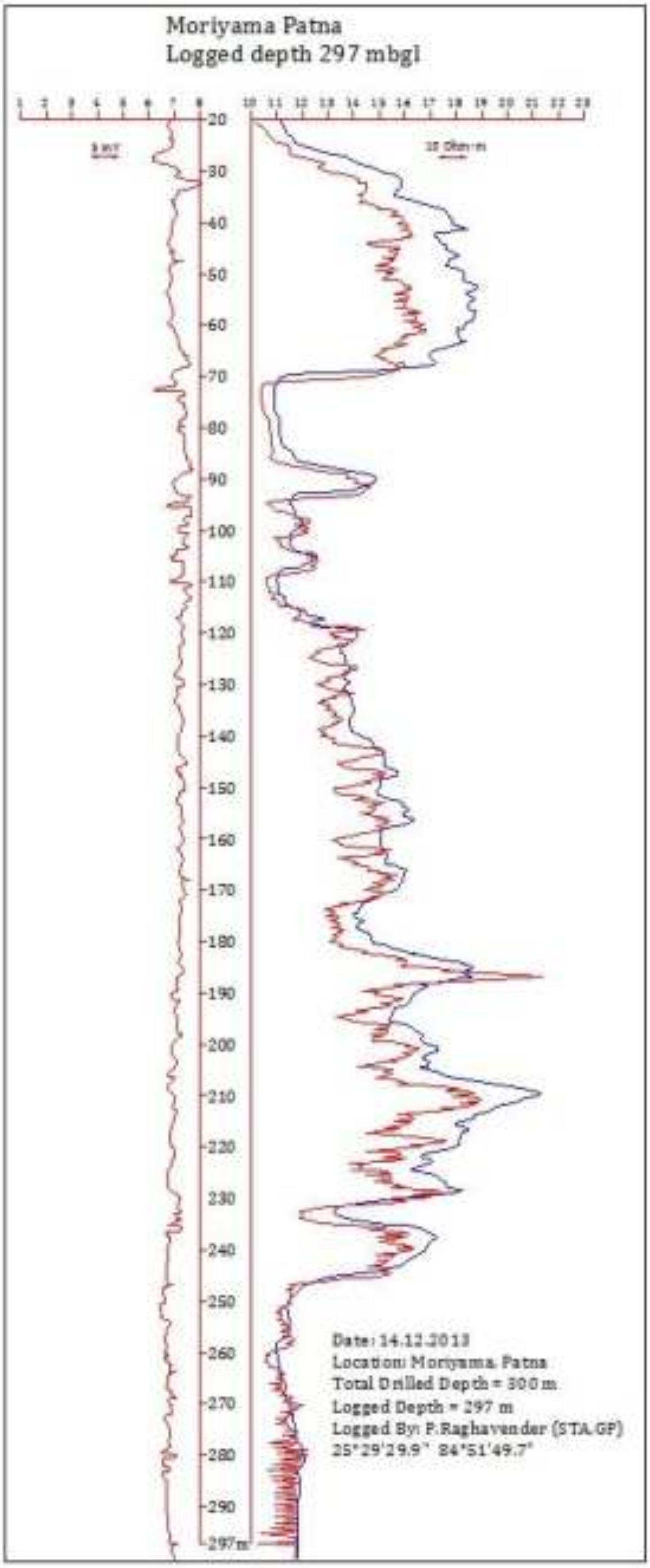
16. Electrical Log of Digha, Patna



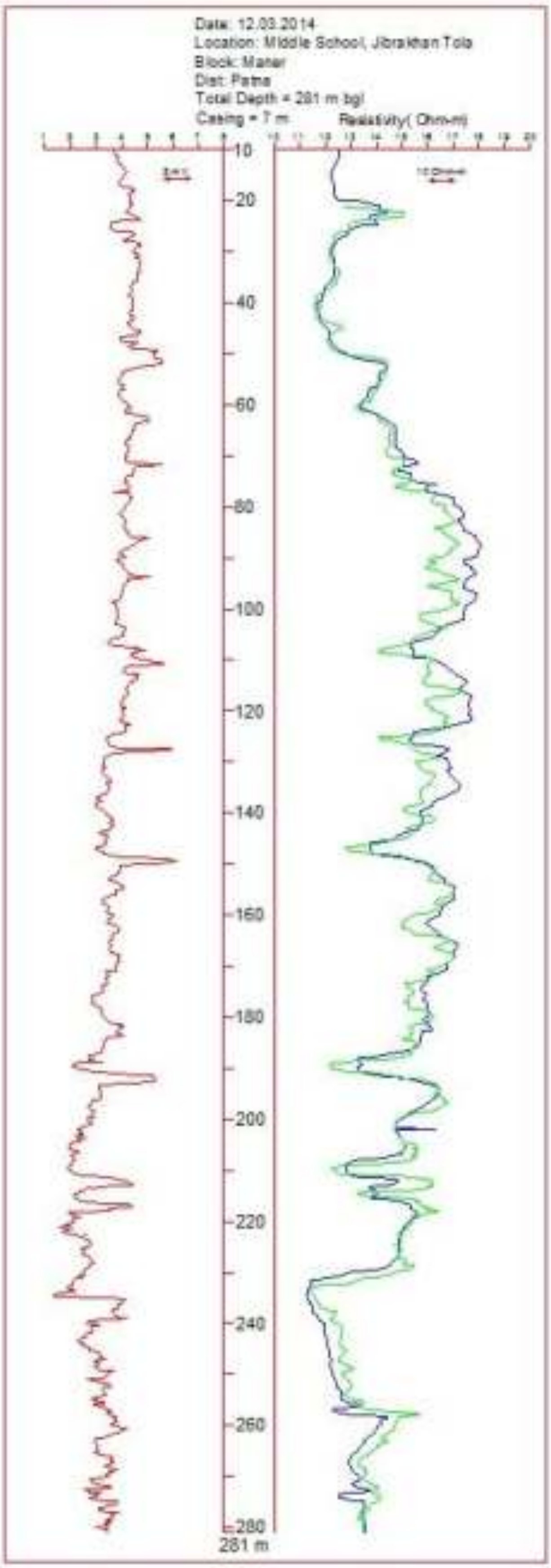
17. Electrical Log of Anisabad, Patna



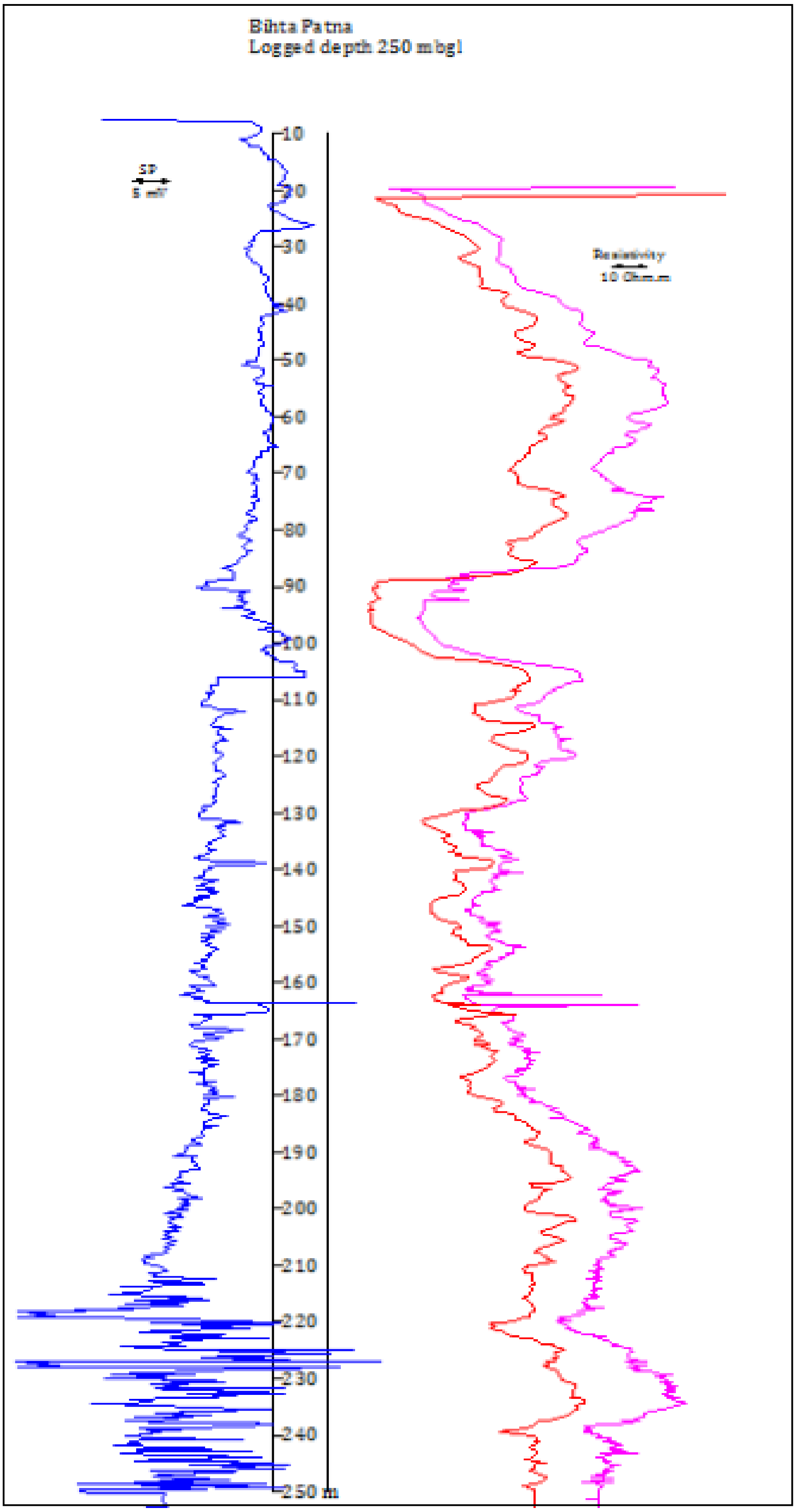
18. Electrical Log of Moriyama, Patna



19. Electrical Log of Jibrakhantola, Patna



20. Electrical Log of Bihta, Patna



Annexure 3.6 (a): Location details of VES survey conducted by NGRI, Hyderabad

VES Nos.	Name of village	Longitude (^{0}E)	Latitude (^{0}N)	Orientation	Max. AB (m)
BV_1	Simri	84.9046	25.6066	EW	1200
BV_2	Naubatpur	84.9699	25.5116	NE-SW	2200
BV_3	Bikram	84.8786	25.4521	EW	2400
BV_4	Kora(Near Rampur)	84.9752	25.5457	WE	1600
BV_5	Jaytipur-Bhela	84.9477	25.5796	EW	2800
BV_6	Shivghar	84.8464	25.4951	EW	2400
BV_7	Dariyapur	84.9316	25.4758	SN	2000
BV_8	Mohmmadpur	85.0283	25.5696	NS	410
BV_9	Lakhni Bagh	85.0277	25.5922	SSE-NNW	470
BV_10	Badipur	84.9853	25.5351	WE	500
BV_11	Baliaban	84.9201	25.4785	WE	200
BV_12	Goura DV School	84.9057	25.4757	NS	300
BV_13	Tarwan	84.9183	25.4874	WE	600
BV_14	Arap (N)	84.9051	25.5002	NS	400
BV_15	Naavi(W)	84.8926	25.5089	WE	500
BV_16	Tilapura(E)	84.8807	25.5139	WE	400
BV_17	Kanchanpura	84.8706	25.5162	EW	400
BV_18	Bhadsara	84.8925	25.4618	SW-NE	200
BV_19	Khoriatha	84.8608	25.4572	SN	300
BV_20	Moriawa	84.8655	25.4999	SN	400
BV_21	Raghopur	84.8623	25.5496	SN	400
BV_22	Bihta HP plant	84.8638	25.5564	NS	400
BV_23	Bisanpura	84.8637	25.5564	WE	300
BV_24	Chiraura_S	84.9758	25.5141	EW	500
BV_25	Naharpura_S	84.9913	25.5193	SW-NE	600
BV_26	Naharpura School	84.9913	25.5193	SW-NE	345
BV_27	Dariyapur_S	85.0004	25.5099	WE	600
BV_28	Baghatola	85.0135	25.5361	WE	690
BV_29	Sherpur	84.9813	25.6593	SE-NW	690
BV_30	Maula	84.9339	25.6126	NS	690
BV_31	Gopalpur	84.9380	25.6070	SW-NE	600
BV_32	Shrafuddinpur	84.8978	25.5838	SN	500
BV_33	Ahahiya	84.9474	25.5829	SW-NE	200
BV_34	Purnea	84.9715	25.5713	EW	700
BV_35	Neura	84.9963	25.5847	WE	800
BV_36	BITs_patna	85.0850	25.5970	NE-SW	500
BV_37	ICAR_Patna	85.0830	25.5939	EW	500
BV_38	Kurji Mohammadpur	85.0290	25.5685	EW	600
BV_39	Parsa	85.1129	25.5315	NE-SW	600

VES Nos.	Name of village	Longitude (⁰E)	Latitude (⁰N)	Orientation	Max. AB (m)
BV_40	Neuraganj	84.9922	25.5837	EW	1800
BV_41	Sabar Chak	85.0168	25.5099	EW	1450
BV_42	Madhopur	85.0607	25.5028	SN	1630
BV_43	Dhibra (W)	85.0552	25.5303	NS	2000
BV_44	Hinduni (N) near AIIMS	85.0571	25.5536	NS	2000
BV_45	Sota Chak	85.0773	25.5195	NS	2000
BV_46	Alipur (N)	85.0789	25.5432	NS	1840
BV_47	Chibbill (E)	85.0915	25.5452	NS	2000
BV_48	Simra (N)	85.1031	25.5417	EW	2000
BV_49	Tajpur (S)	84.9225	25.6194	NS	2000
BV_50	Ratantola (S)	84.9192	25.6525	EW	2000
BV_51	Udarchak	84.8566	25.4383	WE	1400
BV_52	Bauaharpura	84.8945	25.4407	WE	2980
BV_53	Amwasikriya	84.9000	25.4531	NS	1460
BV_54	Samanpura	84.9416	25.4716	WE	2000
BV_55	Azadnagar	84.9781	25.5093	WE	1400
BV_56	Danapur Bhusaula	85.0276	25.5585	NE-SW	1200
BV_57	Pursottampur	84.9056	25.5924	WE	1000
BV_58	Musepur	84.8752	25.5995	WE	2020
BV_59	Bank	84.9508	25.6246	NW-SE	1000
BV_60	Chitnawa Dakhkhin	84.9925	25.6363	NS	1000
BV_61	Chitnhwa Bageecha	84.9938	25.6396	NS	1000
BV_62	Sherpur	84.9851	25.6607	NS	1000
BV_63	Bhita	84.8844	25.5627	WE	1000
BV_64	Patel halt	84.8996	25.5648	WE	1000
BV_65	Sadisopur	84.9217	25.5678	WE	600
BV_66	Jayantipur	84.9454	25.5702	EW	1000
BV_67	Ghudichak	84.9712	25.5730	EW	1200
BV_68	Mahammdpur	85.0286	25.5716	SN	1200
BV_69	Lakhanagar	85.0422	25.6082	NS	800
BV_70	Gosaitola	85.1162	25.6361	EW	3000
BV_71	Digha	85.0777	25.6410	NS	1000
BV_72	Parsa Bazar	85.1141	25.5349	NS	1000

Annexure 3.6 (b): Location details of TEM survey conducted by NGRI, Hyderabad

S No	TEM	Village	Long(^{0}E)	Lat(^{0}N)
1	BT-1	Basanth Chakra	84.99507	25.56536
2	BT-2	Snehi Tola	84.9612	25.50898
3	BT-6	Maner	84.88577	25.64631
4	BT-8	Anandpur	84.86958	25.61399
5	BT-9	Dekuli	84.86657	25.59739
6	BT-10	Bhita	84.87486	25.56352
7	BT-11	Radhopur	84.85881	25.5443
8	BT-12	Amharah	84.8516	25.53011
9	BT-13	Yamunapur	84.84786	25.5225
10	BT-14	Sikaria (Taranagar)	84.83817	25.49822
11	BT-15	Shivgarh	84.84892	25.49568
12	BT-16	Dhatiyana	84.86121	25.47165
13	BT-17	Bikram	84.85863	25.44334
14	BT-18	Andhra Chauk	84.89964	25.46924
15	BT-19	Darbeshpur	84.93974	25.64668
16	BT-20	Bhateri	84.95251	25.63669
17	BT-21	Gopalpur	84.94509	25.619
18	BT-22	Shinghari	84.93373	25.62758
19	BT-23	Bhosola Danapur	85.0609	25.55838
20	BT-24	Naubatpur	84.96673	25.503
21	BT-25	Neora	84.9897	25.56799
22	BT-26	Serpur ISH	84.98083	25.65549
23	BT-27	Simiri(Daulatpur)	84.90554	25.60598
24	BT-28	Arap (North)	84.90227	25.49637
25	BT-30	Babu Chak	85.01101	25.56769
26	BT-31	Hasan Pura	85.05675	25.53226
27	BT-32	Shapur	85.06052	25.52294
28	BT-33	Daray Chak	85.05905	25.50908
29	BT-34	Lakmi Bhur	85.02808	25.59159
30	BT-36	Hinduni	85.06054	25.54506
31	BT-37	Nayan Chauk	85.05451	25.53831
32	BT-38	Bramhpura	85.0801	25.5607
33	BT-39	Parsa bazar	85.1217	25.5451
34	BT-40	Nathupur	85.12234	25.55596
35	BT-41	Dariyapur	85.13507	25.55809

S No	TEM	Village	Long(^{0}E)	Lat(^{0}N)
36	BT-42	Jaganpura	85.15183	25.56884
37	BT-43	Hanuman Nagar	85.16827	25.57711
38	BT-45	Birpur	84.97491	25.52778
39	BT-46	Rampur	84.97207	25.54701
40	BT-47	Faeridpur	84.98288	25.55201
41	BT-48	Basant Chak	84.9923	25.5645
42	BT-49	Usari Udanola	85.0141	25.59541
43	BT-50	Dibra(Usari)	85.02013	25.60755
44	BT-51	Danapur Cant.	85.02326	25.62887
45	BT-52	Mathiyapur	85.02632	25.61926
46	BT-53	Garak	84.87318	25.45411
47	BT-54	Baliari	84.89097	25.4892
48	BT-55	Sarasat	84.9133	25.50557
49	BT-56	Kalapur	84.9221	25.53303
50	BT-57	Gonwa	84.92219	25.54903
51	BT-58	Kanhauli	84.92209	25.58594
52	BT-5	Bits Ground	85.0821	25.5973
53	BT-7	Madhopur	84.8757	25.6309
54	BT-44	Bahadurpur	85.1845	25.5994
55	BT_59	Siariya	25.4524	84.8997
56	BT_60	Marayanpura(N)	25.4754	84.9495
57	BT_61	Chirura(W)	25.5154	84.9796
58	BT_62	Patsa(S)	25.5664	84.881
59	BT_63	Doghra	25.5861	84.89
60	BT_64	Musepur(S)	25.5964	84.8716
61	BT_65	Simri	25.6059	84.9051
62	BT_66	Bahpura(W)	25.6205	84.9035
63	BT_67	Pursottampur	25.5951	84.9028
64	BT_68	Maula (W)	25.6128	84.919
65	BT_69	Tajpur(W)	25.6284	84.9239
66	BT_70	Darbeshpur(W)	25.6544	84.9378
67	BT_71	Kamala Gopalpur	25.6198	84.9442
68	BT_72	Gopalpur(E)	25.6139	84.9552
69	BT_73	Baula	25.6066	84.9726
70	BT_74	Sarai(SE)	25.6001	84.9891
71	BT_75	Tikaipur	25.5898	84.9819

S No	TEM	Village	Long(^{0}E)	Lat(^{0}N)
72	BT_76	Mahuribagh	25.6125	84.9943
73	BT_77	Sahapur (S)	25.6247	85.0099
74	BT_78	Kathuriya	25.6249	84.9935
75	BT_79	Manner_tola	25.6486	84.8875
76	BT_80	Tilhariya(N)	25.6349	84.9301
77	BT_81	Raghabapur	25.544	84.8734
78	BT_82	Kanchanpur(S)	25.5177	84.8707
79	BT_83	Bishambarpur	25.4683	84.8595
80	BT_84	Bikarn	25.4414	84.8663
81	BT_85	Poltu Chantni	25.5418	84.8977
82	BT_86	Jaintipur	25.58	84.9478
83	BT_87	Lakoshmanpur	25.5929	84.9582
84	BT_88	Neura (N)	25.5827	84.9968
85	BT_89	Gorhan	25.5821	84.971
86	BT_90	Burutola (W)	25.5601	84.9845
87	BT_91	Jamaluddin(N)	25.5722	85.0313
88	BT_92	Korji	25.5583	85.0255
89	BT_93	Hudas chack	25.5417	85.0253
90	BT_94	Janipur	25.5212	85.0253
91	BT_95	Mainpuran City Ghat	25.629	85.1244
92	BT_96	Mainpuran City Ghat	25.6333	85.1189
93	BT_97	Chandmari	25.6299	85.0195
94	BT_98	ISM_Jamaluddin	25.5941	85.0213
95	BT_99	Nasirpura	25.5312	85.0959
96	BT_100	Kurkuri	25.5526	85.0766
97	BT_101	Science College Patna	25.6175	85.1704
98	BT_4	Veteranary college	25.60041	85.08524
99	BT_33	Daray Chak	25.50908	85.05905
100	BT_29	Mahatpur	25.56783	85.0285
101	BT_28	Arap (North)	25.49637	84.90227

Annexure 3.6 (c): Location details of ERT survey conducted by NGRI, Hyderabad

Sl.No.	Village name	Longitude(^{0}E)	Latitude (^{0}N)	Direction	Spreading (m)
BE-1	Arap	84.90231	25.49633	W-E	320
BE-2	Simri	84.90455	25.60718	E-W	320
BE-3	Simri	84.90447	25.60503	N-S	320
BE-4	Naubathpur(NE)	84.96992	25.51163	NE-SW	320
BE-5	Bikram	84.8799	25.45208	E-W	320
BE-6	Ghazacheck m.pur	85.0121	25.53621	SW-NE	480
BE-7	Kora	84.97517	25.54571	W-E	480
BE-8	Mohammadpur	85.02826	25.56953	N-S	480
BE-9	Lakhnibhag	85.02766	25.59223	SSE-NNW	480
BE-10	Chandmari	85.01487	25.62566	N-S	480
BE-11	Sadisopur	84.91904	25.56922	S-N	480
BE-12	Gopalpur	84.93851	25.6082	S-N	480
BE-13	Sherpur	84.97057	25.64577	N-S	480
BE-14	Bank(South)	84.94518	25.62627	S-N	480
BE-15	Bank(South)	84.94753	25.62611	W-E	480
BE-16	Bhita(Sugarmill)	84.88166	25.55475	N-S	480
BE-17	Bhita(Sugarmill)	84.881	25.556	W-E	480
BE-18	Sadikpur	84.92614	25.64389	S-N	480
BE-19	Sadikpur	84.92607	25.64283	W-E	480

Annexure 3.6 (d): Aquifer disposition obtained from the SKY-TEM and groundwater geophysical survey in the AQBHR area

Grid Information	Depth of the formation (m bgl)		Mean Resistivity (Ohm-m)	Inferred Aquifers & Clay layer	Inferred hydrogeological formation
	From	To			
II_5 RL=53.02 m, AMSL	67.0	150.8	62.8	First Principal Aquifer	Coarse Sand
	150.8	153.1	17.5	Clay_II	Clay
	153.1	254.8	44.2	Second Principal Aquifer	Fine Sand
II_6 RL=53.65 m, AMSL	72.9	159.5	76.2	First Principal Aquifer	Coarse Sand
	159.5	181.2	19.5	Clay_II	Clay+Sand+Silt
	181.2	267.5	25.2	Second Principal Aquifer	Fine Sand
III_5 RL=52.65 m, AMSL	54.8	136.4	79.9	First Principal Aquifer	Coarse Sand
	136.4	136.4	13.9	Clay_II	Clay
	136.4	258.9	56.1	Second Principal Aquifer	Medium Sand
III_6	54.5	133.4	85.8	First Principal Aquifer	Gravel Sand
RL=52.87m, AMSL	133.4	170.8	16.3	Clay_II	Clay
	170.8	280.0	24.0	Second Principal Aquifer	Finne Sand
III_7 RL=49.46 m, AMSL	31.9	70.7	159.4	First Principal Aquifer	Gravel Sand
	70.7	175.5	14.6	Clay_II	Clay
	175.5	265.5	23.4	Second Principal Aquifer	Sandy Clay
III_8 RL=50.81 m, AMSL	59.3	144.8	104.1	First Principal Aquifer	Gravel +Sand
	144.8	185.4	12.9	Clay_II	Clay
	185.4	260.6	42.4	Second Principal Aquifer	Fine Sand
III_9 RL=51.83 m, AMSL	45.6	103.1	56.3	First Principal Aquifer	Medium Sand
	103.1	149.7	10.5	Clay_II	Clay
	149.7	226.6	50.7	Second Principal Aquifer	Medium Sand

III_10 RL=49.37m, AMSL	47.8	102.8	75.4	First Principal Aquifer	Coarse Sand
	102.8	102.8	9.8	Clay_II	Clay
	102.8	205.7	49.7	Second Principal Aquifer	Medium Sand
III_14 RL=54.93m, AMSL	44.7	119.6	34.9	First Principal Aquifer	Fine Sand
	119.6	152.5	9.2	Clay_II	Clay
	152.5	300.6	38.8	Second Principal Aquifer	Medium Sand
III_15 RL=51.02m, AMSL	56.0	133.5	41.9	First Principal Aquifer	Fine Sand
	133.5	161.9	14.4	Clay_II	Clay
	161.9	331.1	42.5	Second Principal Aquifer	Fine Sand
IV_4 RL=52.58m, AMSL	27.2	79.1	74.5	First Principal Aquifer	Coarse Sand
	79.1	110.7	14.8	Clay_II	Clay
	110.7	252.0	107.5	Second Principal Aquifer	Gravel + Sand
IV_5 RL=54.13m, AMSL	38.4	128.6	147.1	First Principal Aquifer	Gravel + Sand
	128.6	131.2	8.0	Clay_II	Clay
	131.2	278.6	91.0	Second Principal Aquifer	Gravel + Sand
IV_6 RL=52.95m, AMSL	30.5	116.5	94.1	First Principal Aquifer	Gravel + Sand
	116.5	142.1	7.7	Clay_II	Clay
	142.1	305.6	29.6	Second Principal Aquifer	Fine Sand
IV_7 RL=49.10m, AMSL	21.8	83.7	60.3	First Principal Aquifer	Coarse sand
	83.7	139.4	10.9	Clay_II	Clay
	139.4	240.2	23.0	Second Principal Aquifer	Sandy Clay
IV_8 RL=50.27m, AMSL	31.1	82.8	47.7	First Principal Aquifer	Medium Sand
	82.8	130.3	14.2	Clay_II	Clay
	130.3	203.9	50.8	Second Principal Aquifer	Medium Sand

IV_9 RL=50.38m, AMSL	28.4	84.0	48.8	First Principal Aquifer	Medium Sand
	84.0	116.1	16.4	Clay_II	Clay
	116.1	116.1	63.7	Second Principal Aquifer	Coarse Sand
IV_10 RL=50.02m, AMSL	20.0	71.3	46.5	First Principal Aquifer	Medium Sand
	71.3	91.5	19.5	Clay_II	Clay
	91.5	192.1	61.5	Second Principal Aquifer	Medium Sand
IV_11 RL=50.64m, AMSL	20.8	80.6	49.1	First Principal Aquifer	Medium Sand
	80.6	101.3	19.8	Clay_II	Clay
	101.3	204.7	48.1	Second Principal Aquifer	Medium Sand
IV_12 RL=52.35m, AMSL	30.7	99.8	52.5	First Principal Aquifer	Medium Sand
	99.8	115.9	17.0	Clay_II	Clay
	115.9	223.7	36.3	Second Principal Aquifer	Fine Sand
IV_13 RL=54.17m, AMSL	30.3	93.7	44.2	First Principal Aquifer	Fine Sand
	93.7	129.3	12.9	Clay_II	Clay
	129.3	246.2	26.3	Second Principal Aquifer	Fine Sand
IV_14 RL=55.79m, AMSL	38.2	99.0	48.6	First Principal Aquifer	Medium Sand
	99.0	139.9	10.7	Clay_II	Clay
	139.9	272.3	28.7	Second Principal Aquifer	Fine Sand
IV_15 RL=54.85m, AMSL	54.4	120.3	59.3	First Principal Aquifer	Medium Sand
	120.3	149.8	14.6	Clay_II	Clay
	149.8	303.1	22.6	Second Principal Aquifer	Sandy Clay
IV_16 RL=55.24m, AMSL	64.0	137.9	58.8	First Principal Aquifer	Medium Sand
	137.9	157.0	20.3	Clay_II	Clay+Sand
	157.0	322.1	26.0	Second Principal Aquifer	Fine Sand

V_4 RL=52.29m, AMSL	30.2	77.7	85.1	First Principal Aquifer	Gravel+Sand
	77.7	110.1	24.1	Clay_II	Clay+Sand
	110.1	263.4	134.0	Second Principal Aquifer	Gravel+Sand
V_5 RL=50.79m, AMSL	29.2	98.4	87.2	First Principal Aquifer	Gravel +Sand
	98.4	113.5	17.9	Clay_II	Clay
	113.5	245.9	164.6	Second Principal Aquifer	Gravel + Sand
V_6 RL=52.73m, AMSL	24.7	108.3	87.3	First Principal Aquifer	Gravel +Sand
	108.3	135.0	12.0	Clay_II	Clay
	135.0	282.4	91.7	Second Principal Aquifer	Gravel + Sand
V_7 RL=50.15m, AMSL	37.1	91.6	114.2	First Principal Aquifer	Gravel + Sand
	91.6	115.3	12.5	Clay_II	Clay
	115.3	167.9	39.0	Second Principal Aquifer	Fine Sand
V_8 RL=48.61m, AMSL	32.0	89.7	68.4	First Principal Aquifer	Coarse Sand
	89.7	130.7	17.2	Clay_II	Clay
	130.7	212.8	71.4	Second Principal Aquifer	Coarse Sand
V_9 RL=50.16m, AMSL	27.5	84.3	59.9	First Principal Aquifer	Medium Sand
	84.3	104.3	23.8	Clay_II	Clay Silt
	104.3	240.5	77.2	Second Principal Aquifer	Coarse Sand
V_10 RL=52.26m, AMSL	22.5	74.2	55.9	First Principal Aquifer	Medium Sand
	74.2	82.4	31.3	Clay_II	Sandy Clay
	82.4	223.5	67.4	Second Principal Aquifer	Coarse Sand
V_11 RL=55.24m, AMSL	24.5	87.8	47.2	First Principal Aquifer	Medium Sand
	87.8	99.7	26.3	Clay_II	Sandy clay
	99.7	206.3	46.5	Second Principal Aquifer	Medium Sand

V_12 RL=48.70m, AMSL	11.6	66.2	45.9	First Principal Aquifer	Fine Sand
	66.2	114.9	21.4	Clay_II	Clay Silt
	114.9	216.0	34.1	Second Principal Aquifer	Fine Sand
V_13 RL=52.70m, AMSL	17.2	68.3	44.3	First Principal Aquifer	Fine Sand
	68.3	127.8	15.2	Clay_II	Clay
	127.8	232.9	25.1	Second Principal Aquifer	Fine Sand
V_14 RL=56.61m, AMSL	30.6	76.2	71.1	First Principal Aquifer	Coarse Sand
	76.2	126.7	11.5	Clay_II	Clay
	126.7	238.4	20.4	Second Principal Aquifer	Fine Sand
V_15 RL=55.35m, AMSL	55.8	104.3	92.1	First Principal Aquifer	Gravel+Sand
	104.3	125.5	12.9	Clay_II	Clay
	125.5	245.0	29.5	Second Principal Aquifer	Fine Sand
V_16 RL=59.64m, AMSL	58.9	112.5	79.8	First Principal Aquifer	Coarse Sand
	112.5	122.4	16.2	Clay_II	Clay
	122.4	242.0	31.1	Second Principal Aquifer	Fine Sand
V_17 RL=58.67m, AMSL	47.7	89.1	66.3	First Principal Aquifer	Coarse Sand
	89.1	103.6	18.1	Clay_II	Clay Silt
	103.6	212.0	55.5	Second Principal Aquifer	Medium Sand
V_18 RL=58.06m, AMSL	47.3	89.9	55.3	First Principal Aquifer	Medium Sand
	89.9	103.6	18.9	Clay_II	Clay+ silt
	103.6	228.1	65.8	Second Principal Aquifer	Coarse Sand
V_19 RL=55.73m, AMSL	35.1	86.2	45.4	First Principal Aquifer	Medium Sand
	86.2	114.4	19.3	Clay_II	Clay+silt
	114.4	244.9	61.9	Second Principal Aquifer	Coarse Sand

V_20 RL=53.54m, AMSL	27.5	84.5	41.5	First Principal Aquifer	Fine sand
	84.5	120.1	19.2	Clay_II	Clay Silt
	120.1	256.5	59.4	Second Principal Aquifer	Medium Sand
VI_4 RL=52.31m, AMSL	26.9	80.1	70.4	First Principal Aquifer	Coasre Sand
	80.1	114.1	30.3	Clay_II	Sandy Clay
	114.1	267.9	120.7	Second Principal Aquifer	Gravel +sand
VI_5 RL=52.38m, AMSL	24.2	102.9	59.5	First Principal Aquifer	Medium Sand
	102.9	137.4	32.2	Clay_II	Sandy Clay
	137.4	273.5	142.6	Second Principal Aquifer	Gravel + Sand
VI_6 RL=53.04m, AMSL	25.0	115.2	56.5	First Principal Aquifer	Medium Sand
	115.2	144.1	21.1	Clay_II	Sand+Silt
	144.1	247.4	102.2	Second Principal Aquifer	Gravel +Sand
VI_7 RL=48.61m, AMSL	33.5	109.8	96.2	First Principal Aquifer	Gravel +Sand
	109.8	137.7	18.9	Clay_II	Sandy clay
	137.7	213.5	57.4	Second Principal Aquifer	Medium Sand
VI_8 RL=49.52m, AMSL	31.5	110.3	87.2	First Principal Aquifer	Gravel +Sand
	110.3	133.3	20.5	Clay_II	Sand silt
	133.3	226.6	85.7	Second Principal Aquifer	Gravel +Sand
VI_9 RL=50.07m, AMSL	30.0	118.5	73.3	First Principal Aquifer	Coarse Sand
	118.5	136.0	23.1	Clay_II	Sandy clay
	136.0	276.9	75.2	Second Principal Aquifer	Coarse Sand
VI_10 RL=50.50m, AMSL	38.3	96.7	86.8	First Principal Aquifer	Gravel +sand
	96.7	116.5	33.1	Clay_II	Sandy Caly
	116.5	218.6	42.5	Second Principal Aquifer	Fine sand

VI_11 RL=50.40m, AMSL	20.3	92.1	63.2	First Principal Aquifer	Coarse Sand
	92.1	117.6	25.5	Clay_II	Sandy Clay
	117.6	0.0	34.0	Second Principal Aquifer	Fine Sand
VI_12 RL=53.04m, AMSL	26.5	93.5	70.4	First Principal Aquifer	Coarse Sand
	93.5	143.8	18.0	Clay_II	Clay
	143.8	231.9	27.6	Second Principal Aquifer	Fine Sand
VI_13 RL=54.77m, AMSL	22.0	77.5	46.7	First Principal Aquifer	Medium Sand
	77.5	149.6	14.0	Clay_II	Clay
	149.6	244.1	21.3	Second Principal Aquifer	Sandy Clay
VI_14 RL=58.69m, AMSL	20.1	85.2	37.3	First Principal Aquifer	Fine Sand
	85.2	134.7	10.6	Clay_II	Clay
	134.7	229.1	27.8	Second Principal Aquifer	Fine Sand
VI_15 RL=58.75m, AMSL	53.0	115.5	117.7	First Principal Aquifer	Gravel+Sand
	115.5	125.1	11.0	Clay_II	Clay
	125.1	215.5	20.6	Second Principal Aquifer	Sandy Clay
VI_16 RL=56.97m, AMSL	50.7	103.0	89.8	First Principal Aquifer	Gravel +Sand
	103.0	111.7	13.6	Clay_II	Clay
	111.7	212.2	32.0	Second Principal Aquifer	Fine Sand
VI_17 RL=55.21m, AMSL	55.6	104.2	71.4	First Principal Aquifer	Coarse Sand
	104.2	114.1	15.9	Clay_II	Clay
	114.1	224.6	46.9	Second Principal Aquifer	Medium Sand
VI_18 RL=53.83m, AMSL	55.6	93.5	60.6	First Principal Aquifer	Coarse Sand
	93.5	113.9	17.5	Clay_II	Sandy Clay
	113.9	231.8	56.0	Second Principal Aquifer	Medium Sand

VI_19 RL=52.28m, AMSL	24.3	82.1	50.5	First Principal Aquifer	Medium Sand
	82.1	117.4	18.9	Clay_II	Clay
	117.4	241.7	58.0	Second Principal Aquifer	Medium Sand
VII_4 RL=55.50m, AMSL	21.7	73.6	64.7	First Principal Aquifer	Coasre Sand
	73.6	109.9	24.4	Clay_II	Sandy Clay
	109.9	252.9	77.2	Second Principal Aquifer	Coarse Sand
VII_5 RL=56.55m, AMSL	24.5	99.2	48.3	First Principal Aquifer	Medium Sand
	99.2	119.7	19.5	Clay_II	Clay
	119.7	251.7	56.5	Second Principal Aquifer	Medium Sand
VII_6 RL=54.92m, AMSL	24.0	64.3	53.3	First Principal Aquifer	Medium Sand
	64.3	123.0	16.9	Clay_II	Clay
	123.0	229.8	58.7	Second Principal Aquifer	Medium Sand
VII_7 RL=56.25m, AMSL	20.5	82.0	76.1	First Principal Aquifer	Coarse Sand
	82.0	128.5	23.2	Clay_II	Sandy Clay
	128.5	226.8	48.1	Second Principal Aquifer	Medium Sand
VII_8 RL=51.88m, AMSL	21.2	84.0	63.6	First Principal Aquifer	Coarse Sand
	84.0	118.7	26.7	Clay_II	Sandy Clay
	118.7	201.8	166.0	Second Principal Aquifer	Gravel +Sand
VII_9 RL=53.45m, AMSL	35.7	92.7	66.1	First Principal Aquifer	Coarse Sand
	92.7	112.5	25.6	Clay_II	Sandy Clay
	112.5	205.8	39.8	Second Principal Aquifer	Fine Sand
VII_10 RL=50.51m, AMSL	40.7	95.9	72.8	First Principal Aquifer	Coarse Sand
	95.9	130.3	21.0	Clay_II	Sandy Clay
	130.3	219.6	28.0	Second Principal Aquifer	Fine Sand

VII_11 RL=52.00m, AMSL	23.3	86.1	190.4	First Principal Aquifer	Gravel +Sand
	86.1	113.5	18.6	Clay_II	Clay
	113.5	190.4	22.4	Second Principal Aquifer	Fine Sand
VII_12 RL=55.58m, AMSL	37.6	115.1	67.2	First Principal Aquifer	Coarse Sand
	115.1	160.7	12.0	Clay_II	Clay
	160.7	247.8	22.2	Second Principal Aquifer	Fine Sand
VII_13 RL=54.53m, AMSL	30.7	91.5	56.1	First Principal Aquifer	Medium Sand
	91.5	178.7	13.1	Clay_II	Clay
	178.7	278.4	27.5	Second Principal Aquifer	Fine Sand
VII_14 RL=54.74m, AMSL	28.9	89.8	60.3	First Principal Aquifer	Coarse Sand
	89.8	162.6	12.1	Clay_II	Clay
	162.6	258.5	24.7	Second Principal Aquifer	Fine Sand
VII_15 RL=56.42m, AMSL	38.8	102.5	81.8	First Principal Aquifer	Gravel
	102.5	152.7	11.0	Clay_II	Clay
	152.7	242.4	18.1	Second Principal Aquifer	Sandy Clay
VII_16 RL=53.69m, AMSL	37.4	97.2	76.0	First Principal Aquifer	Coarse Sand
	97.2	142.3	12.4	Clay_II	Clay
	142.3	238.1	27.3	Second Principal Aquifer	Fine Sand
VII_17 RL=50.17m, AMSL	35.0	99.3	67.3	First Principal Aquifer	Coarse Sand
	99.3	133.9	14.9	Clay_II	Clay
	133.9	235.2	38.1	Second Principal Aquifer	Fine sand
VII_18 RL=47.81m, AMSL	25.6	95.3	60.5	First Principal Aquifer	Coarse Sand
	95.3	129.0	17.1	Clay_II	Clay Silt
	129.0	236.4	47.0	Second Principal Aquifer	Medium Sand

VIII_4 RL=55.70m, AMSL	27.6	68.1	67.3	First Principal Aquifer	Coarse Sand
	68.1	110.9	18.0	Clay_II	Clay
	110.9	234.4	55.0	Second Principal Aquifer	Medium Sand
VIII_5 RL=54.73m, AMSL	22.5	58.3	56.3	First Principal Aquifer	Medium Sand
	58.3	115.2	13.9	Clay_II	Clay
	115.2	224.5	35.7	Second Principal Aquifer	Fine Sand
VIII_6 RL=53.65m, AMSL	25.6	74.6	60.8	First Principal Aquifer	Coarse Sand
	74.6	150.9	12.9	Clay_II	Clay
	150.9	250.1	40.1	Second Principal Aquifer	Fine Sand
VIII_7 RL=55.19m, AMSL	17.5	92.5	63.0	First Principal Aquifer	Coarse Sand
	92.5	121.0	15.8	Clay_II	Clay
	121.0	216.3	56.8	Second Principal Aquifer	Medium Sand
VIII_8 RL=54.64m, AMSL	21.6	71.1	69.3	First Principal Aquifer	Coarse Sand
	71.1	104.1	26.1	Clay_II	Sandy Clay
	104.1	195.6	74.4	Second Principal Aquifer	Coarse Sand
VIII_9 RL=52.23m, AMSL	32.2	81.3	72.6	First Principal Aquifer	Coarse Sand
	81.3	116.9	13.0	Clay_II	Sandy Clay
	116.9	210.5	33.8	Second Principal Aquifer	Fine Sand
VIII_10 RL=51.60m, AMSL	22.2	95.3	66.1	First Principal Aquifer	Coarse Sand
	95.3	122.3	12.0	Clay_II	Sandy Clay
	122.3	208.7	17.5	Second Principal Aquifer	Fine Sand
VIII_11 RL=52.49m, AMSL	31.9	109.4	62.7	First Principal Aquifer	Coarse Sand
	109.4	118.0	20.3	Clay_II	Sandy Clay
	118.0	206.6	27.0	Second Principal Aquifer	Fine Sand

VIII_12 RL=52.59m, AMSL	34.5	138.1	73.9	First Principal Aquifer	Coarse Sand
	138.1	156.0	15.5	Clay_II	Clay
	156.0	263.1	19.9	Second Principal Aquifer	Sandy Clay
VIII_13 RL=51.19m, AMSL	26.9	126.4	66.8	First Principal Aquifer	Coarse Sand
	126.4	207.4	16.9	Clay_II	Clay
	207.4	333.0	24.6	Second Principal Aquifer	Fine Sand
VIII_14 RL=47.04m, AMSL	19.4	98.5	50.2	First Principal Aquifer	Medium Sand
	98.5	166.2	16.1	Clay_II	Clay
	166.2	271.5	20.2	Second Principal Aquifer	Fine Sand
VIII_15 RL=49.71m, AMSL	16.2	117.9	58.5	First Principal Aquifer	Medium Sand
	117.9	177.5	11.1	Clay_II	Clay
	177.5	289.5	22.5	Second Principal Aquifer	Fine Sand
VIII_16 RL=52.31m, AMSL	18.7	109.8	50.1	First Principal Aquifer	Medium sand
	109.8	172.7	12.4	Clay_II	Clay
	172.7	268.2	21.9	Second Principal Aquifer	Fine Sand
IX_3 RL=55.90m, AMSL	21.2	71.7	94.6	First Principal Aquifer	Gravel +sand
	71.7	106.6	12.1	Clay_II	Clay
	106.6	206.7	70.2	Second Principal Aquifer	Coarse Sand
IX_4 RL=55.36m, AMSL	24.5	86.6	75.5	First Principal Aquifer	Coarse Sand
	86.6	124.6	15.5	Clay_II	Clay
	124.6	212.4	55.7	Second Principal Aquifer	Medium Sand
IX_5 RL=55.28m, AMSL	25.0	92.1	59.9	First Principal Aquifer	Medium sand
	92.1	157.8	14.7	Clay_II	Clay
	157.8	230.1	49.1	Second Principal Aquifer	Medium Sand

IX_6 RL=53.00m, AMSL	25.5	107.1	56.5	First Principal Aquifer	Medium Sand
	107.1	182.2	13.2	Clay_II	Clay
	182.2	274.6	47.1	Second Principal Aquifer	Medium Sand
IX_7 RL=54.12m, AMSL	20.0	92.5	58.0	First Principal Aquifer	Medium Sand
	92.5	133.4	10.0	Clay_II	Clay
	133.4	229.4	51.7	Second Principal Aquifer	Medium Sand
IX_8 RL=57.46m, AMSL	23.4	70.1	72.4	First Principal Aquifer	Coarse Sand
	70.1	109.1	16.9	Clay_II	Clay
	109.1	211.8	51.7	Second Principal Aquifer	Medium Sand
IX_9 RL=51.95m, AMSL	23.9	82.6	56.0	First Principal Aquifer	Medium Sand
	82.6	128.3	28.6	Clay_II	Sandy Clay
	128.3	224.0	50.4	Second Principal Aquifer	Medium Sand
IX_10 RL=53.80m, AMSL	21.5	115.7	67.4	First Principal Aquifer	Coarse Sand
	115.7	129.2	26.8	Clay_II	Sandy Clay
	129.2	210.5	25.5	Second Principal Aquifer	Fine sand
IX_11 RL=56.39m, AMSL	41.1	137.5	78.9	First Principal Aquifer	Coarse Sand
	137.5	137.2	13.0	Clay_II	Clay
	137.2	238.6	16.0	Second Principal Aquifer	Fine Sand
IX_12 RL=52.13m, AMSL	30.4	133.0	71.2	First Principal Aquifer	Coarse Sand
	133.0	160.2	19.4	Clay_II	Clay
	160.2	275.8	28.9	Second Principal Aquifer	Fine Sand
IX_13 RL=47.25m, AMSL	23.0	84.0	53.4	First Principal Aquifer	Medium Sand
	84.0	164.4	22.4	Clay_II	Sandy Clay
	164.4	270.5	23.4	Second Principal Aquifer	Fine Sand

IX_14 RL=48.22m, AMSL	22.9	115.6	63.0	First Principal Aquifer	Coarse Sand
	115.6	131.6	25.0	Clay_II	Sandy Clay
	131.6	222.8	28.7	Second Principal Aquifer	Fine Sand
IX_15 RL=50.33m, AMSL	14.3	182.3	65.3	First Principal Aquifer	Coarse Sand
	182.3	195.4	17.6	Clay_II	Clay
	195.4	305.2	21.7	Second Principal Aquifer	Fine Sand
X_2 RL=61.14m, AMSL	53.9	78.9	72.2	First Principal Aquifer	Coarse Sand
	78.9	123.2	19.6	Clay_II	Clay
	123.2	196.0	67.3	Second Principal Aquifer	Medium Sand
X_3 RL=58.82m, AMSL	38.3	78.8	83.8	First Principal Aquifer	Gravel
	78.8	111.5	18.4	Clay_II	Clay
	111.5	216.8	63.3	Second Principal Aquifer	Coarse Sand
X_4 RL=57.25m, AMSL	24.4	90.0	63.6	First Principal Aquifer	Coasre Sand
	90.0	128.8	23.2	Clay_II	Sandy Clay
	128.8	208.5	52.7	Second Principal Aquifer	Medium Sand
X_5 RL=56.94m, AMSL	24.2	102.2	52.0	First Principal Aquifer	Medium Sand
	102.2	176.6	18.2	Clay_II	Clay, Silt
	176.6	210.6	62.3	Second Principal Aquifer	Coarse Sand
X_6 RL=58.51m, AMSL	28.5	98.1	38.2	First Principal Aquifer	Fine sand
	98.1	187.2	11.9	Clay_II	Clay
	187.2	264.5	61.4	Second Principal Aquifer	Coarse Sand
X_7 RL=53.51m, AMSL	25.1	73.1	55.2	First Principal Aquifer	Medium Sand
	73.1	140.4	9.8	Clay_II	Clay
	140.4	230.5	50.1	Second Principal Aquifer	Medium Sand

X_8 RL=56.97m, AMSL	31.0	71.2	69.9	First Principal Aquifer	Coarse Sand
	71.2	113.9	15.0	Clay_II	Clay
	113.9	179.2	34.4	Second Principal Aquifer	Fine Sand
X_9 RL=59.29m, AMSL	33.2	120.0	54.7	First Principal Aquifer	Medium Sand
	120.0	130.6	21.9	Clay_II	Sandy Clay
	130.6	220.9	27.0	Second Principal Aquifer	Fine Sand
X_10 RL=59.69m, AMSL	25.0	121.7	64.4	First Principal Aquifer	Coarse Sand
	121.7	116.1	26.7	Clay_II	Sandy Clay
	116.1	190.6	33.0	Second Principal Aquifer	Fine Sand
X_11 RL=57.22m, AMSL	33.8	140.6	67.5	First Principal Aquifer	Coarse Sand
	140.6	149.9	26.7	Clay_II	Sandy Clay
	149.9	264.3	35.0	Second Principal Aquifer	Fine Sand
X_12 RL=53.82m, AMSL	28.5	129.1	70.7	First Principal Aquifer	Coarse Sand
	129.1	149.9	17.5	Clay_II	Clay
	149.9	300.4	31.2	Second Principal Aquifer	Fine Sand
X_13 RL=51.99m, AMSL	22.6	113.2	66.3	First Principal Aquifer	Coarse Sand
	113.2	138.5	19.1	Clay_II	Clay
	138.5	298.1	29.9	Second Principal Aquifer	Fine Sand
X_14 RL=51.62m, AMSL	22.6	104.2	66.1	First Principal Aquifer	Coarse Sand
	104.2	124.6	23.0	Clay_II	Sandy Clay
	124.6	278.5	27.6	Second Principal Aquifer	Fine Sand
XI_2 RL=63.82m, AMSL	26.4	87.1	71.2	First Principal Aquifer	Coarse Sand
	87.1	142.8	15.3	Clay_II	Clay
	142.8	217.6	55.2	Second Principal Aquifer	Medium Sand

XI_3 RL=61.77m, AMSL	30.7	73.4	74.4	First Principal Aquifer	Coarse Sand
	73.4	98.1	24.5	Clay_II	Sandy Clay
	98.1	232.9	51.0	Second Principal Aquifer	Medium sand
XI_4 RL=59.21m, AMSL	21.7	76.8	52.4	First Principal Aquifer	Medium Snad
	76.8	111.2	19.8	Clay_II	Clay, Silt, Sand
	111.2	214.7	44.8	Second Principal Aquifer	Fine Sand
XI_5 RL=56.45m, AMSL	29.6	88.9	64.3	First Principal Aquifer	Coarse Sand
	88.9	147.9	17.3	Clay_II	Clay
	147.9	231.6	46.2	Second Principal Aquifer	Medium sand
XI_6 RL=60.19m, AMSL	24.9	77.1	36.3	First Principal Aquifer	Fine Sand
	77.1	157.9	15.6	Clay_II	Clay
	157.9	234.3	50.2	Second Principal Aquifer	Medium Sand
XI_7 RL=58.07m, AMSL	26.9	66.7	49.3	First Principal Aquifer	Medium Sand
	66.7	117.3	12.4	Clay_II	Clay
	117.3	218.1	47.2	Second Principal Aquifer	Medium sand
XI_8 RL=57.04m, AMSL	27.1	64.3	89.5	First Principal Aquifer	Gravel
	64.3	115.8	12.1	Clay_II	Clay
	115.8	238.1	38.9	Second Principal Aquifer	Fine sand
XI_9 RL=59.19m, AMSL	28.8	77.1	70.5	First Principal Aquifer	Coarse Sand
	77.1	128.1	14.1	Clay_II	Clay
	128.1	323.2	30.7	Second Principal Aquifer	Fine Sand
XI_10 RL=56.535m, AMSL	24.1	74.1	52.4	First Principal Aquifer	Medium Sand
	74.1	96.6	26.6	Clay_II	Sandy Clay
	96.6	424.1	29.2	Second Principal Aquifer	Fine Sand

XII_3 RL=61.06m, AMSL	28.7	69.8	37.6	First Principal Aquifer	Fine Sand
	69.8	119.1	12.6	Clay_II	Clay
	119.1	176.3	38.4	Second Principal Aquifer	Fine Sand
XII_4 RL=60.97m, AMSL	17.3	63.6	48.7	First Principal Aquifer	Medium Sand
	63.6	109.9	12.2	Clay_II	Clay
	109.9	255.3	51.9	Second Principal Aquifer	Medium Sand
XII_5 RL=63.88m, AMSL	24.4	81.8	39.7	First Principal Aquifer	Fine Sand
	81.8	122.5	17.2	Clay_II	Clay
	122.5	187.3	24.9	Second Principal Aquifer	Fine Sand
XII_6 RL=60.57m, AMSL	25.3	63.7	44.6	First Principal Aquifer	Fine Sand
	63.7	100.5	14.0	Clay_II	Clay
	100.5	190.5	40.4	Second Principal Aquifer	Fine Sand
XII_7 RL=62.93m, AMSL	20.2	63.0	45.9	First Principal Aquifer	Fine sand
	63.0	100.8	15.3	Clay_II	Clay
	100.8	277.1	40.5	Second Principal Aquifer	Fine sand
XII_8 RL=55.49m, AMSL	26.4	72.2	54.7	First Principal Aquifer	Medium sand
	72.2	101.5	15.2	Clay_II	Clay
	101.5	295.7	48.5	Second Principal Aquifer	Medium Sand
XIII_3 RL=67.40m, AMSL	25.8	63.5	40.9	First Principal Aquifer	Fine Sand
	63.5	120.5	11.9	Clay_II	Clay
	120.5	191.0	57.3	Second Principal Aquifer	Medium Sand
XIII_4 RL=60.46m, AMSL	23.2	74.1	43.3	First Principal Aquifer	Fine Sand
	74.1	103.4	15.7	Clay_II	Clay
	103.4	267.5	35.9	Second Principal Aquifer	Fine Sand

XIII_5 RL=60.67m, AMSL	22.5	64.7	40.4	First Principal Aquifer	Coarse Sand
	64.7	121.5	13.1	Clay_II	Clay
	121.5	222.5	23.8	Second Principal Aquifer	Fine Sand
XIV_3 RL=63.79m, AMSL	19.2	66.3	63.5	First Principal Aquifer	Coarse Sand
	66.3	102.4	15.8	Clay_II	Clay
	102.4	200.9	30.4	Second Principal Aquifer	Fine Sand
XIV_4 RL=63.57m, AMSL	23.2	72.3	46.6	First Principal Aquifer	Medium Sand
	72.3	110.6	12.2	Clay_II	Clay
	110.6	232.0	33.9	Second Principal Aquifer	Fine Sand
XIV_5 RL=58.25m, AMSL	21.7	71.3	53.9	First Principal Aquifer	Medium Sand
	71.3	122.5	12.7	Clay_II	Clay
	122.5	209.8	44.8	Second Principal Aquifer	Fine Sand

Annexure 3.8 (a): Location details of key wells established (dug wells)

Sl No.	Place	Block	Location	Long. (^{0}E)	Lat. (^{0}N)	RL**	MP#	Depth*
1	Khazpura	Patna Sadar	In the campus of Shiv Mandir	85.08	25.604	48	0.35	12
2	Rajapur	Patna Sadar	In the premises of Radhakrishna Mandir, Near Rajapur Tempo stand	85.11	25.633	49.1	0.5	9.5
3	Digha	Patna Sadar	In campus of Maa Sardha - Siddhi Mandir	85.09	25.643	50.6	0.62	14
4	Nasriganj, Patna	Danapur	Shiv Mandir Complex near Shankar cold storage	85.06	25.64	50.4	0.56	8
5	Goptal, Danapur	Danapur	Opposite Tulsi Bhawan, Near house of Manoj Kumar	85.05	25.634	49.7	0.5	11.5
6	Dalluchak	Danapur	RHS of road in Dallu chak	85.05	25.586	49.1	0.32	6.5
7	Phulwari	Phulwari	Behind Gauri Shankar Mandir, RHS of road after crossing Phulwari sharif block office towards Anisabad	85.08	25.578	48.7	0.8	10
8	Soranpur	Phulwari	RHS of Anisabad-Fatua by pass road near Fatua 21 Km mile stone, inside the temple campus	85.15	25.583	51	0.5	10
9	Nandlal Chapra	Patna Sadar	LHS of Anisabad-Fatua by pass road, before petrol pump and turn	85.17	25.586	50.8	0.55	9.5
10	Patna law college	Patna Sadar	Near Patna Law college	85.15	25.619	49	0.9	9.5
11	Mithapur	Patna Sadar	B-Block, 50 m ahead of Dr Anita Singh Nursing Home towards Gauriya math (Infront of Baidnath Viswakarma House)	85.13	25.602	46.9	0.78	6
12	Khaspur	Danapur	In the Rajkiya Prathmic Vidyalaya, Daudpur	85.01	25.637	50.2	0.5	12
13	Lalbegwan	Maner	In the Rajkiya Prathmic Vidyalaya,	84.98	25.651	50.9	0.62	11

Sl No.	Place	Block	Location	Long. (^{0}E)	Lat. (^{0}N)	RL**	MP#	Depth*
			Maner,Pashim Sherpur					
14	Maner	Maner	Opposit Post office Maner	84.89	25.648	49.4	0.54	7
15	Chheditola	Phulwari	RHS On Phulwari-Janipur road, before Vishal nagar officers colony, In front of house of Jagdish Manjhi	85.04	25.565	46.8	0.54	5.95
16	Hulaschak	Phulwari	RHS On Phulwari-Janipur road, Near Shiv Mandir	85.03	25.538	46.9	0.7	6.16
17	Saristabad	Naubatpur	LHS of culvert on Akbarpur, Naubatpur road	85.01	25.513	45.9	0.5	9.7
18	Gyaspur (Purvatola)	Maner	In the beginning of Village	84.89	25.627	50.7	0.65	7.92
19	Gopalpur (Dhibrapur)	Maner	At the trijunction	84.94	25.613	50.9	0.25	8.25
20	Doghra (Chamtoli)	Bihta	RHS of the road, In front of house of Sri Durga Prasad	84.9	25.592	54.8	0.6	8.3
21	Bishambharpur	Bihta	Near chowk,Opposite to Hanuman temple, 10 m from main road	84.89	25.578	55.6	0.7	9.26
22	Mahmadpur	Bihta	In front of primary school , near temple, 10 m from main road	84.94	25.584	51.5	0.55	7
23	Snehi Tola, Naubatpur	Naubatpur	RHS Khagaul-Naubatpur Road, Just reaching Naubatpur, Near Shiv Temple	84.96	25.505	54.5	0.4	7.3
24	Dariapur, Chainpura	Naubatpur	LHS Naubatpur-Bikram Road	84.93	25.48	59.8	0.5	6.05
25	Andhra chowki	Bikram	RHS Naubatpur-Bikram road, Just after crossing canal	84.9	25.466	59.6	0.63	6.14
26	Din Bigha	Bikram	LHS Bikram-Bihta Road, Near Shiv Temple	84.86	25.458	61.6	0.55	7.26
27	Amraha	Bihta	RHS Bikram-Bihta Road, Near Rajendra Pustkalaya, Amraha	84.86	25.529	57.3	0.43	6.4
28	Raghopur, Bihta	Bihta	RHS Bikram-Bihta Road, Front Gram Devi Maa Mandir, Opposite Raghopur	84.86	25.548	56.8	0.75	6.9

Sl No.	Place	Block	Location	Long. (^{0}E)	Lat. (^{0}N)	RL**	MP#	Depth*
			Madhya Vidyalya					
29	Faridpur	Naubatpur	LHS Shivala-Naubatpur road. Front of Kiran Niwas	84.98	25.549	53.2	0.7	7.35
30	Azwa	Naubatpur	RHS of Naubatpur - Bihta road. Front of Ramadevi Sadan. Ramnath Yadav marked on dugwell	84.95	25.527	52.9	0.5	6.9
31	Gonwa	Naubatpur	RHS Naubatur-Sadisopur road. Front of Suresh Rai house	84.92	25.552	52.6	0.45	8.6
32	Murarchak	Danapur	On the main road near Mahabir near Jamsaut village	85.02	25.611	49.7	0.6	11
33	Anisabad	Phulwari	In the campus of Anisabad Police Chowki, Near Temple	84.99	25.587	50.9	0.5	5.82
34	Chiraura	Naubatpur	In front of house of Jagnarayan Sahu, Near Bus stand. RHS Chiraura-Naubatpur road.	84.99	25.521	55.5	0.37	7.5
35	Parsa bazar	Phulwari	In front of Parsa station, back side of Hanuman temple	85.12	25.551	49.8	0.62	10.4
36	Nisirpura	Phulwari	In front of Sri lalan Paswan on Parsa Ganjpar road. 6 km from Parsa towards Ganjpar	85.09	25.53	48.7	0.37	12.8
37	Khadika	Phulwari	Near corner in front of House of Param Singh. 0.5 km before Dhibra on Dhibra-Hasanpura mission road.	85.07	25.528	48.4	0.62	10.6
38	Etwarpur	Phulwari	In the campus of Ramjanki Mandir on Sipara Parsa road.	85.13	25.575	50.2	0.4	12
39	Raunia	Naubatpur	In front of Ramashish Yadav within Village road RHS (Khadwa Kiuwa)	84.95	25.55	52.2	0.65	10.8
40	Sarasat	Naubatpur	In front of Bijali Yadav house, RHS Sarasat-Naubatpur Road	84.92	25.509	51.7	0.52	9.2

Sl No.	Place	Block	Location	Long. (^{0}E)	Lat. (^{0}N)	RL**	MP#	Depth*
41	Korhar	Bihta	Near Mahabir Temple. 4 km from Bihta towards Maner	84.87	25.595	53.2	0.6	9
42	Noniatola	Bikram	In the house of Late Bishun Sah, Near temple on Bikram-Aurangabad road.	84.87	25.438	59.6	0.65	10.8
43	Darbeshpur	Danapur	In the house of Sudhir Kumar	84.94	25.652	50.3	0.35	12.7
44	Nagwa	Maner	In front of house of Munilal Rai	84.91	25.621	50.7	0.3	9.5
45	Bhateri	Maner	In open ground of Agriculture field and the adjecent to the house of Rameshwar Rai	84.95	25.634	51	0.75	9.25
46	Mehnawa	Maner	In the front of the house Laxman Singh, Mehnawa tola on the LHS road	84.91	25.648	49.4	0.66	9.85
47	Chhiyattar	Maner	Approach from Chiyattar more on Kachhi road about 1 km towards Mahabir tola and well locate adjecent to the Pipal tree, Samudayik Bhawan	84.89	25.665	49.5	0.44	6.2
48	Jinpura	Bihta	In front of the house of Ramjanam Sharma compound	84.89	25.547	54.8	0.5	8.05
49	Tishkhora	Naubatpur	Inside the village Tiskhora and about 300 m from main road in the front of the house Ajit Kumar Ajad	84.9	25.527	52.7	0.35	12
50	Moriyawa	Bikram	In the compound of Dhanushdhari Sarvodaya (10+2) Highschool	84.86	25.492	62.4	0.4	4.25

RL: Reduced Level, MP: Measuring Point, *Depth in m, bgl; **RL in m, amsl; #MP in m, agl
LHS: Left Hand Side, RHS: Right Hand Side

Annexure 3.8 (b): Location details of key-wells established (Piezometer tapping aquifer-1)

S. No.	Location	block	Location details	Longitude (^{0}E)	Latitude (^{0}N)	Depth*	RL**	MP#
1	Frazer Road	Patna	In the campus of Lok Nayak Bhawan	85.139	25.609	100	47.5	1.5
2	Khagaul PZ-1	Danapur	Khagaul Refferal Hospital Campus, Khagaul	85.041	25.579	98	47.7	0.4
3	Khagaul PZ-2	Danapur	Khagaul Refferal Hospital Campus, Khagaul	85.041	25.579	80	47.7	0.4
4	Kankerbagh	Patna	In the campus of GSI office	85.161	25.601	100	51.2	0.3
5	Gandhi Maidan	Patna	In the campus of S.K.Memorial hall	85.149	25.619	100	48.6	0.3
6	Circuit House	Patna	In the campus of Circuit house	85.129	25.603	100	46	0.6
7	A N College, Pani tanki	Patna	Near Pani tanki	85.111	25.620	167	47.9	0.5
8	Kumhrar	Patna	In the campus of Kumhrar ASI site	85.185	25.600	95	52.2	0.3
9	B V College (Pz-2)	Phulwari	In the campus of B.V. College	85.087	25.599	80	47.7	1
10	Anisabad	Phulwari	In the campus of Anisabad police Chowki	85.099	25.588	172	47.8	0.5
11	Arap	Bihta	Govt. well, care taker Sri Ashok Singh	84.898	25.489	110	56.8	0.5
12	Naubatpur	Naubatpur	In the campus of Naubatpur telephone exchange office	84.960	25.495	100	55	0.6
13	Bikram	Bikram	In the campus of Jawarhar Navoday vidhyalay	84.856	25.447	75	60.8	0.4
14	B. N. College PZ-2	Patna	In the campus of B.N. College	85.151	25.622	186	48.6	1.05
15	Maner	Maner	In the campus of Maner police station	84.888	25.646	176	48.8	0.5
16	Amhara	Bihta	Govt. well on Bihta-Moriyama road	84.864	25.522	110	57.2	0.5

S. No.	Location	block	Location details	Longitude (⁰E)	Latitude (⁰N)	Depth*	RL**	MP#
17	Naubatpur - 2	Naubatpur	Naubatpur Refferal Hospital Campus, Naubatpur	84.961	25.503	58	54.1	0.7
18	Phulwari Thana	Phulwari	In the campus of Phuwari police station	85.068	25.576	165	47.9	0.43
19	kurji	Patna	In the campus of Kurji Hospital	85.111	25.636	100	47.9	0.45
20	A. N. College Campus	Patna	In the campus of A. N. College	85.110	25.617	71.5	47.9	0.85

RL: Reduced Level, MP: Measuring Point *Depth in m, bgl; **RL in m, amsl; #MP in m, agl

Annexure 3.8 (c): Location details of key-wells established (Piezometer tapping aquifer-2)

Sl. No.	Location	Block	Location details	Long. (^{0}E)	Lat. (^{0}N)	Depth*	RL**	MP#
1	B. V. College (Pz-1)	Phulwari	In the campus of B.V College	85.087	25.599	177	47.7	1.0
2	B. N. College PZ-1	Patna	In the campus of B.N. College	85.151	25.622	186	48.6	1.05
3	Naubatpur-1	Naubatpur	Naubatpur Refferal Hospital Campus,Naubatpur	84.9612	25.503	181	54.1	0.7
4	Simri-2	Maner	In the campus Vishwakarma High School	84.905	25.606	196	51	0.65
5	Bihta	Bihta	In the campus of Minor irrigation, Govt. of Bihar on Bihta -Bikram road	84.868	25.554	211	50	1.0
6.	A. N. College	Patna	In the campus of A.N. College	85.11	25.617	174	47.9	0.66
7	Moriyama	Bikram	In the campus of Dhanusdhari high school, Moriyama	84.8638	25.491	220	62	0.9
8	Goriyasthan (Jibrakhan Tola)	Maner	In the campus of Jibrakhan Tola middle school, Goriyasthan	84.9332	25.643	235	--	1.0

RL: Reduced Level, MP: Measuring Point; *Depth in m, bgl; **RL in m, amsl; #MP in m, agl

Annexure 3.8 (d): Month-wise depth to water level -dug well in m, bgl

Sl No.	locations	m.p	Feb-12	Mar -12	Apr -12	May -12	Jun -12	Jul-12	Aug -12	Sep-12	Oct -12	Nov -12	Dec-12	Jan -13	Feb -13	Mar -13	Apr -13	May -13	Jun -13	Jul-13	Aug -13	Sep-13	Oct -13	Nov -13	Dec-13	Jan -14	Feb -14	Mar -14
1	Khazpura	0.35	4.93	7.37	7.58	8.44	10.05	2.95	1.73	1.95	2.41	4.47	4.77	6.72	6.83	5.39	6.03	6.85	6.53	5.63	5.37	3.64	2.83	2.9	3.93	5.35	5.37	5.7
2	Rajapur	0.5	3.9	4.22	4.52	4.7	5.1	2.1	1.34	1.05	1.82	1.95	2.15	2.32	2.55	2.55	3	4.35	3.7	3.2	3	2.85	2.3	2.72	3.1	3.4	3.5	2.32
3	Digha	0.62	1.85	2.06	2.25	2.8	3.11	1.58	1.28	1.14	1.4	1.63	1.77	1.78	1.85	2.01	2.3	2.75	1.68	1.3	1.28	1.2	1.18	1.27	1.7	1.79	2.4	2.6
4	Nasriganj, Patna	0.56	1.6	2.33	2.49	2.86	3.16	0.94	0.54	0.33	0.78	1.02	1.32	1.76	1.74	2.02	2.4	2.82	2.04	1.19	0.76	0.51	0.53	0.94	1.36	1.42	1.59	1.66
5	Goptal, Danapur	0.5	3.19	3.94	4.36	5.05	2.75	1.62	0.79	0.55	1.04	1.7	2.29	3.45	3.48	3.78	4	4.32	2.95	2.95	0.9	0.71	0.68	1.15	1.65	2.6	2.75	2.85
6	Dalluchak	0.32	0.54	0.68	0.77	1.32	1.68	1.16	0.41	0.38	0.58	0.61	0.64	0.66	0.69	0.77	1.03	1.36	1.27	0.53	0.58	0.5	0.38	0.48	0.53	0.51	0.48	0.73
7	Phulwari	0.8	1.48	1.5	1.74	1.92	1.8	1.37	0.85	0.65	0.99	1.3	1.35	1.4	1.43	1.51	1.6	1.77	0.36	1.33	1.18	1.06	0.92	1.27	1.38	1.48	1.52	1.38
8	Soranpur	0.5	1.55	1.95	1.9	2.16	3.08	1.87	1	0.94	0.98	1.05	1.11	1.15	1.38	1.43	1.5	2.45	1.34	0.88	0.62	0.6	0.53	0.74	0.9	0.95	1.02	1.04
9	Nandlal Chapra	0.55						2.67	1.33	1.06	1.3	1.33	2.43	3.56	3.76	4.96	5.1	5.28	5.17	3.39	3.16	1.79	1.3	1.88	2.67	3.87	3.91	2.88
10	Patna law college	0.9	3.84	4.06	4.35	4.45	4.52	3.92	2.03	1.43	1.94	2.23	2.78	3.3	3.75	3.94	4.18	4.75	3.55	2.78	2.42	2.03	2.17	2.62	3	3.58	3.62	3.74
11	Mithapur	0.78	0.99	1.52	1.74	2.4	4.2	1.06	1.02	1.03	1.08	1.13	1.22	1.32	1.7	1.82	1.97	2.43	1.25	1.52	1	0.8	1	1.11	1.09	1.12	1.2	1.09
12	Khaspur	0.5	4.85	7.15	7.8	8.22	8.53	7.9	4.04	1.75	2.92	3.87	5.35	5.54	6.71	7.09	7.57	7.97	7.62	5.08	1.95	2.34	2.46	3.8	4.67	5.81	6.29	6.62
13	Lalbegwan	0.62	4.16	4.98	5.68	6.29	6.7	6.63	3.57	1.39	2.2	2.92	3.83	4.3	4.82	4.99	5.73	6.25	6.05	4.02	2.18	1.88	1.79	2.75	3.46	4.15	4.48	4.83
14	Maner DW	0.54	2.93	3.64	4.06	4.36	4.83	3.96	1.15	0.76	1.36	1.85	2.51	3.03	3.26	3.58	4.18	4.39	3.57	2.01	2.1	1.31	0.77	1.27	1.94	2.53	3.01	3.13
15	Chheditola	0.54	2.53	2.68	2.97	3.51	4.08	2.96	1.36	0.81	1.26	1.61	2.11	2.31	2.41	2.61	2.82	3.12	2.94	2.5	2.25	1.52	1.39	1.6	1.95	2.09	2.12	2.21
16	Hulaschak	0.7	3.32	2.93	4.1	4.78	5.25	5.3	3.49	1.25	0.8	1.15	1.58	1.8	2.6	3.06	3.53	4.16	3.87	4.26	4.66	3.95	1.35	1.26	2.06	2.2	2.22	3.21
17	Saristabad	0.5	1.24	2.23	3	5.53	7.38	4.8	1.2	0.85	1.1	1.45	1.85	2.15	2.46	2.91	3.17	6.42	6.23	2.77	3.79	1.33	1.16	1.52	2.16	2.37	1.72	2.68
18	Gyaspur (Purvatola)	0.65	2.65	3.15	4.25	4.7	5.17	4.2	0.51	0.24	0.39	0.7	1.38	1.58	2.16	2.94	3.47	4.33	2.9	0.91	0.95	0.36	0.27	0.52	0.98	1.37	1.43	1.91
19	Gopalpur (Dhibrapur)	0.25	2.11	2.39	3.32	3.94	4.15	3.37	0.75	0.58	0.89	1.57	1.79	2.16	2.21	2.6	3.45	4.05	2.33	1.24	1.9	1.31	0.86	1.25	1.4	1.75	1.77	1.98
20	Doghra (Chamtoli)	0.6	2.4	2.72	3.68	4.04	4.38	3.58	0.99	0.9	1.05	1.5	2.43	2.86	3.07	3.28	3.7	4.28	2.68	1.78	1.53	1.22	0.95	1.69	2.22	2.51	2.58	3.11
21	Bishambharpur	0.7	2	2.4	2.82	3.27	3.8	3.78	0.89	0.48	0.75	1.37	1.72	1.98	2.11	2.34	2.81	3.18	2.85	2.25	2.4	2	0.64	0.95	1.45	1.75	1.81	2.1
22	Mahmadpur	0.55	1.8	2.17	2.71	2.91	2.95	2.35	1.15	0.89	1.04	1.48	1.8	1.91	1.96	2.36	2.72	3.01	2.53	1.8	1.79	1.26	0.96	1.35	1.65	2.8	2.83	2.09

Sl No.	locations	m.p	Feb-12	Mar -12	Apr -12	May -12	Jun -12	Jul-12	Aug -12	Sep-12	Oct -12	Nov -12	Dec-12	Jan -13	Feb -13	Mar -13	Apr -13	May -13	Jun -13	Jul-13	Aug -13	Sep-13	Oct -13	Nov -13	Dec-13	Jan -14	Feb -14	Mar -14
23	Snehi Tola, Naubatpur	0.4	2.99	3.04	3.63	5.57	6.22	4.3	2.04	1.25	1.55	2	2.7	2.9	3.02	3.2	3.87	5.68	4.2	3.9	2.8	1.7	1.3	2	2.69	1.75	3.22	3.45
24	Dariapur, Chainpura	0.5	3.24	3.58	3.92	4.34	4.74	4.5	4.3	1.2	1.35	1.88	2	2.5	2.8	3.1	3.35	4.22	4.05	4.45	4.72	2.28	1.72	2.52	3.17	2.31	3.5	3.65
25	Andhra chowki	0.63	1.99	1.87	2	2.34	2.42	1.58	0.51	0.41	0.77	1.32	1.47	2.02	2.04	2.42	2.92	3.03	2.43	1.89	1.42	0.99	0.88	1.26	1.57	2		
26	Din Bigha	0.55	2.08	2.13	3.85	5.3	5.88	3.49	0.54	0.4	0.39	1.6	1.95	2.08	2.4	3.29	4.99	5.3	4.22	1.55	1.6	0.55	0.45	1.53	2.42	2.41	2.47	3.54
27	Amraha	0.43	2.02	2.3	2.87	3.15	2.87	1.18	0.77	0.82	1.04	1.57	1.82	1.89	2.05	2.13	2.77	3.11	1.78	1.09	1.14	1.13	1.08	1.37	1.61	1.52	1.55	2.02
28	Raghopur,Bihta	0.75	4.51	4.8	5.05	5.85	5.65	5.54	5.31	5	4.67	4.8	4.21	4.39	4.5	4.6	4.9	5.13	5.1	4.95	5.3	5.25	5	4.6	4.44	4.58	4.55	4.75
29	Faridpur	0.7	3.9	3.8	4.52	4.98	5.18	4.2	3.61	1.19	1.4	2	2.7	3.1	3.26	4.1	4.29	5.35	5.09	4.9	5.21	4.25	3.45	2.92	3.88	4.28	4.76	4.99
30	Azwa	0.5	3.13	3.84	4.38	5.28	5.1	4.6	4.55	1.1	1.2	1.85	2.7	3	3.02	3.3	3.75	4.5	4.42	3.96	4.1	2	1.17	1.86	2.54	2.03	2.9	3
31	Gonwa	0.45	2.41	3.03	3.48	3.77	4.25	3.75	3.55	1.15	1.34	1.75	2.55	2.75	3.05	3.15	3.44	3.46	2.75	2.37	2.96	1.05	0.6	1.46	2.15	1.11	2.5	2.85
32	Murarchak	0.6	6.82	7.73	8.46	9.37	9.2	4.8	2.01	1.55	2.1	3.24	5.05	6.17	6.85	7.21	8.37	9.03	7.75	5.03	4.45	2.29	1.97	3.1	4.4	5.37	6	6.76
33	Anisabad	0.5	1.6	1.9	1.9	2.23	2.45	1.25	0.23	0.37	0.7	1.02	1.1	1.15	1.16	1.44	1.77	2.5	1.52	1.44	1.08	1	1.05	1.75	1.14	1.12	1.16	1.22
34	Chiraura	0.37	2.93	3.06	3.26	3.75	4.05	3.83	2.18	1.13	1.3	1.53	2.13	2.43	2.48	2.67	2.82	2.89	3.63	3.38	3.93	1.76	1.38	1.77	2.58	2.61	2.74	2.91
35	Parsa bazar	0.62	5.66	6.78	7.53	8.54	8.66	7.51	0.14	0.16	1.2	2.14	2.48	4.69	5.08	6.21	6.83	7.86	7.67	0.38	0.15	0.09	0.09	0.48	2.13	3.39	3.44	5.02
36	Nisirpura	0.37	7.31	8.4	8.71	9.69	9.38	8.78	5.33	3.23	3.48	4.04	4.88	6.38	6.86	8.02	8.47	9.39	9.15	8.56	8.47	5.43	3.53	4.45	5.73	6.04	6.09	7.15
37	Khadika	0.62	6.88	7.58	8.2	8.4	8.7	8.53	7.93	3.48	3.83	4.23	5.13	5.54	6.91	7.19	7.47	8.46	8.22	8.33	8.49	6.95	4.31	4.8	5.93	6.41	6.46	6.94
38	Etwarpur	0.4	2.9	3.6	4.42	4.71	4.95	3.52	0.74	0.47	1.38	1.86	2.12	2.28	2.61	3.02	3.08	4.2	3.42	2.87	2.07	0.75	0.57	1.07	1.77	1.98	2.02	2.22
39	Raunia	0.65	3.75	4.73	5.39	6.41	7.32	6.95	4.14	1.8	1.9	2.1	2.95	3.15	3.63	3.85	4.51	5.66	4.85	4.3	5.25	3.31	1.96	2.14	3.75	3.33	3.85	4.03
40	Sarasat	0.52	3.9	4.32	4.7	5.09	5.5	5.58	4.88	1.92	2.18	3.07	3.68	3.88	3.98	4.1	4.18	4.2	4.23	4.58	4.85	4.03	3.18	3.53	4.18	4.1	4.53	4.18
41	Korhar	0.6	1.59	2.37	5.23	5.34	5.64	5.31	4.34	3.84	4.35	4.35	4.4	4.66	5.01	5.14	5.45	5.52	5.4	5.71	5.4	5.4	5.12	4.28	4.34	4.6	4.62	4.97
42	Noniatola	0.65	2.55	2.95	3.49	4.07	4.4	2.89	1.39	1.23	1.35	1.75	2.49	2.62	2.76	2.85	3.51	3.96	3.71	2.04	1.95	1.45	1.05	1.74	2.47	2.77	2.83	3.21
43	Darbeshpur	0.35	7.42	8.2	8.51	8.86	8.85	7.69	3.32	2.02	3.22	4.96	6.58	7.41	7.77	7.97	8.53	8.93	8.22	5.4	3.61	2.85	2.46	4.84	6.09	7.15	7.48	7.82
44	Nagwa	0.3	2.47	3.75	6.3	7.99	5.75	5.13	0.92	0.87	1	1.86	2.23	2.27	2.41	2.8	5.53	7.03	2.63	2.12	1.25	1.08	0.91	1.95	2.1	2.14	2.36	2.53
45	Bhateri	0.75	3.27	4.45	4.83	5.67	6.45	5.33	0.22	0.01	0.2	1.03	2.26	2.8	3.38	3.86	5.38	6.19	4.67	2.82	2.82	0.27	0.1	0.7	1.55	2.4	2.81	3.12

Sl No.	locations	m.p	Feb-12	Mar-12	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14
46	Mehdawa	0.66	3.71	4.51	5.34	5.99	6.64	6.64	2.03	2.02	2.04	2.74	3.17	3.6	4.16	5.05	5.51	6.08	5.61	3.91	2.22	1.93	1.32	2.51	3.9	3.32	3.65	4.12
47	Chhiyattar	0.44	5.58	6.42	6.9	7.23	7.54	5.96	5.64	4.7	3.96	4.34	4.7	5.32	5.66	6.01	6.41	7.47	4.73	5.85	4.01	1.86	1.81	2.38	4.26	4.69	4.87	5.32
48	Jinpura	0.5	1.65	1.96	2.26	3.12	4.5	2.03	0.99	0.66	0.86	1.28	1.48	1.66	1.68	1.9	2.35	3.09	2.16	1.6	1.84	1.28	0.62	1.07	1.32	1.45	1.52	1.65
49	Tishkhora	0.35	1.77	2.35	3.45	3.42	3.5	3.4	0.84	0.3	0.9	1.05	1.45	1.57	1.7	2.28	2.34	2.78	2.61	1.56	1.5	0.3	0.67	1.27	1.87	0.37	2.37	2.5
50	Moriyawa	0.4	2.9	3.24	3.5	3.3	3.4	2.94	2.4	0.71	0.77	1.76	2.24	2.86	2.9	3.23	3.75	3.81	3.81	3.2	3.45	0.77	0.63	1.48	2.09	2.57	2.64	3.04

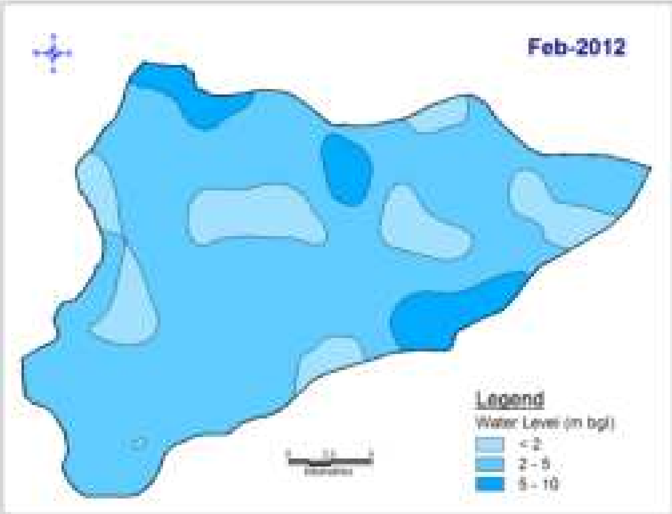
Annexure 3.8 (e): Month wise depth to piezometric level (Aquifer -1) in m, bgl

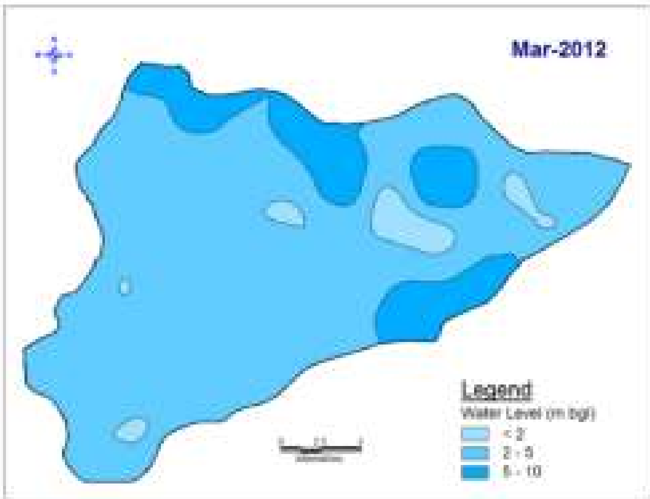
Sl. No.	Location	MP	Nov-11	Jan-12	Mar-12	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14
1	Frazer Road	1.5	8.81	10.9	11.63	11.85	11.25	11.32	11.9	11.31	8.61	8.74	9.74	10.4	11.69	11.7	11.73	11.7	11.67	11.47	10.39	9.59	8.9	8.4	9.8	10.91		10.93	11.28	12.89	11.71	11.75
2	Khagaul PZ-1	0.4	5.05	7.04	8.12	8.94	9.77	9.62	8.42	8.09	3.5	3.94	4.98	5.99	6.8	6.91	7.58	9.07	9.2	8.31	7.2	6.8	5.14	3.89	4.58	6.17	6.57	6.86	7.36	9.01	9.94	9.96
3	Khagaul PZ-2	0.4												5.77	6.4	7.5	7.38	8.85	8.94	8.09	7.58	7.42	4.94	3.68	4.36	5.95	6.35	6.64	7.15	8.82	9.73	9.76
4	Kankerbagh	0.3	7.96	9.12	10.55	11.11	11.5	11.05	9.56	7.05	5.81	6.57	7.99	8.5	8.07	9.33	10.09	11.43	11.67	10.4	9.19	7.75	7.67	7.02	8.22	8.9	9.21	9.85	9.43	11.03	11.82	11.88
5	Gandhi Maidan	0.3	9.9	12.78	13.65	12.88	13.24	13.42	10.15	8.69	7.18	8.9	9.9	11.3	10.99	11.43	11.9	11.12	13.16	12.43	10.11	8.58	9.12	8.65	10.08	10.87	11.07	11.26	11.69	13.02	13.68	13.4
6	Circuit House	0.6	8.5	9.4	10.93	12.1	12.94	10.55	11.4	8.93	7.2	7.62	9.15	8.79	9.97	9.51	10.97	12.74	12.7	11.78	10.57	9.21	8.34	7.86	9.27	10	10.33	10.35		12.54	13.2	13.11
7	A N College	0.5	7.04	8.54	9.57	10.47	10.99	10.6	8.12	6.57	5.95	6.09	7.22	7.87	8.44	9.4	8.89	10.82	10.71	9.8	7.99	6.84	6.61	5.99	7.24	7.95	8.27	9.4	8.89	10.61	11.14	11.35
8	Kumhrar	0.3	7.64	9.02	10.12	10.85	10.91	10.75	8.26	6.65	5.88	6.25	7.35	11.26	8.37	9.16	10.03	11.13	11.25	10.06	8.15	6.84	7.03	6.72	8.08	8.83	8.62	9.6	9.52	10.05	11.47	11.15
9	B V College (Pz-2)	1			8.9	9.68	10.31	10.43	9.8	8.4	6.25	5.94	6.67	6.69	7.26	7.76	8.1	10.45	9.82	9.92	9.03	8.5	7.12	6.51	7.31	8.38	8.09	8.42	8.88	9.95	10.32	10.39
10	Anisabad	0.5			8.68	9.88	10.6	9.58	7.87	6.56	4.67	5.39	6.44	7.09	8	8.04	8.57	10.41	10.47	9.61	8.49	8.35	6.32	5.46	6.11	7.46	7.82	8.28	8.67	10.27	11.1	11.16
11	Arap	0.5				9.27	10.5	10.7	8.54	7.53	7.11	6.58	6.96	7.5	8.75	9.2	8.95	9.78	9.76	9.44	8.9	8.62	7	7.1	7.12	8.25			8.84	9.8	10.13	10.77
12	Naubatpur	0.6			8.23	8.53	9.91	9.52	8.79	7.37	6.3	5.51	5.81	7.3	7.17	7.4	7.65	9.12	8.74	8.61	8.6	7.72	6.5	5.66	5.88	6.87		5.61	5.61	9		
13	Bikram	0.4					5.83	6.31	4.72	3.17	2.7	2.2	2.55	3.54	4.49	4.37	4.48	5.59	5.73	5.65	4.88	3.65	2.51	2.13	2.75	4.21	4.13	4.71	5.03	5.47	6.11	6.49
14	B. N. CollegePZ-1	1.05	6.57	7.72	8.86	8.45	11.23	11.36	10.76	10.09	8.92	8.83	8.81	8.79	8.83	8.85	8.89	10.02	9.2	9.1	9.13	9.05	8.93	8.88	8.82	8.87	10.89	11.05	8.5	9.01	9.11	9.17
15	Maner	0.5	5.48	6.77	7.1	8.16	8.56	8.74	7.37	5.05	4.3	4.28	4.22	6.19	6.39	6.86	7.32	8.57	8.6	7.97	6.31	3.42	4.08	3.5	5.48	6.67	6.8	6.99	7.34	8.02	8.67	8.54
16	Amhara	0.5									2.4	1.9	1.77		3.32	3.41	3.62	3.93	4.1	3.49	3.69	3.66	2.49	1.39	1.49	1.96			3.21		4.15	
17	Naubatpur-2	0.7																7.09	6.79	6.86	6.08	7.02	3.98	2.8	3.57	4.84		5.06	5.58	6.46	7.06	7.56
18	Phulwari Thana	0.43												5.23	7.37	7.56	8.05	8.82	10.15	10.36	8.24	7.24	5.19	3.97	4.9	6.11		6.71	8.3	8.63	9.57	9.2
19	kurji	0.45																	10.72	10.02	7.74	5.77	6.3	6.11	7.55	11.27	11.61	8.38	9.25	11.51	11.09	10.96
20	A.N.College Campus-2	0.85																							7.24	7.7	8.91	8.24	8.58	10.4	10.97	10.93

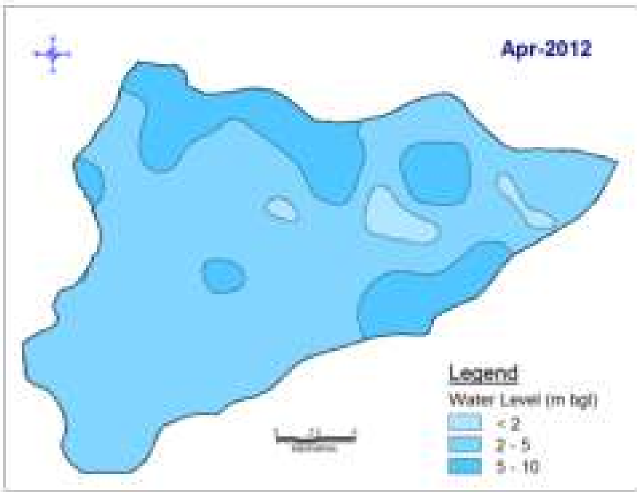
Annexure 3.8 (f): Monthwise depth to piezometric level (Aquifer -2) in m, bgl

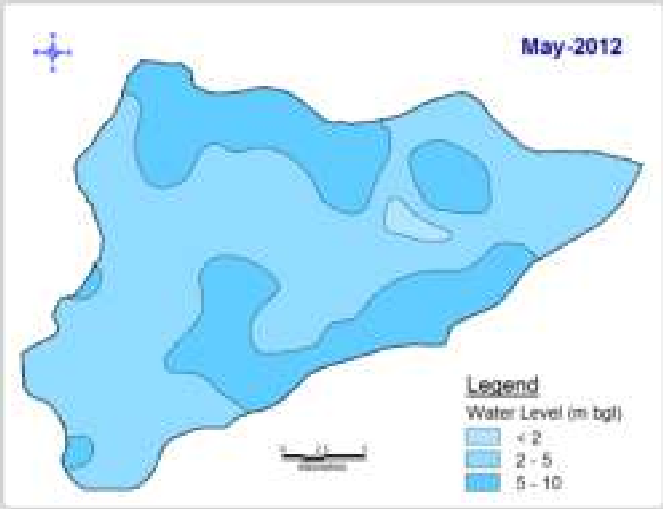
Sl. No.	Location	MP	Nov-11	Jan-12	Mar-12	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14
1	B V College (Pz-1)	1	7.13	9.06	9.9	10.85	11.65	11.62	9.14	7.84	5.68	6.27	7.43	8.2	8.57	9.2	9.25	11.78	11.33	10.45	9.22	8.8	7.1	6.43	6.88	6.77	8.77	9.22	9.65	11.21	12.07	12.06
2	B. N. College PZ-2	1.05												10.28	10.63	11.35	11.45	13.55	12.84	12.14	9.77	8.17	8.95		10.04	10.87	8.87	8.91	11.1	12.61	13.33	13.27
3	Naubatpur -1	0.7															6.68	8.43	7.88	7.55	7.45	7.77	5.39	4.53	4.78	5.79		5.27	6.65	7.54	8.3	9.11
4	Simri-2	0.65																6.97	6.64	6.6	5.26	4.06	3.21	2.37	3.56	5.22	4.79	5.05	5.4	6.29	6.84	6.97
5	Bihta	1																				6.43	5.29	4.91	5.09	5.42		5.7	6.07	6.28	9.11	8.6
6	A. N. College Campus-1	0.66																				6.92	6.46	5.91	7.18	7.74	8.85	8.27	8.67	10.66	11.12	11.06
7	Moriyama (OW)	0.9																										6.03	6.05		7.64	7.3

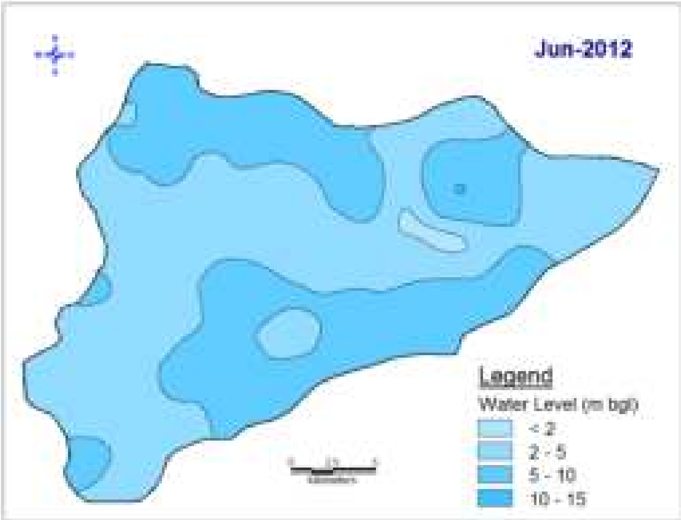
Annexure 3.8 (g): Month-wise Depth to water level map (Aquitard)

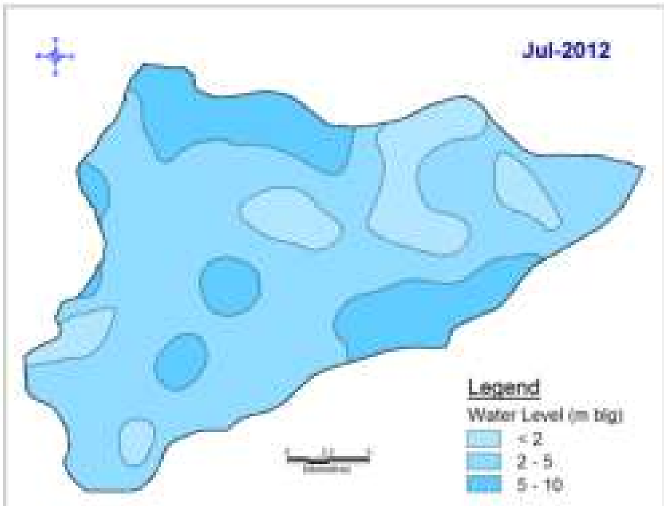


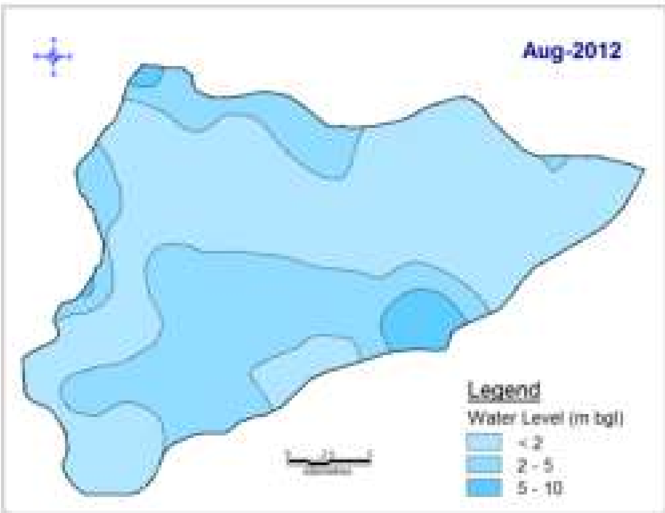


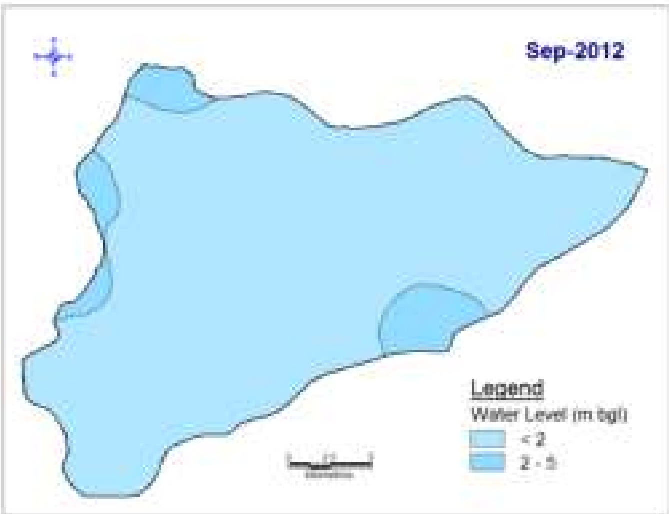


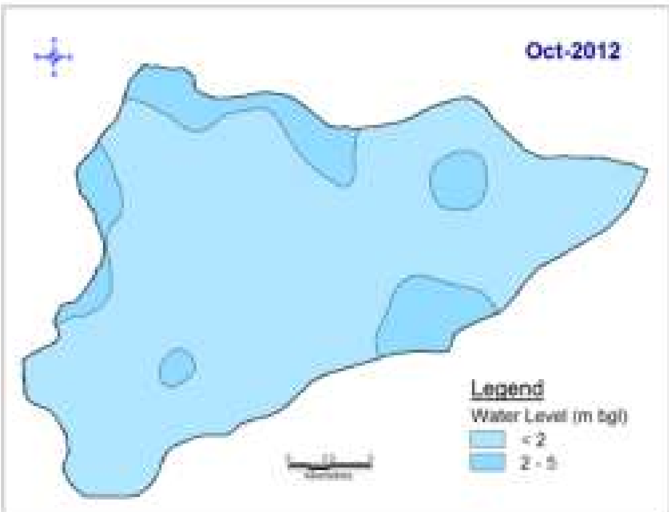

May-2012
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10


Jun-2012
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10
10 - 15


Jul-2012
Legend
Water Level (m blg)
< 2
2 - 5
5 - 10


Aug-2012
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10


Sep-2012
Legend
Water Level (m bgl)
< 2
2 - 5


Oct-2012
Legend
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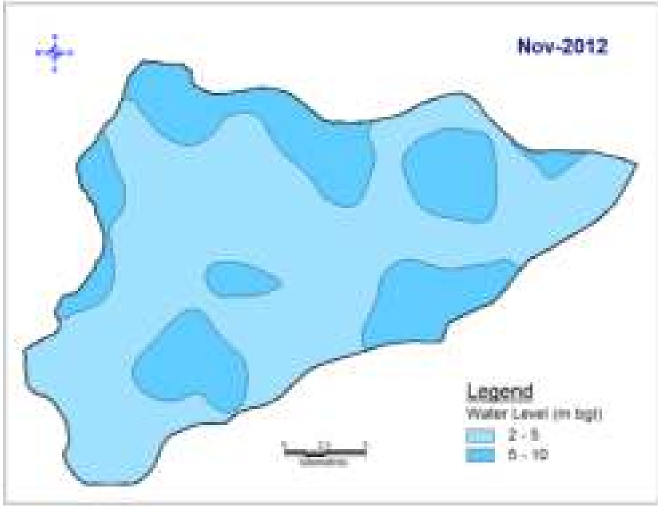
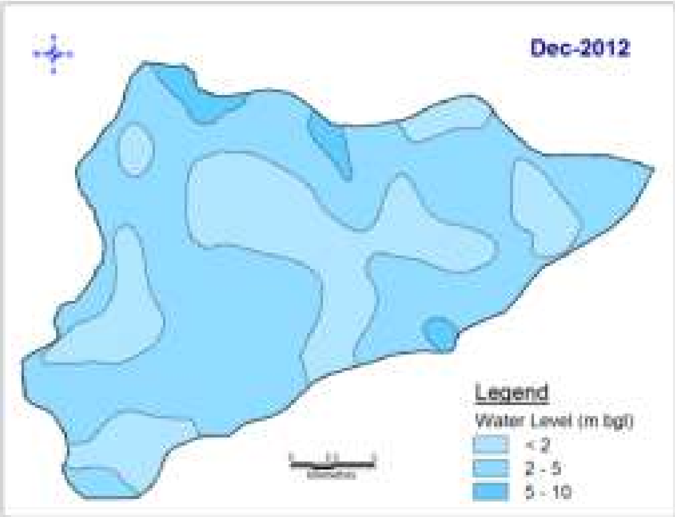
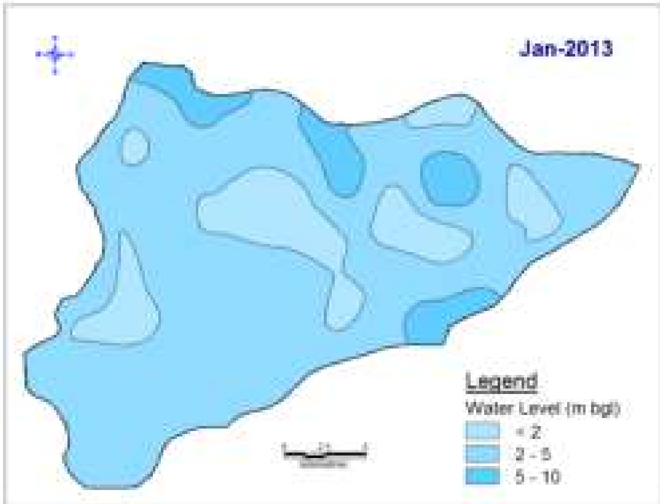
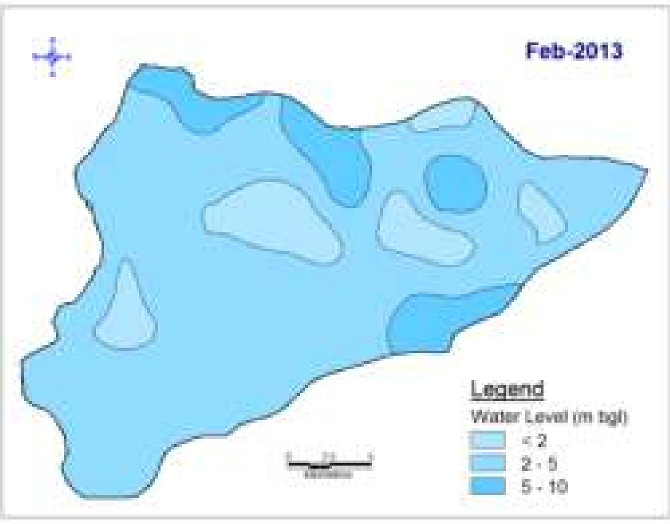
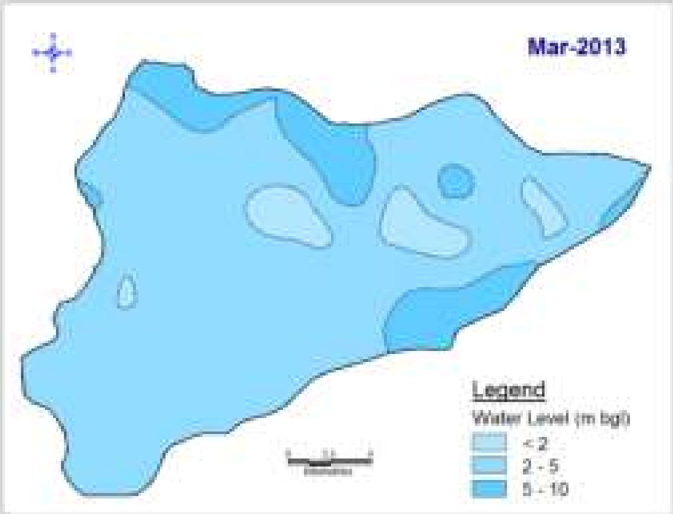
< 2
2 - 5

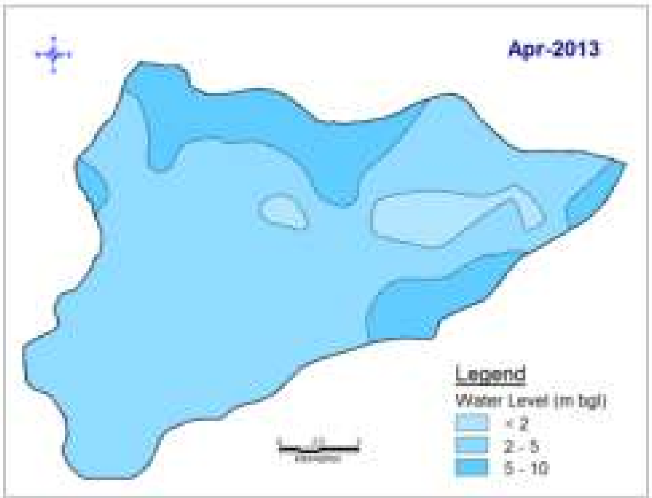

Nov-2012
Legend
Water Level (m bgl)
2 - 5
5 - 10

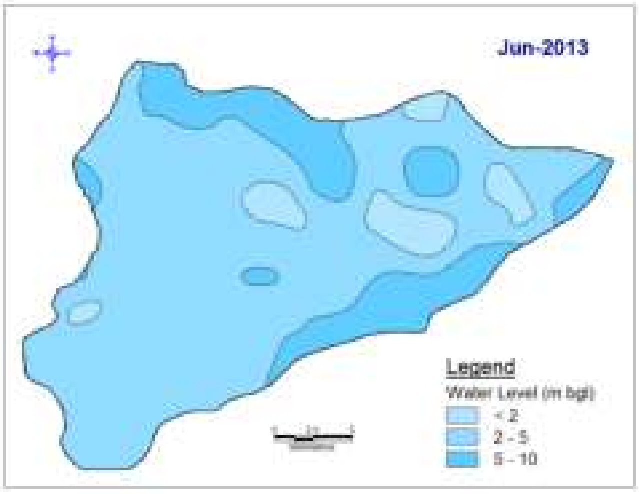

Dec-2012
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

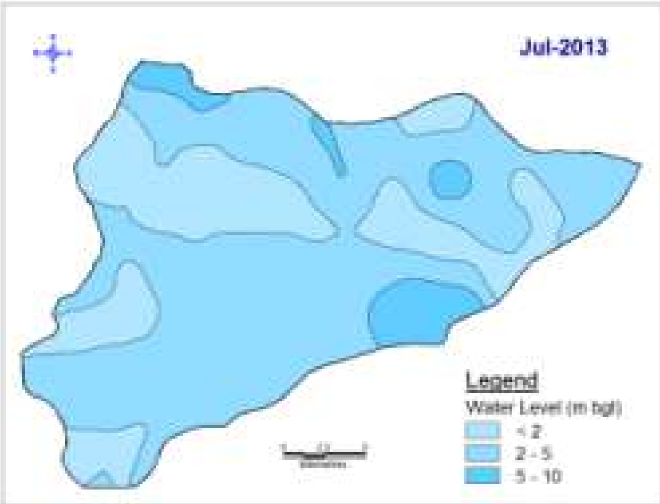

Jan-2013
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

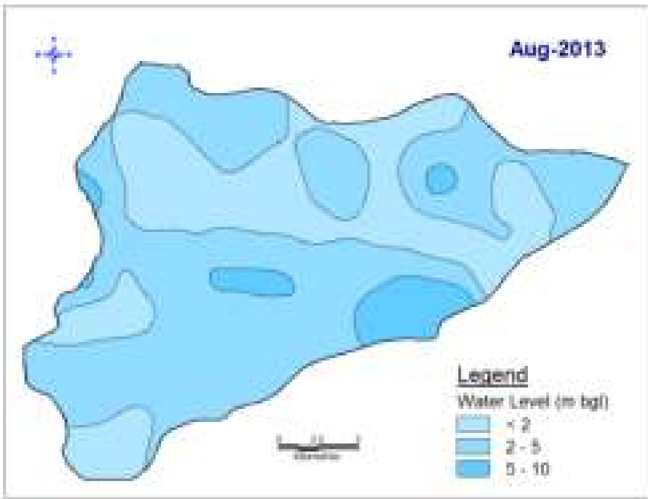

Feb-2013
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

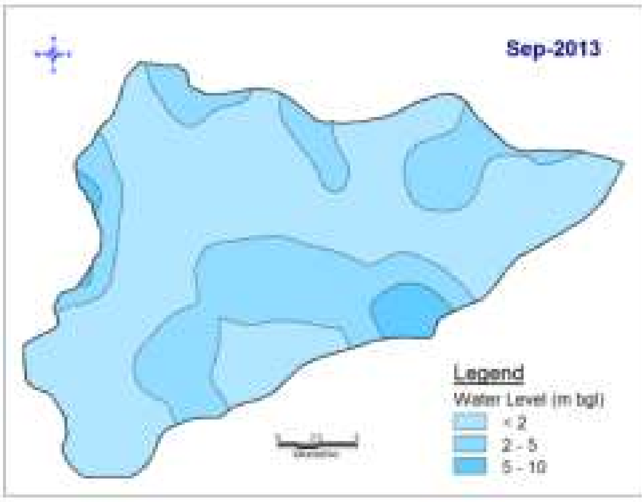

Mar-2013
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

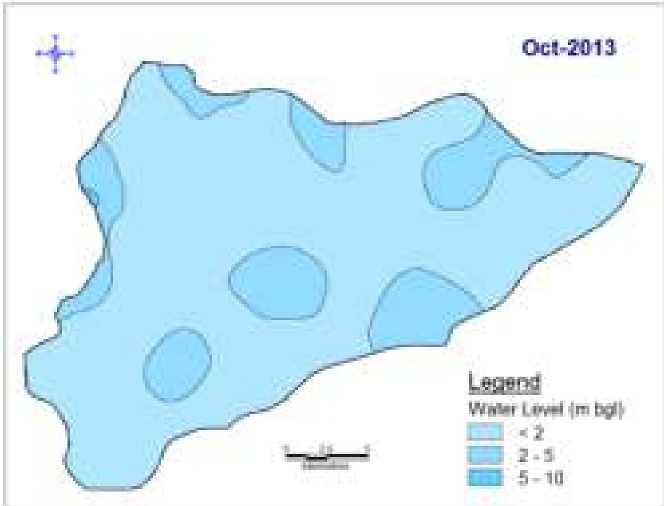

Apr-2013
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

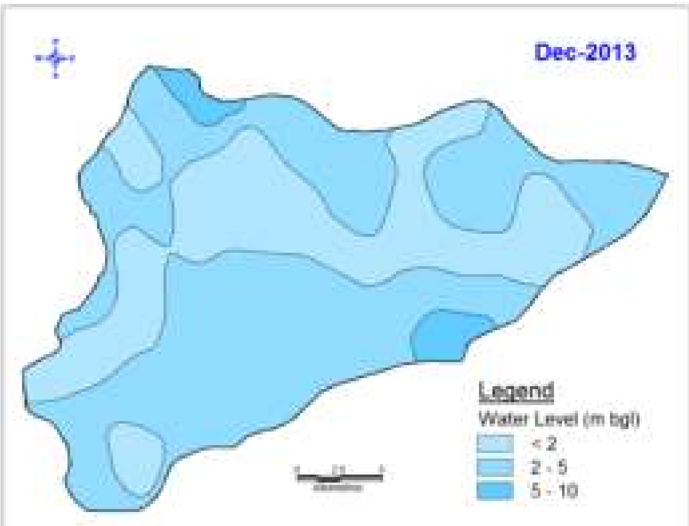

Jun-2013
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

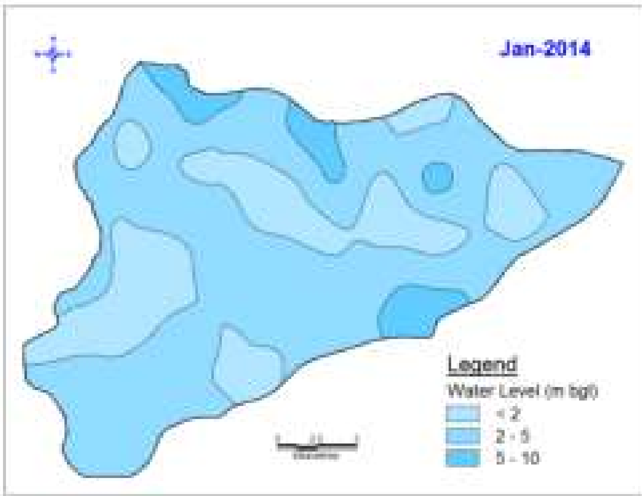

Jul-2013
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

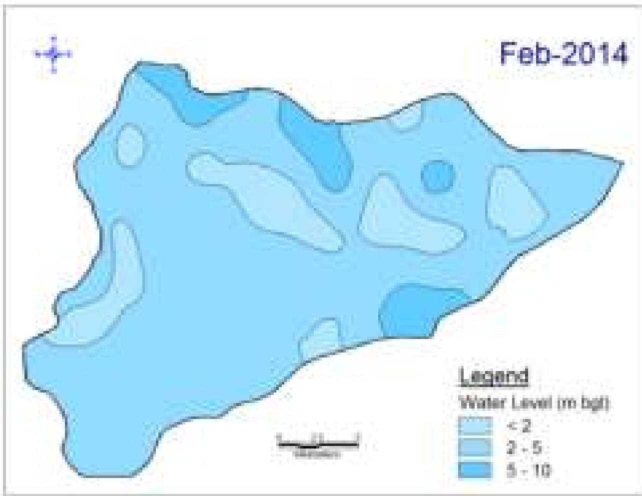

Aug-2013
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

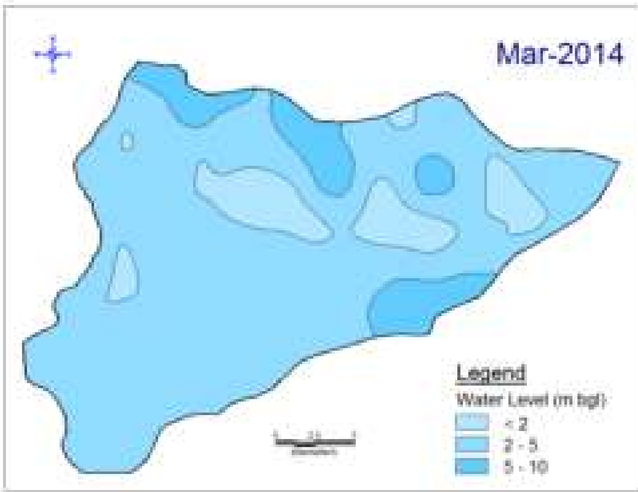

Sep-2013
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

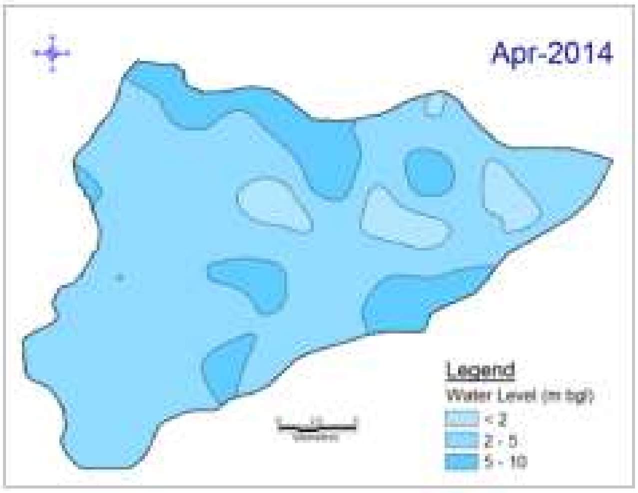

Oct-2013
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

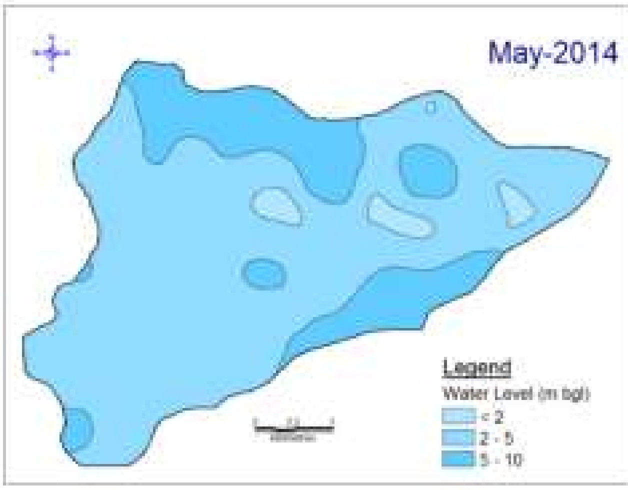

Dec-2013
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

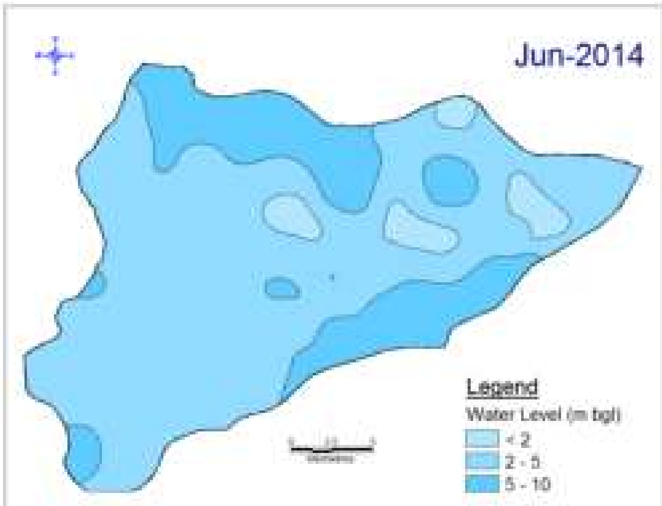

Jan-2014
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10


Feb-2014
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

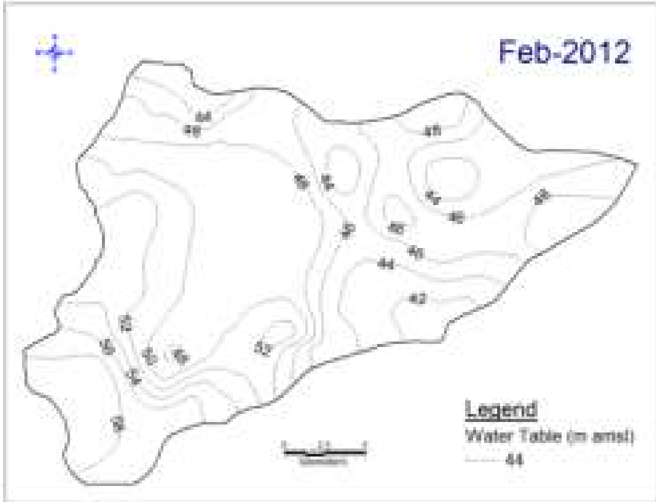

Mar-2014
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

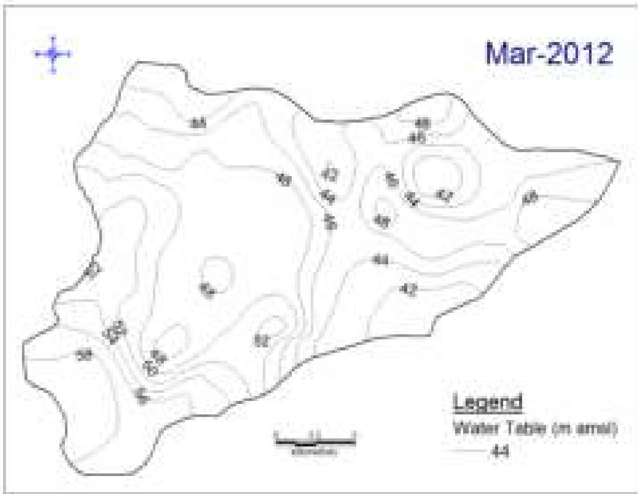

Apr-2014
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

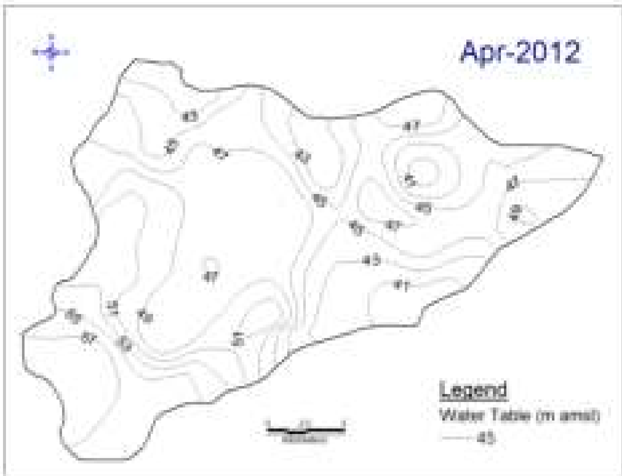

May-2014
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

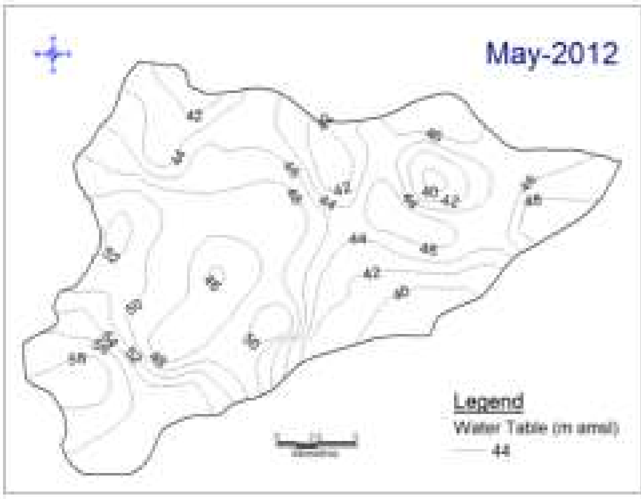

Jun-2014
Legend
Water Level (m bgl)
< 2
2 - 5
5 - 10

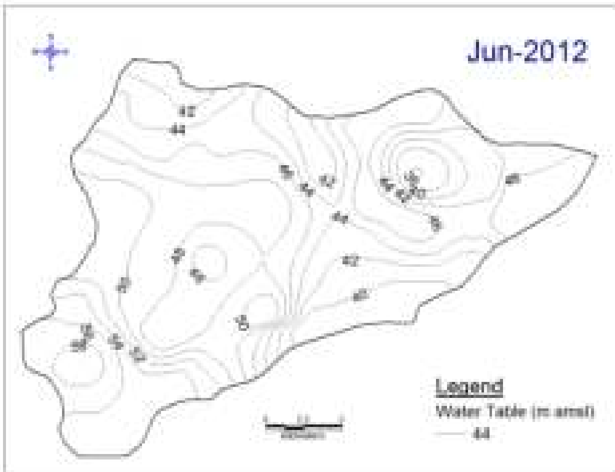
Annexure 3.8 (h): Month wise water table map (Aquitard)

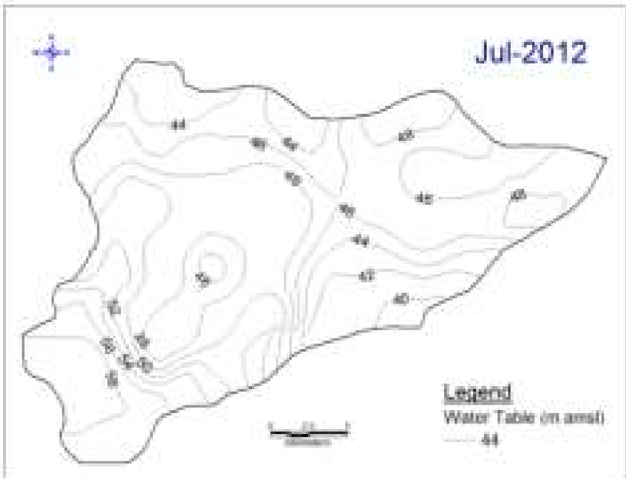


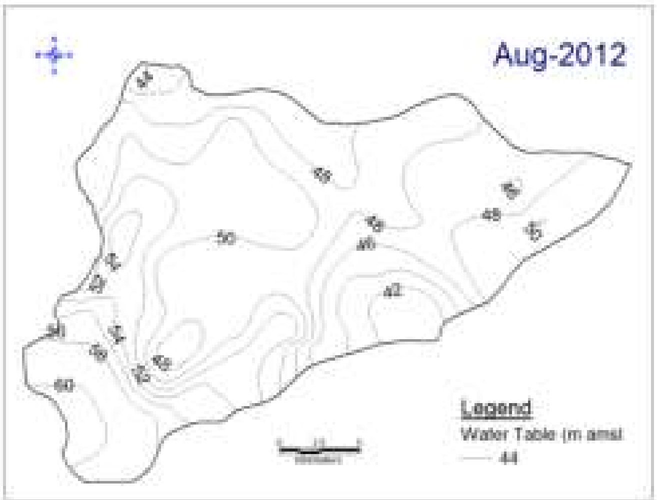


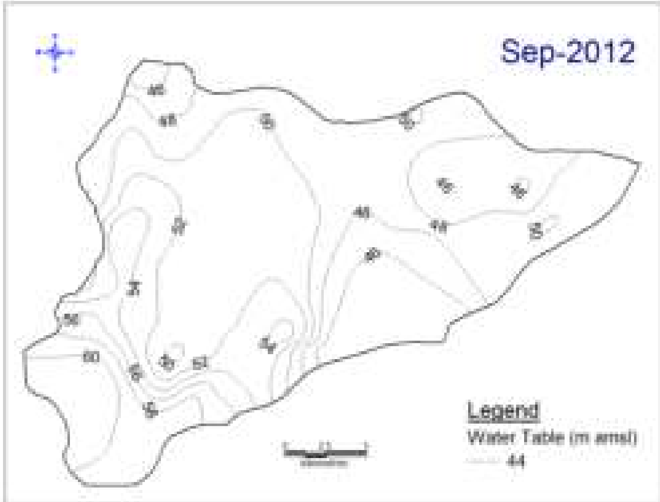


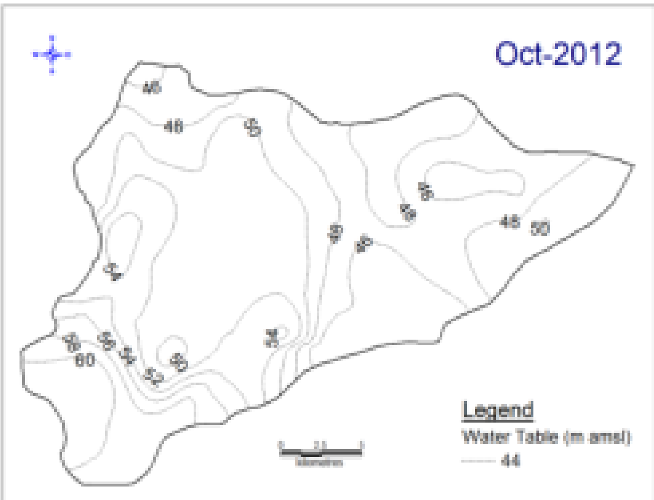

May-2012
Legend
Water Table (m amsl)
44

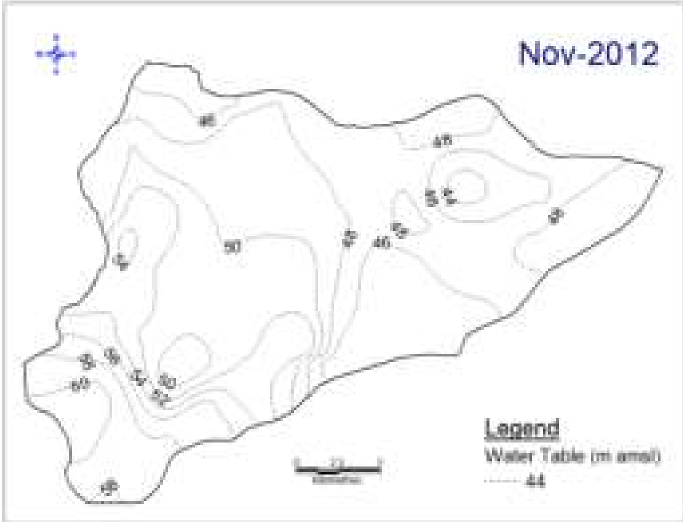

Jun-2012
Legend
Water Table (m amsl)
44

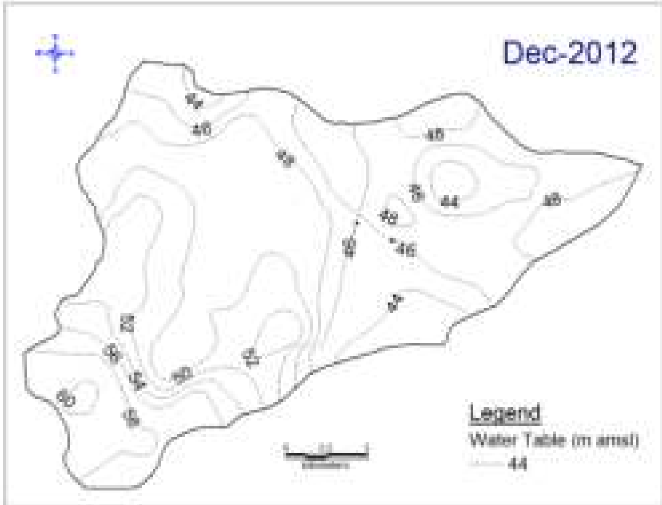

Jul-2012
Legend
Water Table (m amsl)
44

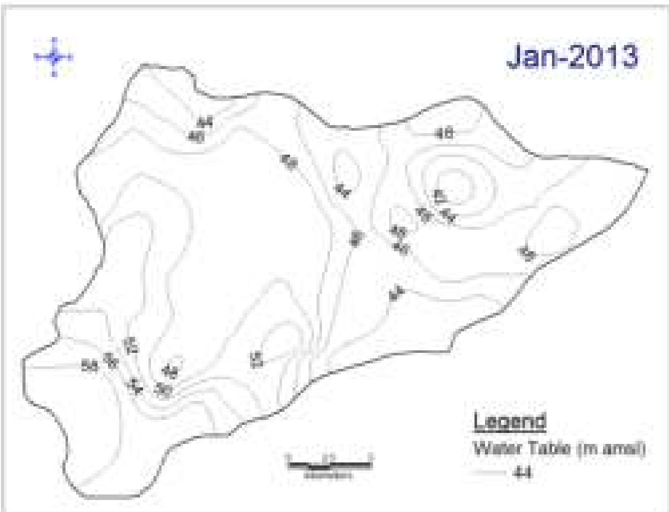

Aug-2012
Legend
Water Table (m amsl
44

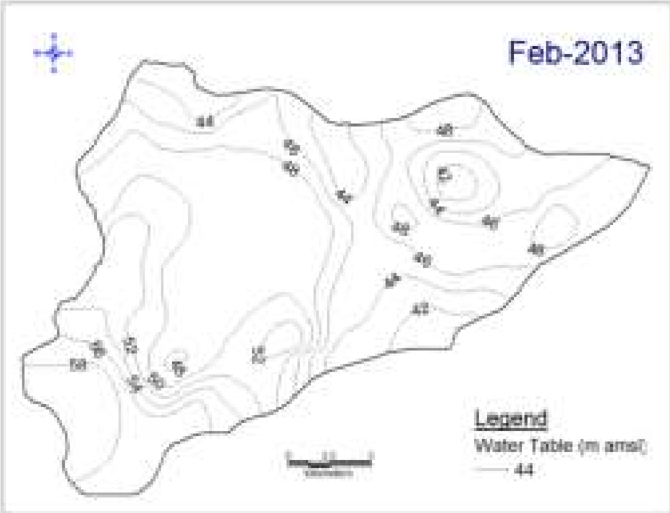

Sep-2012
Legend
Water Table (m amsl)
44

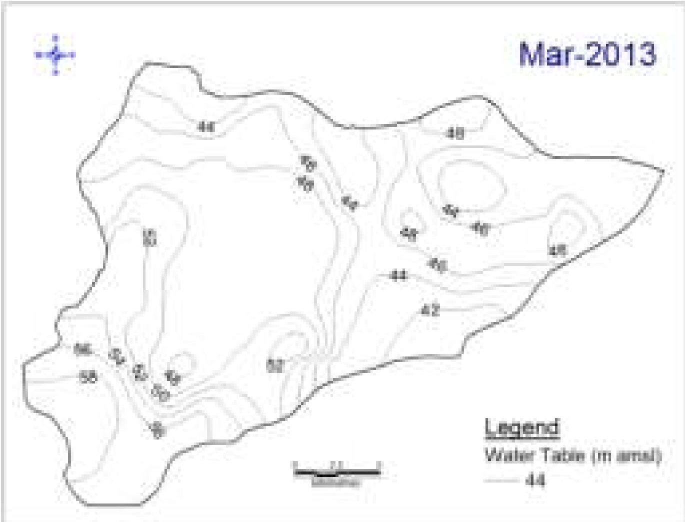

Oct-2012
Legend
Water Table (m amsl)
44

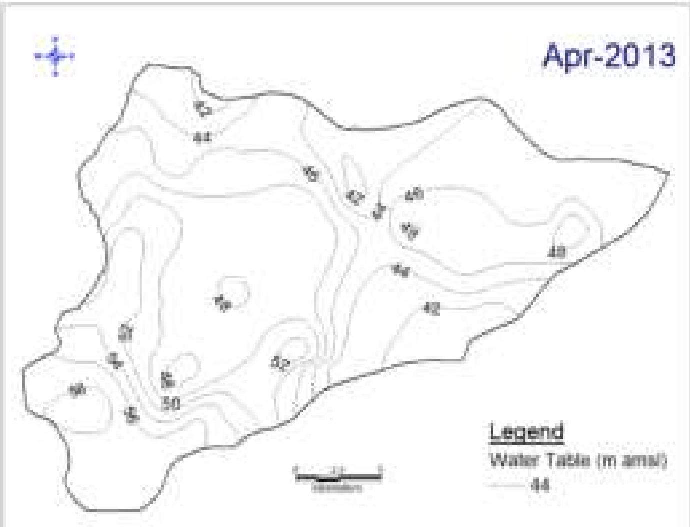

Nov-2012
Legend
Water Table (m amsl)
44

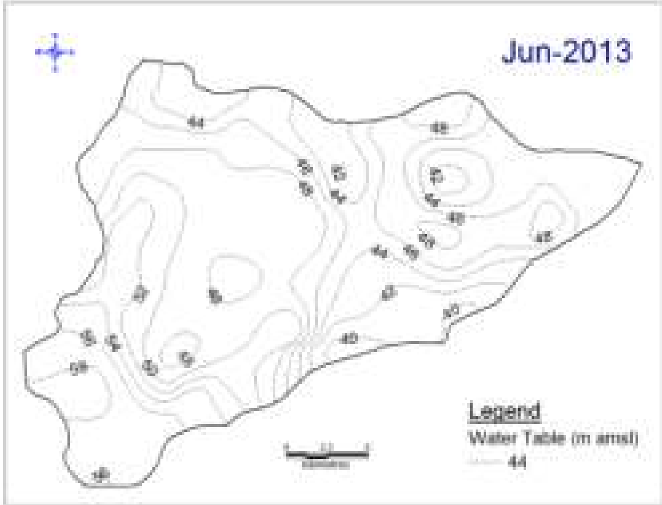

Dec-2012
Legend
Water Table (m amsl)
44

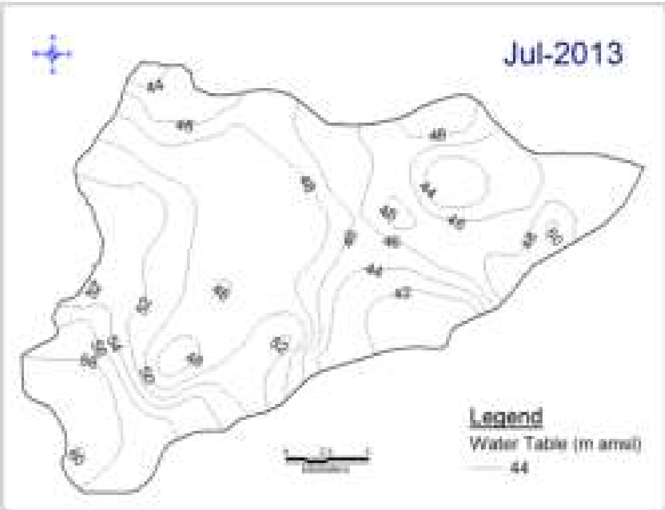

Jan-2013
Legend
Water Table (m amsl)
44

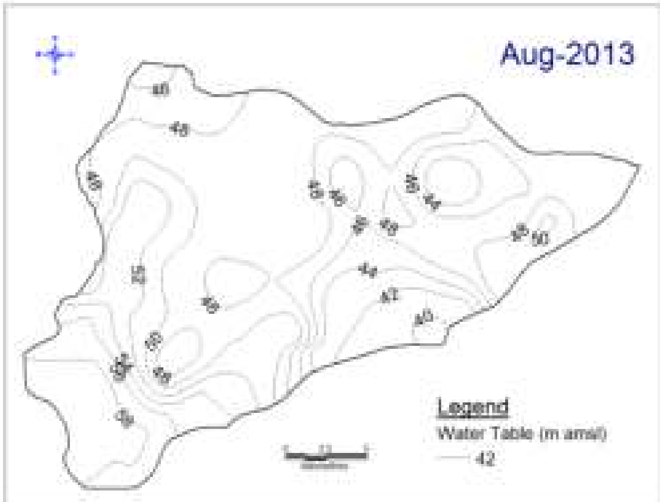

Feb-2013
Legend
Water Table (m amsl)
44

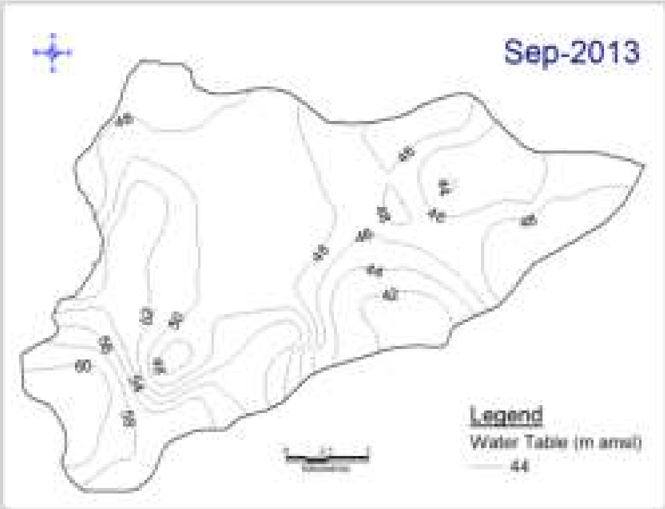

Mar-2013
Legend
Water Table (m amsl)
44

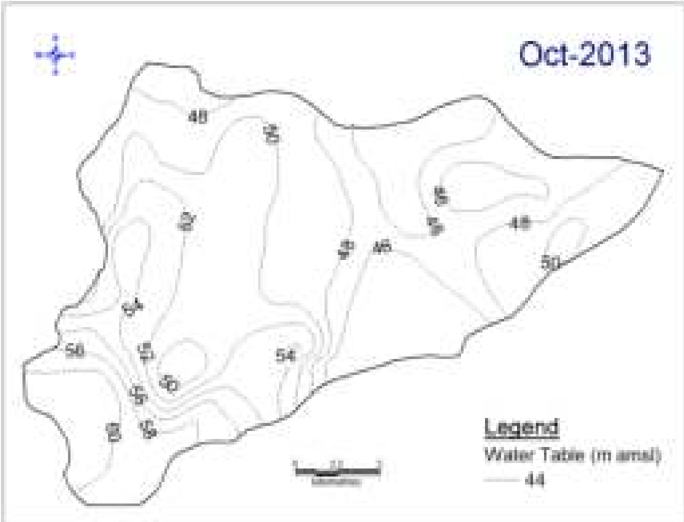

Apr-2013
Legend
Water Table (m amsl)
44

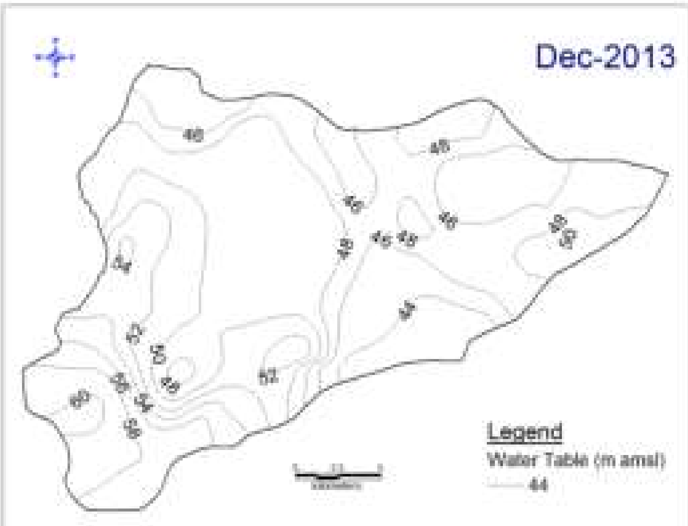

Jun-2013
Legend
Water Table (m amsl)
44

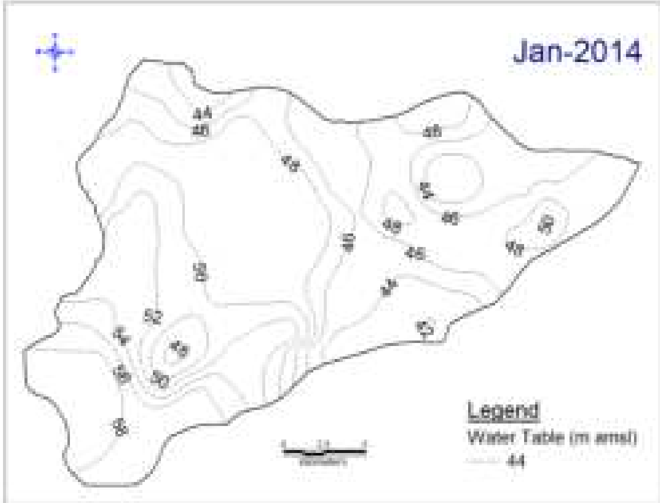

Jul-2013
Legend
Water Table (m amsl)
44

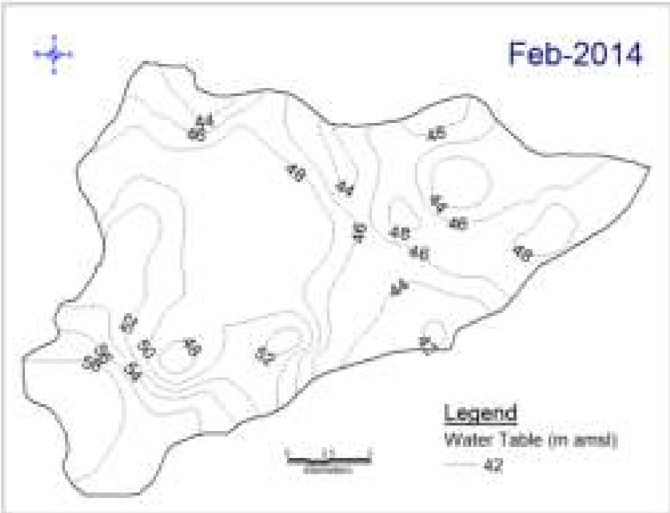

Aug-2013
Legend
Water Table (m amsl)
42

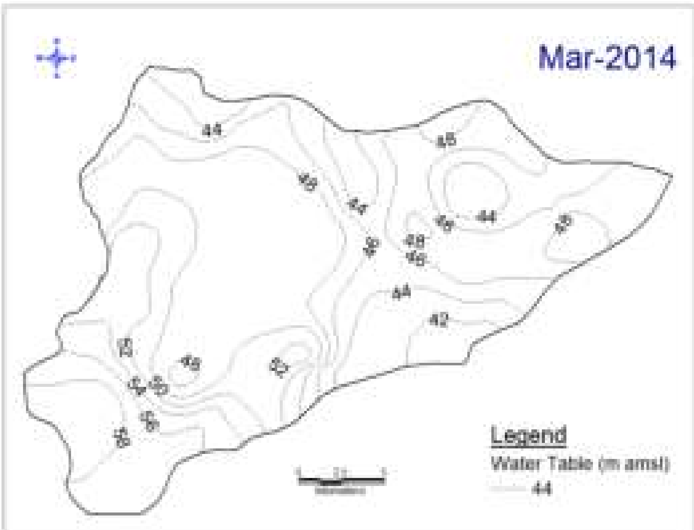

Sep-2013
Legend
Water Table (m amsl)
44

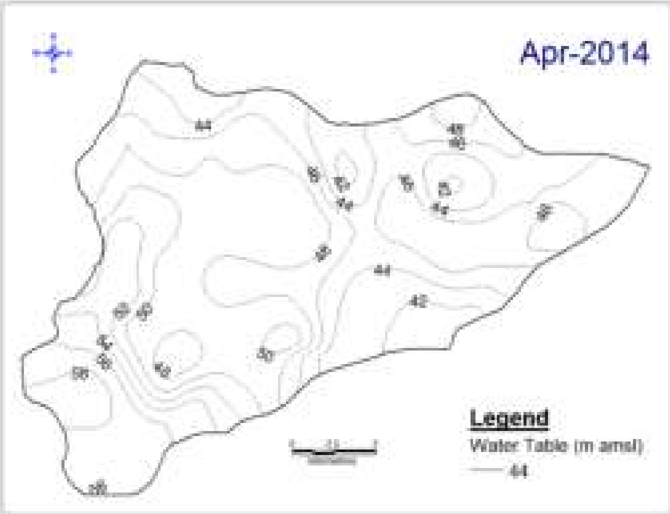

Oct-2013
Legend
Water Table (m amsl)
44

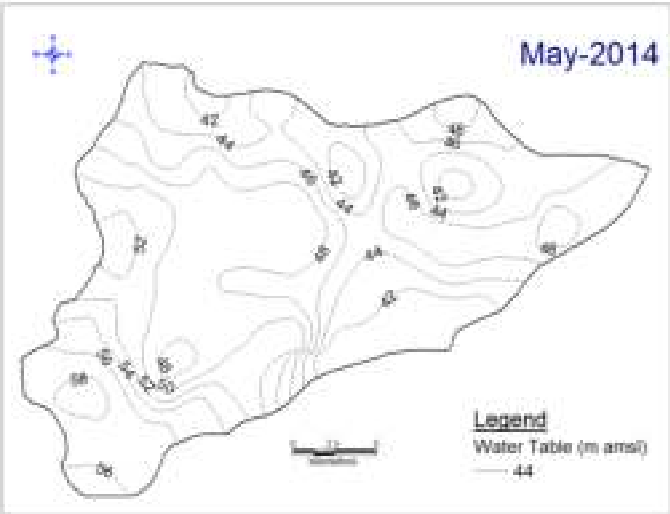

Dec-2013
Legend
Water Table (m amsl)
44

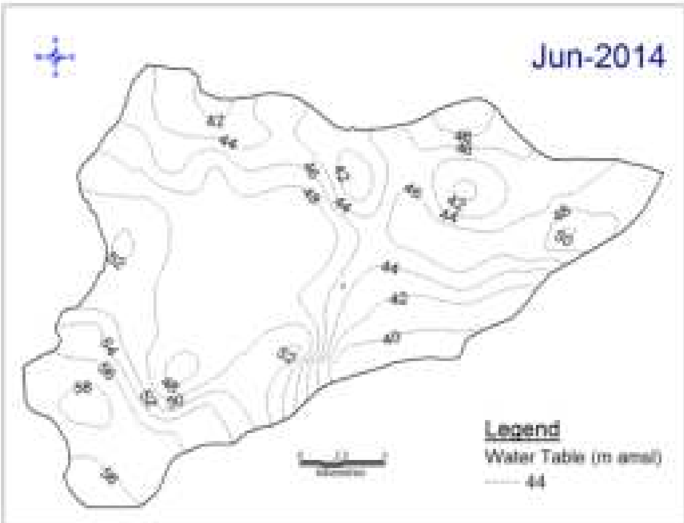

Jan-2014
Legend
Water Table (m amsl)
44


Feb-2014
Legend
Water Table (m amsl)
42

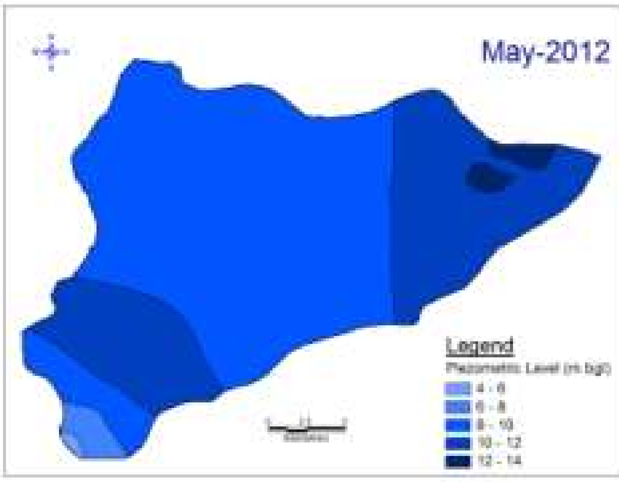

Mar-2014
Legend
Water Table (m amsl)
44

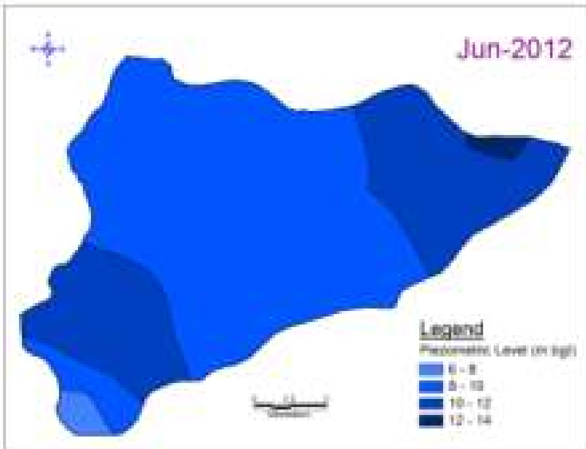

Apr-2014
Legend
Water Table (m amsl)
44

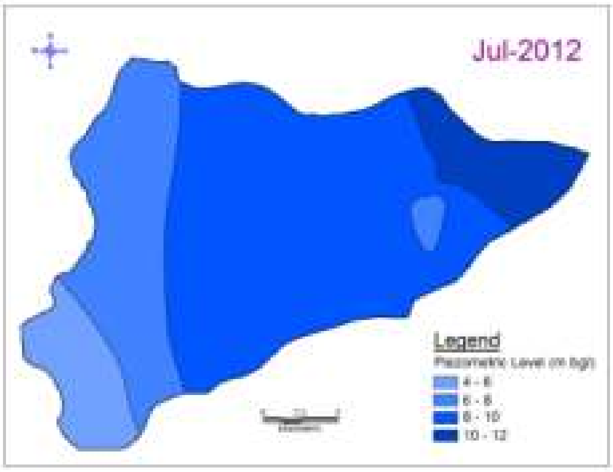

May-2014
Legend
Water Table (m amsl)
44

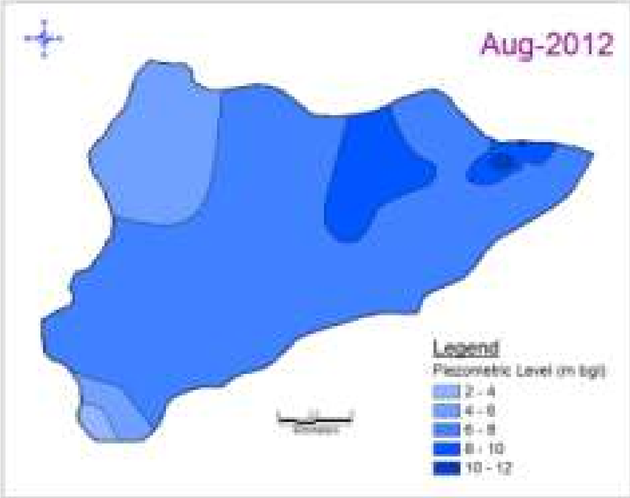

Jun-2014
Legend
Water Table (m amsl)
44

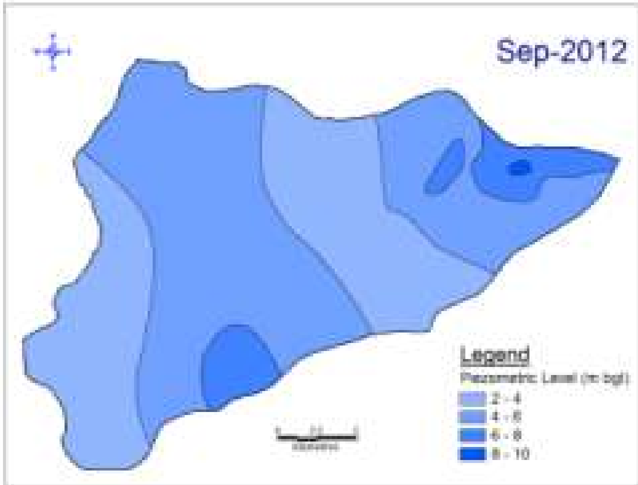
Annexure 3.8 (i): Month wise Depth to Piezometric level map (Aquifer-1)

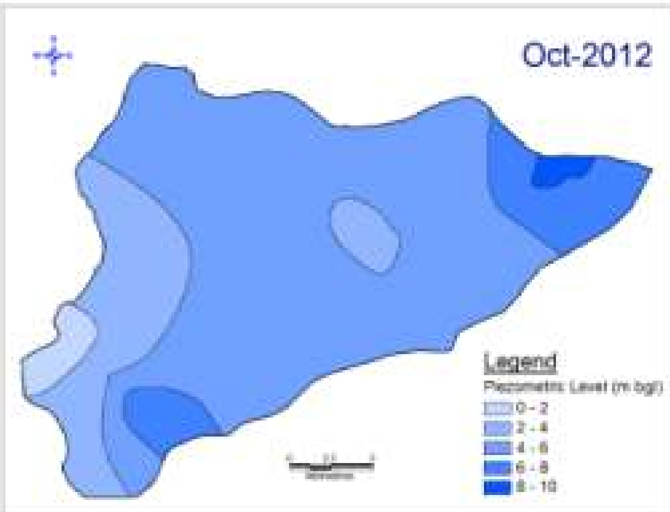


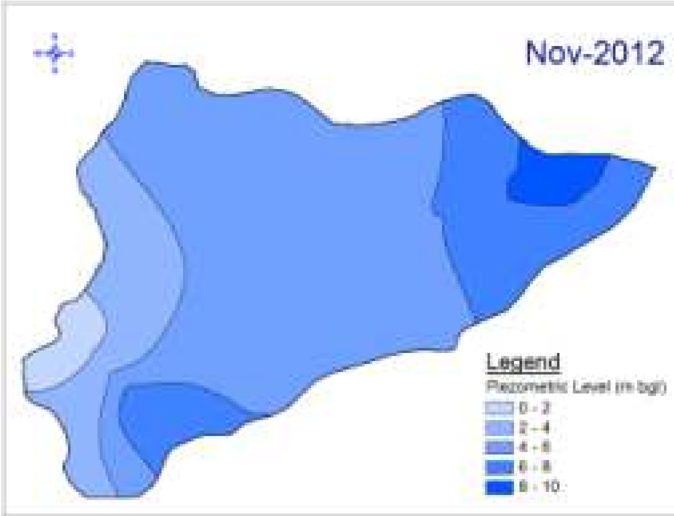


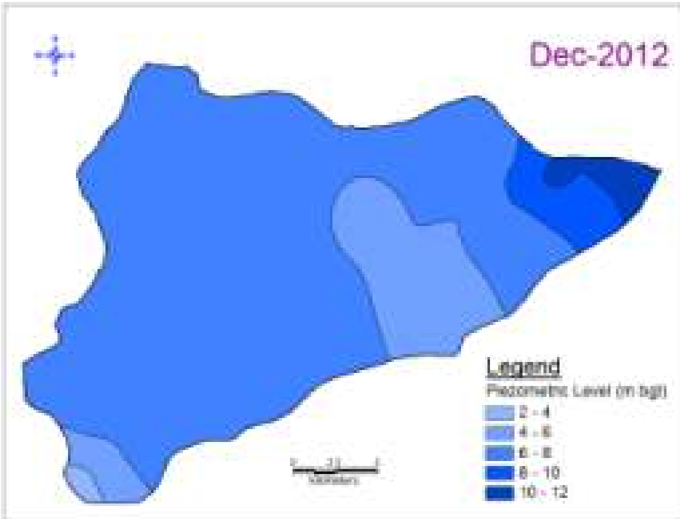


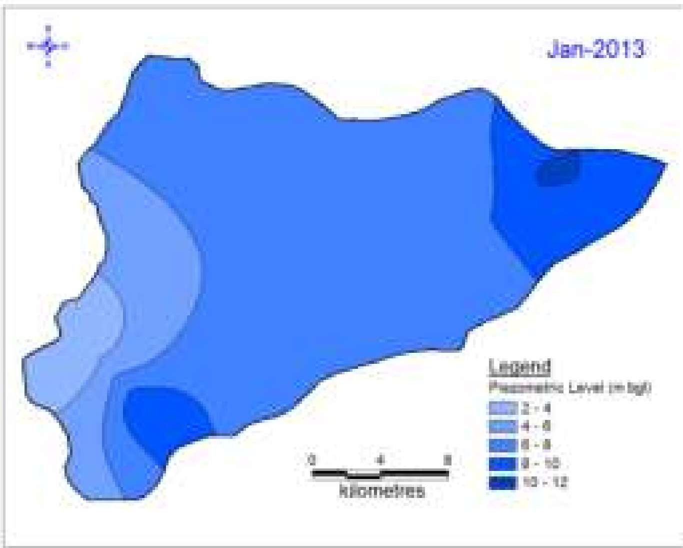

Aug-2012
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12

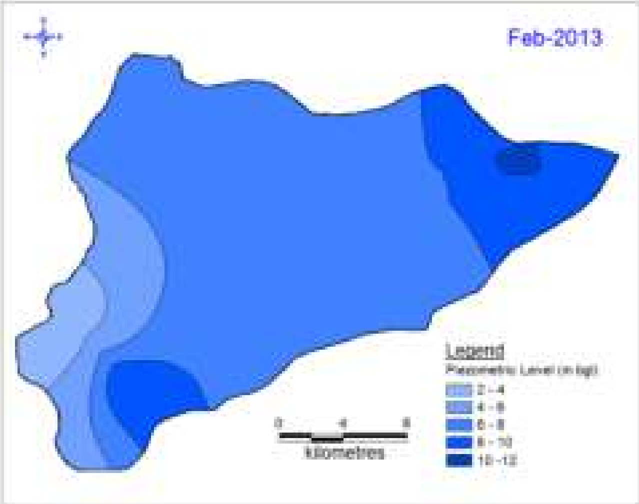

Sep-2012
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10


Oct-2012
Legend
Piezometric Level (m bgl)
0 - 2
2 - 4
4 - 6
6 - 8
8 - 10

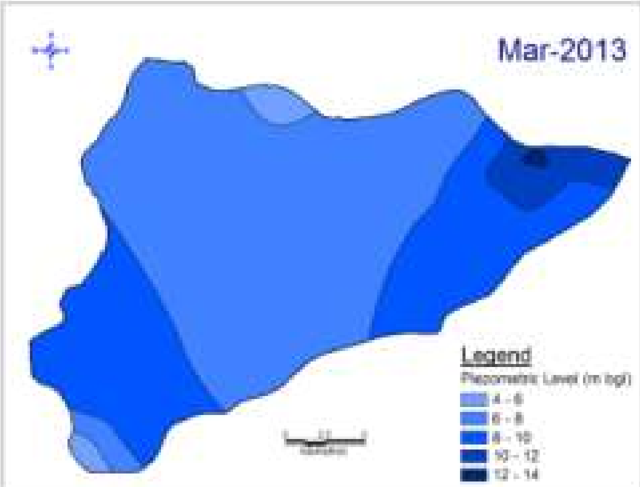

Nov-2012
Legend
Piezometric Level (m bgl)
0 - 2
2 - 4
4 - 6
6 - 8
8 - 10


Dec-2012
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12

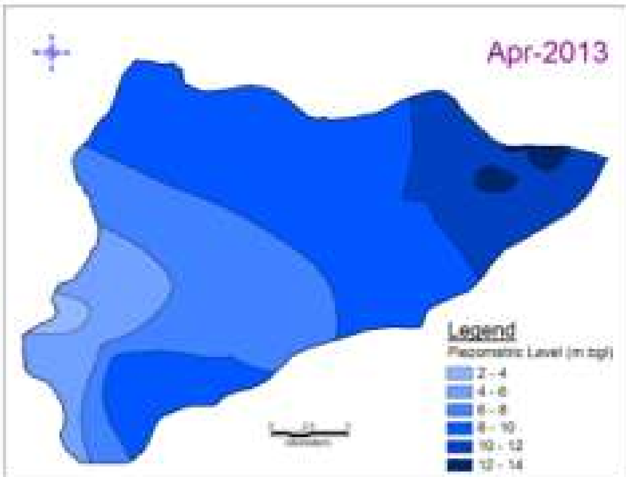

Jan-2013
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
0 4 8
kilometres



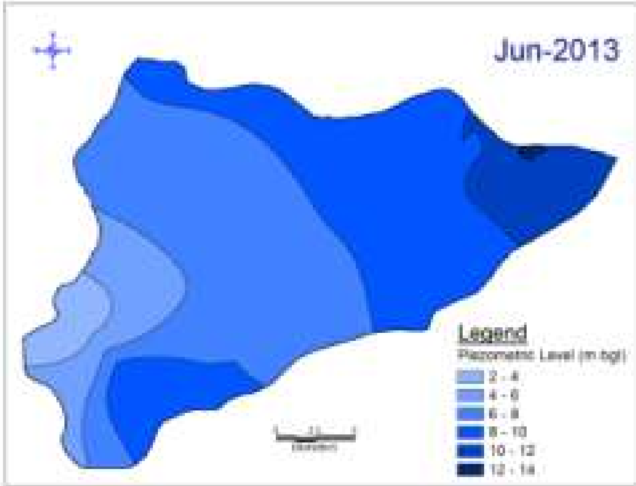
Feb-2013
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
0
4
8
kilometres



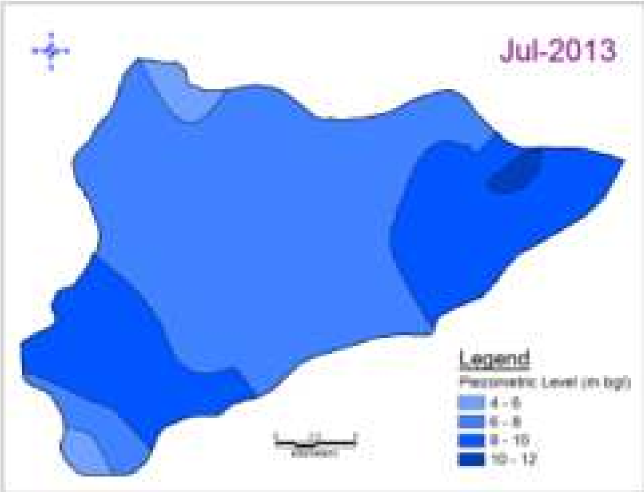
Mar-2013
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10
10 - 12
12 - 14



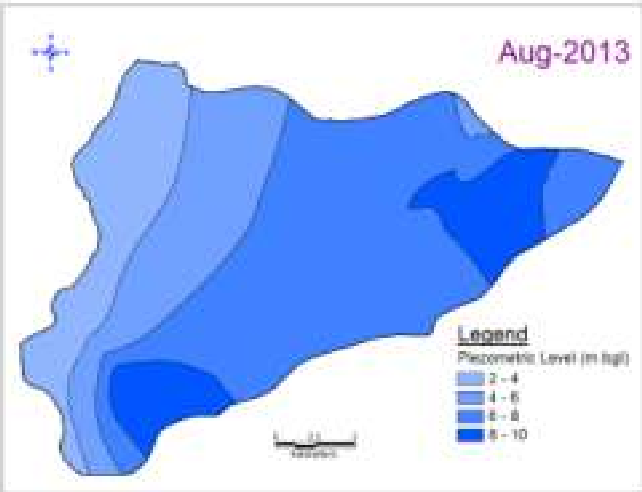
Apr-2013
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12 - 14



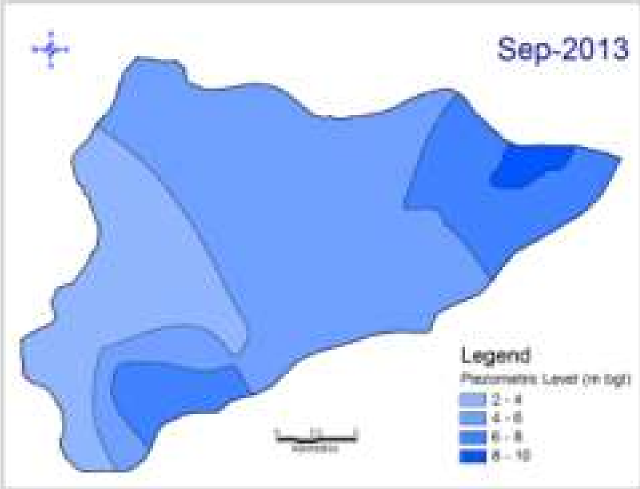
Jun-2013
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12 - 14

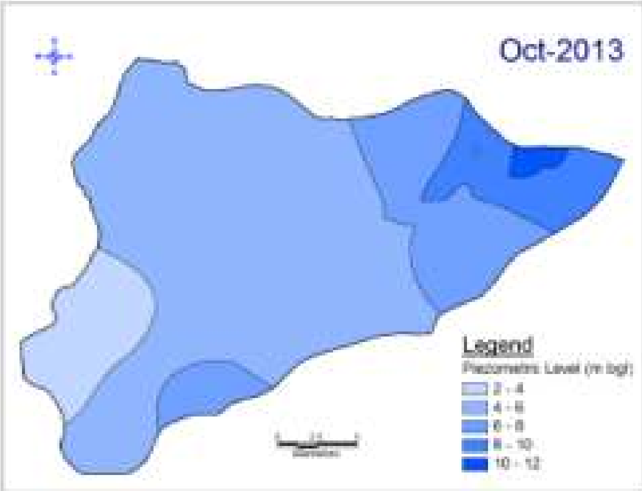


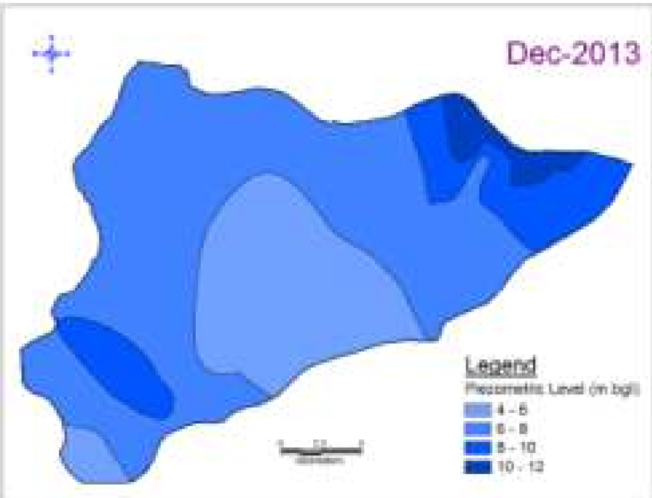
Jul-2013
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10
10 - 12

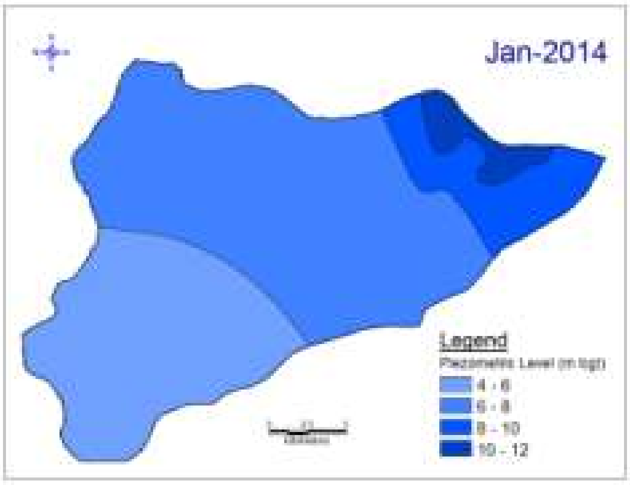


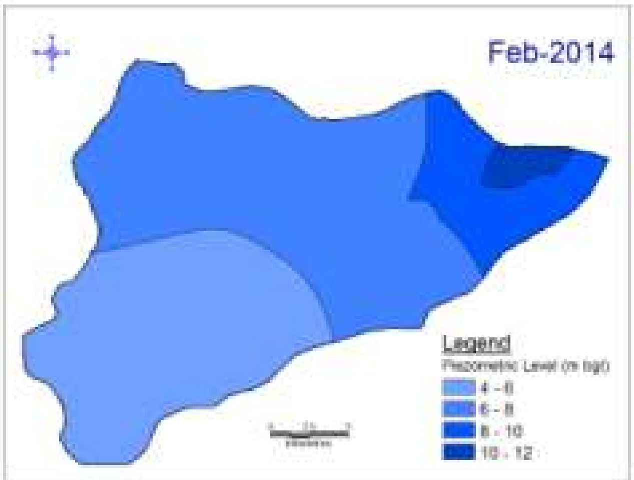
Aug-2013
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10

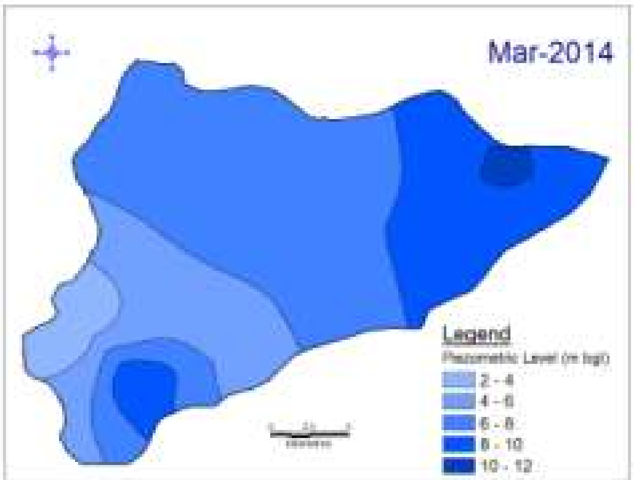

Sep-2013
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10

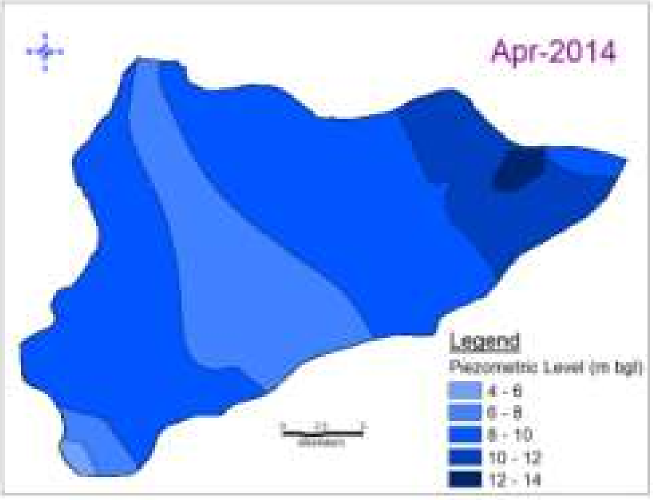

Oct-2013
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12

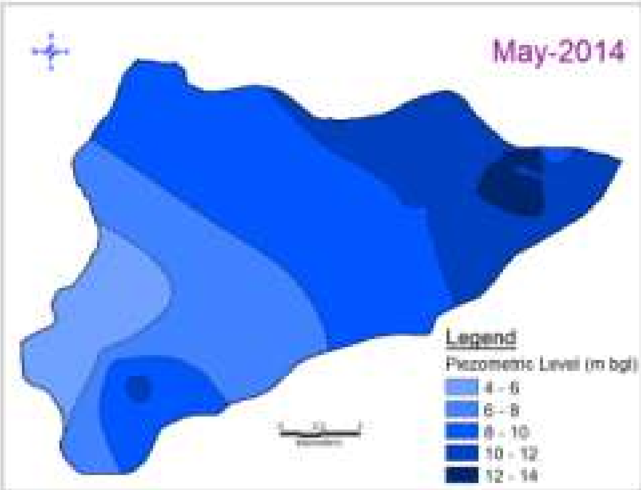

Dec-2013
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10
10 - 12

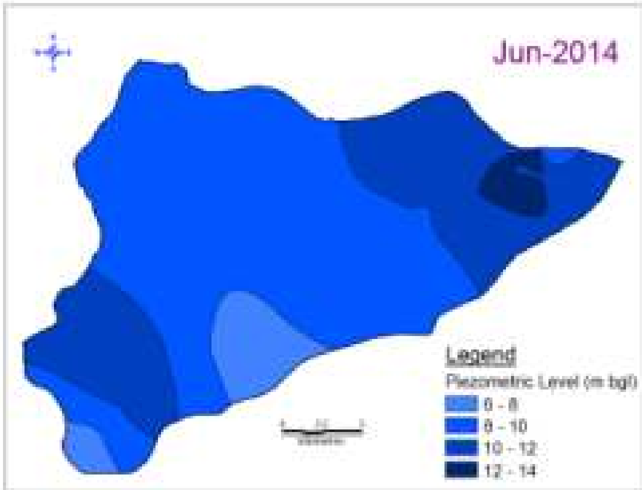

Jan-2014
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10
10 - 12


Feb-2014
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10
10 - 12

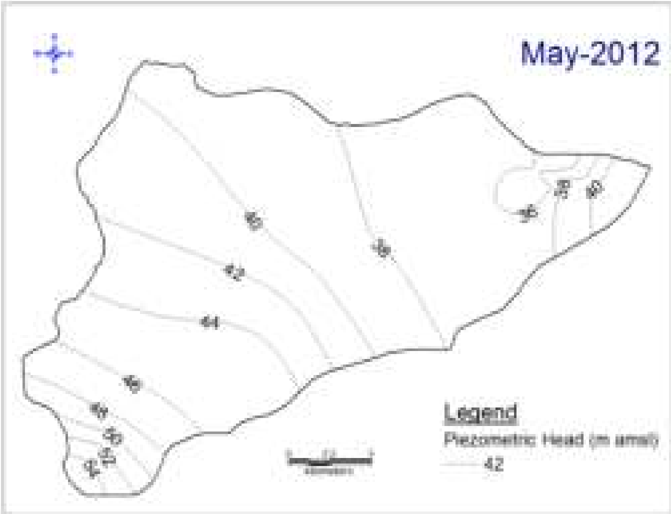

Mar-2014
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12

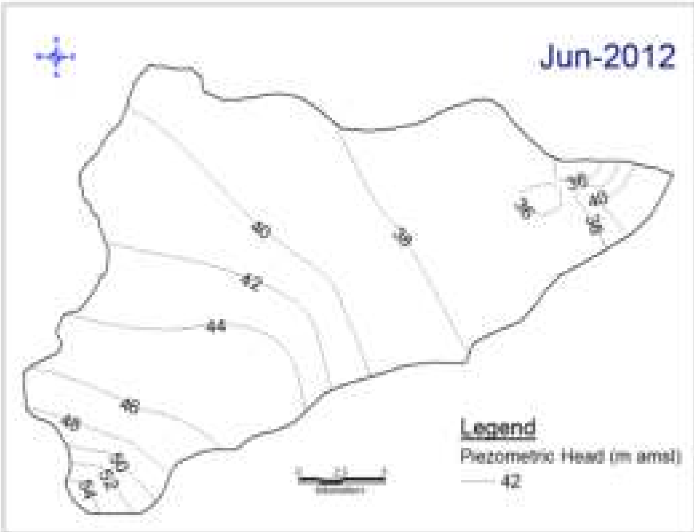

Apr-2014
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10
10 - 12
12 - 14

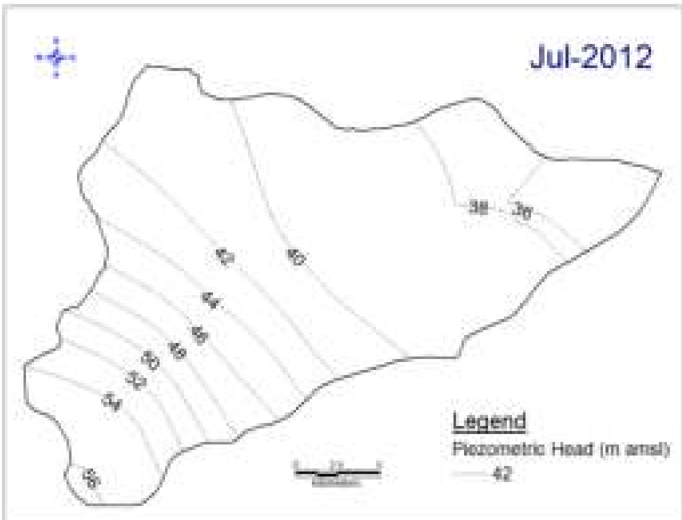

May-2014
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10
10 - 12
12 - 14

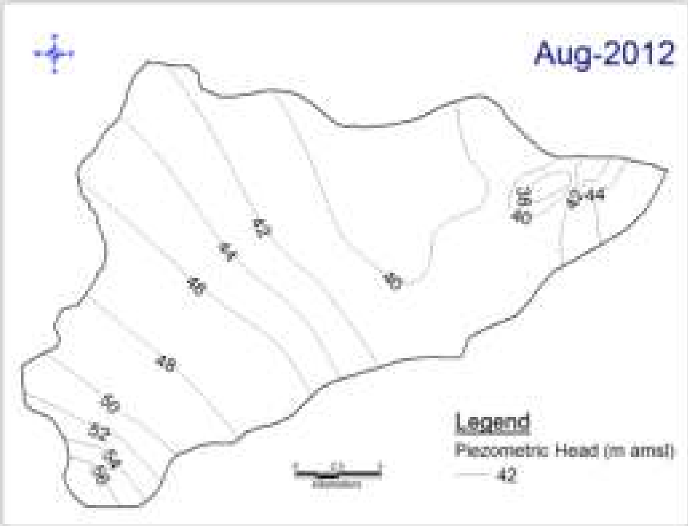

Jun-2014
Legend
Piezometric Level (m bgl)
6 - 8
8 - 10
10 - 12
12 - 14

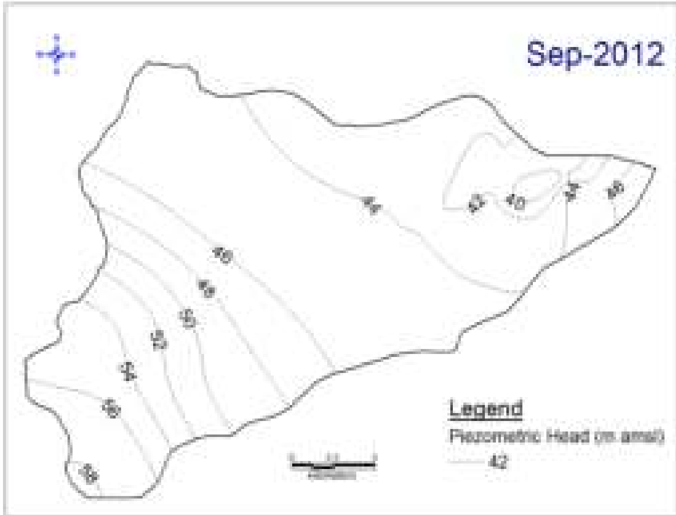
Annexure 3.8 (j): Month wise Piezometric head map (Aquifer-1)

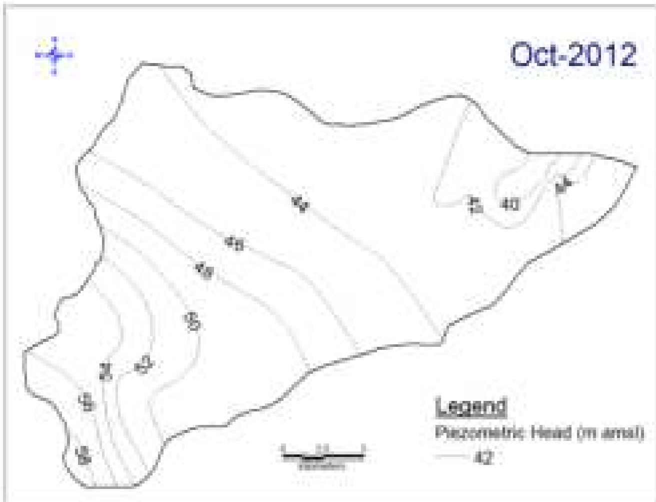


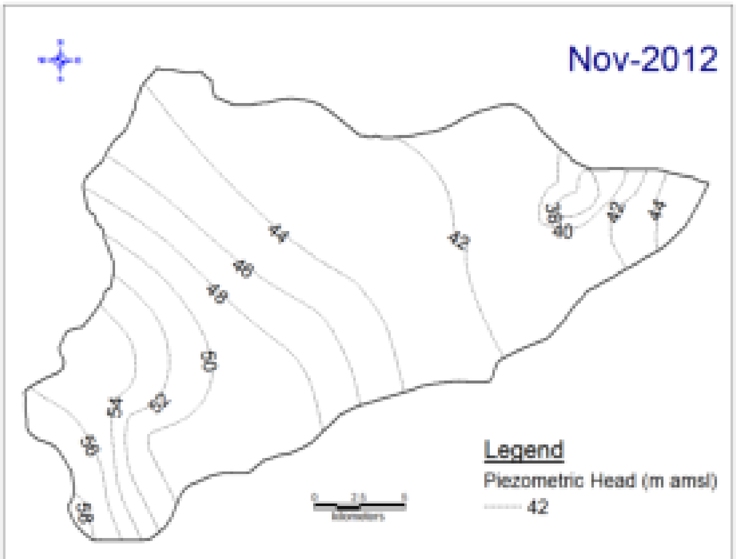


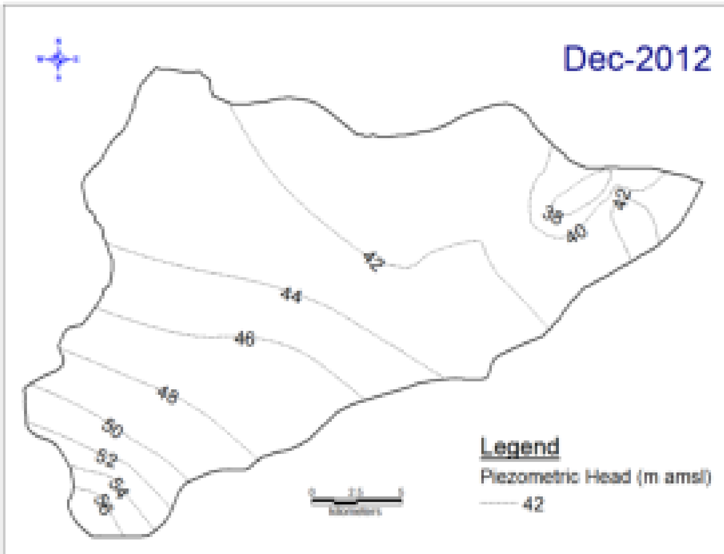


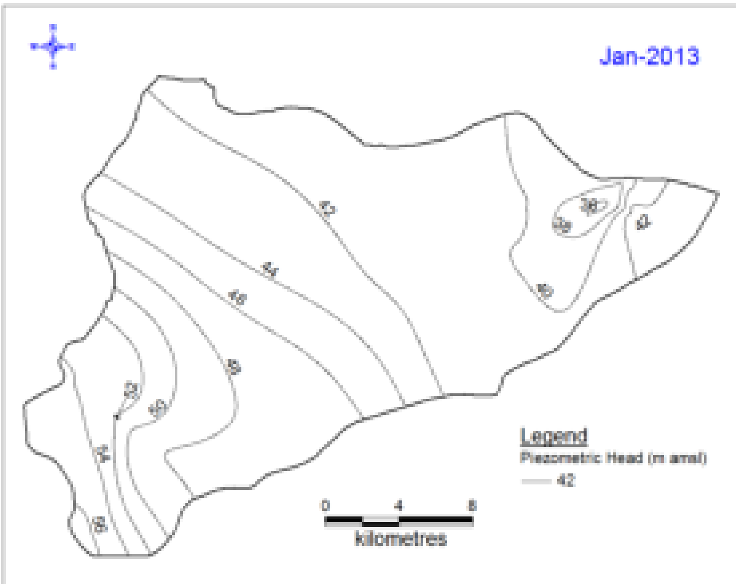

Aug-2012
Legend
Piezometric Head (m amsl)
42

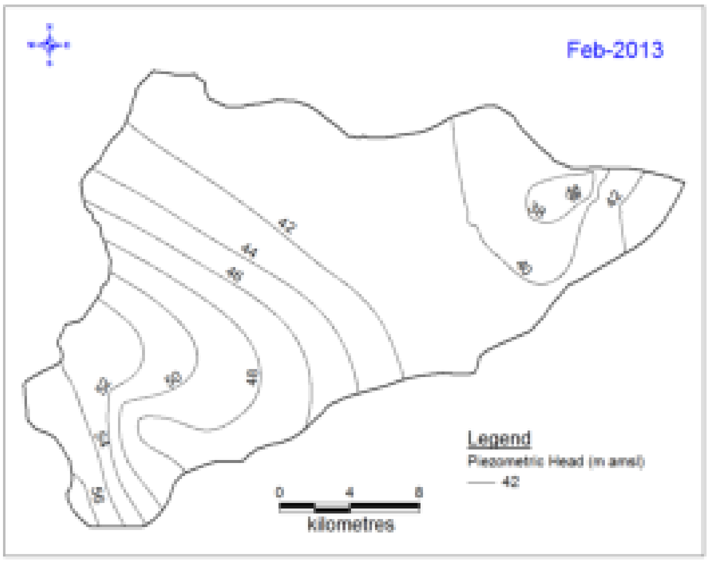

Sep-2012
Legend
Piezometric Head (m amsl)
42

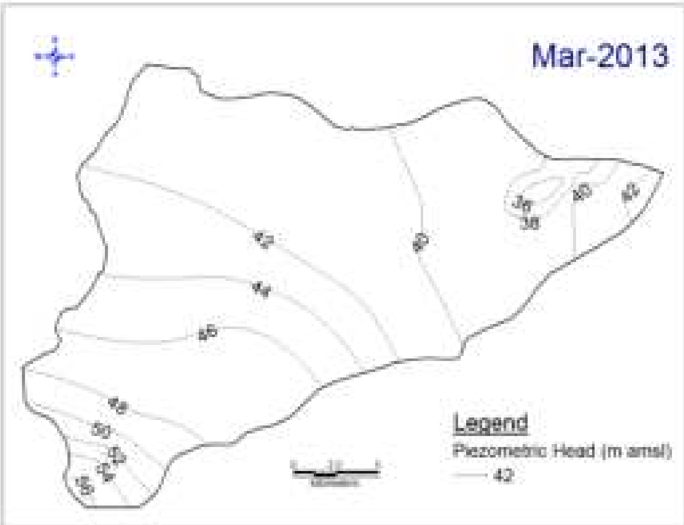

Oct-2012
Legend
Piezometric Head (m amsl)
42

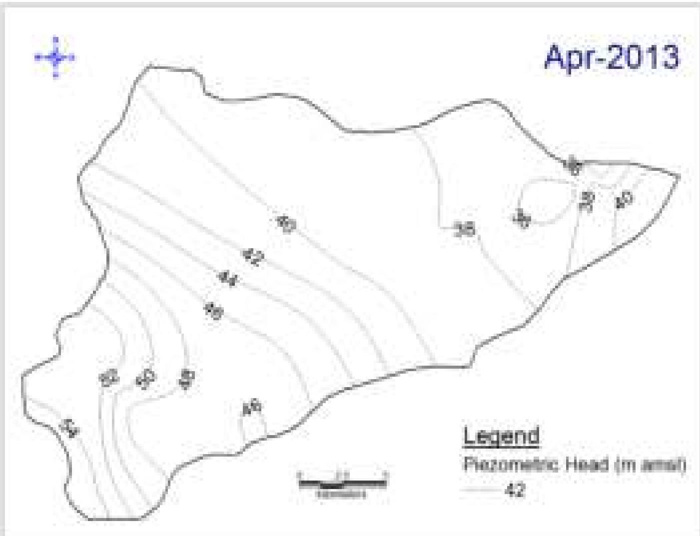

Nov-2012
Legend
Piezometric Head (m amsl)
42

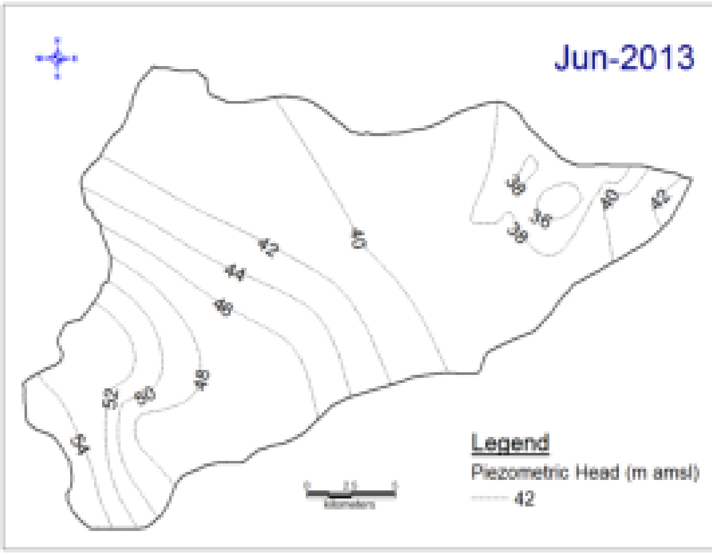

Dec-2012
Legend
Piezometric Head (m amsl)
42


Jan-2013
Legend
Piezometric Head (m amsl)
42
0
4
8
kilometres


Feb-2013
Legend
Piezometric Head (m amsl)
42
0 4 8
kilometres


Mar-2013
Legend
Piezometric Head (m amsl)
42


Apr-2013
Legend
Piezometric Head (m amsl)
42


Jun-2013
38
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38
40
42
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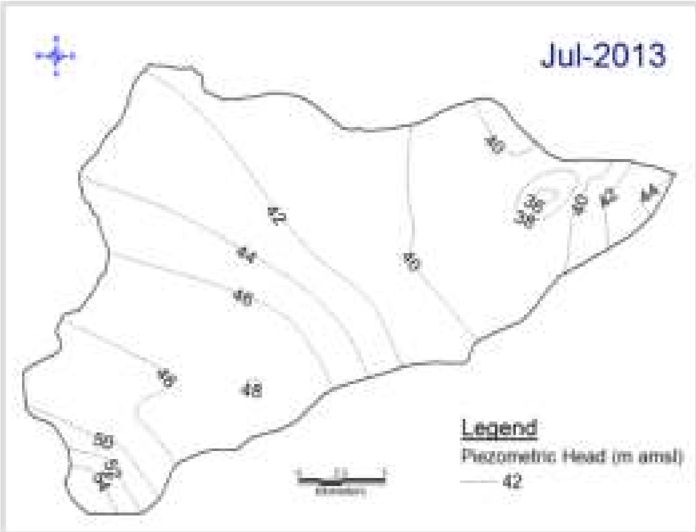
44
46
48
50
52
54
Legend
Piezometric Head (m amsl)
42


Jul-2013
40
36
38
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42
44
42
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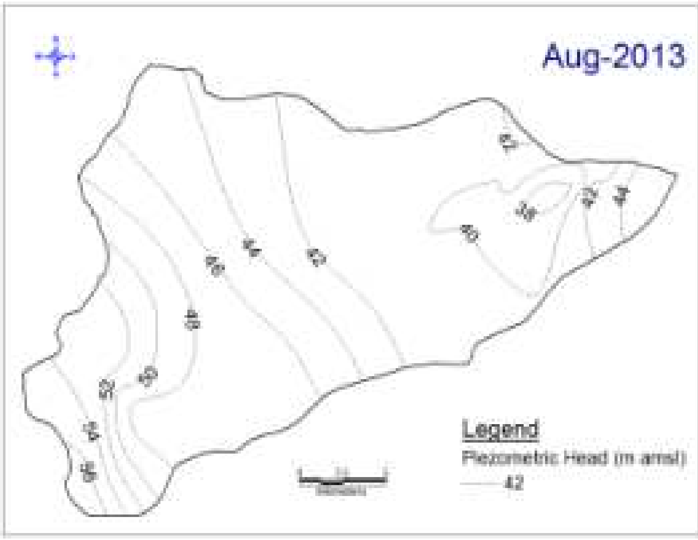
44
46
48
48
50
Legend
Piezometric Head (m amsl)
42


Aug-2013
42
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42
44
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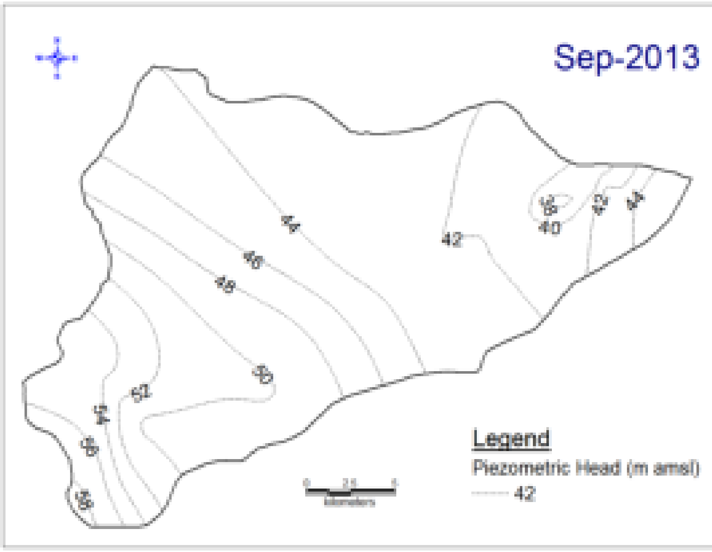
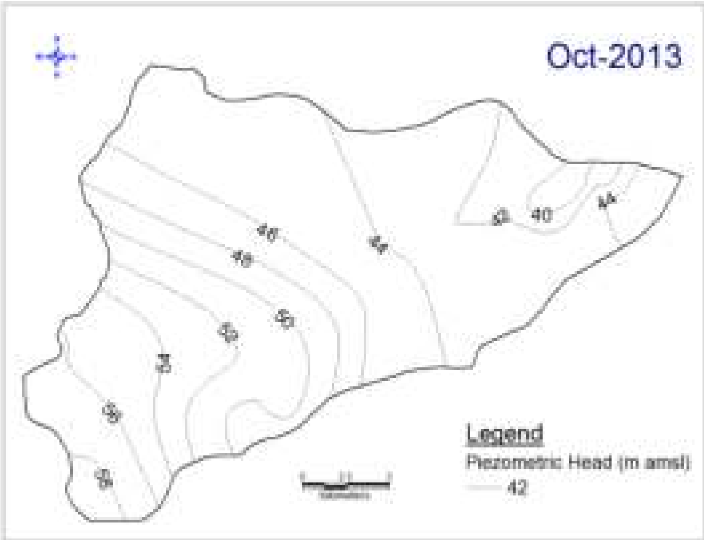
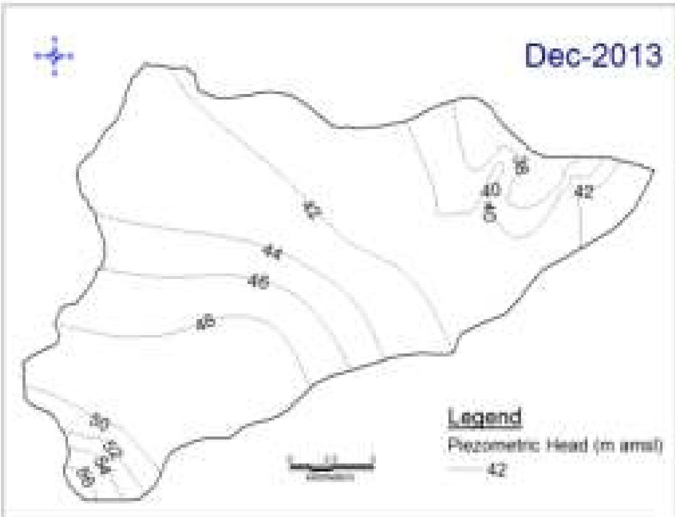
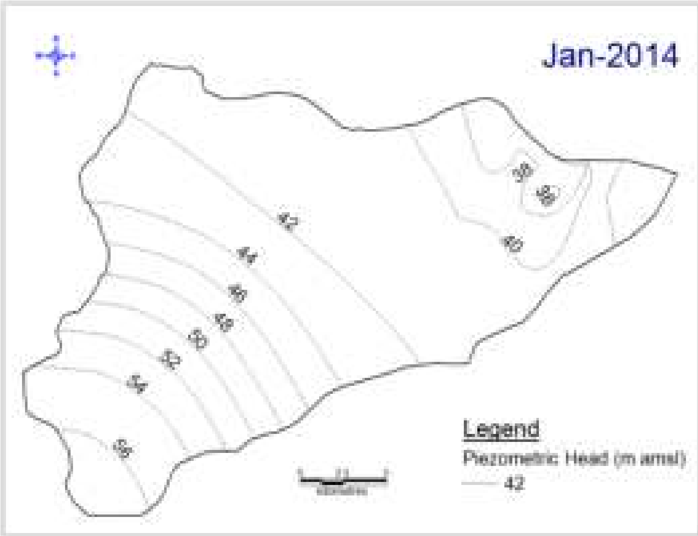
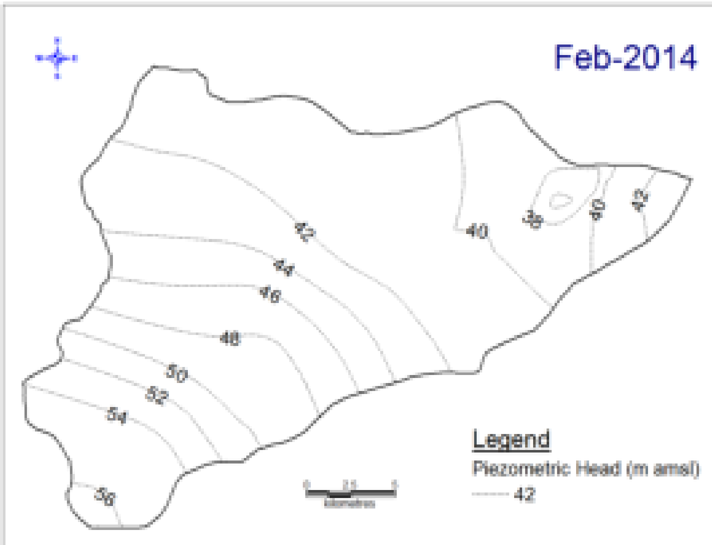
46
44
42
48
50
52
54
56
Legend
Piezometric Head (m amsl)
42


Sep-2013
Legend
Piezometric Head (m amsl)
42


Oct-2013
Legend
Piezometric Head (m amsl)
42


Dec-2013
Legend
Piezometric Head (m amsl)
42


Jan-2014
42
44
46
48
50
52
54
56
38
36
40
Legend
Piezometric Head (m amsl)
42


Feb-2014
42
44
46
48
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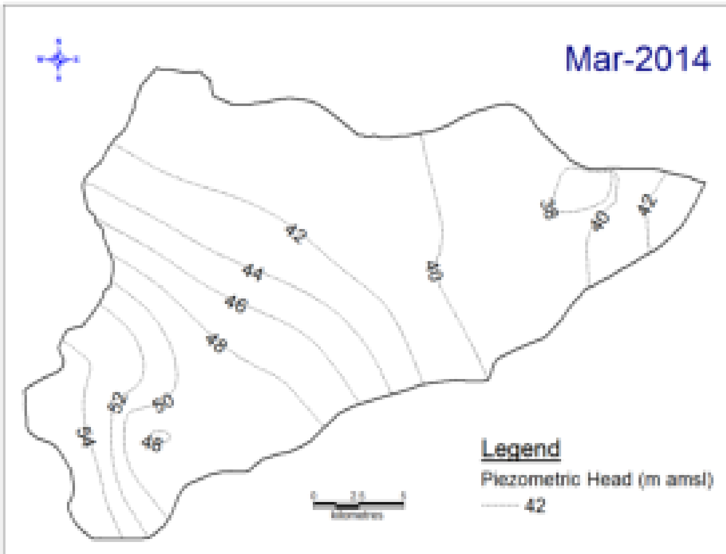
52
54
56
40
38
40
42
Legend
Piezometric Head (m amsl)
42


Mar-2014
42
44
46
48
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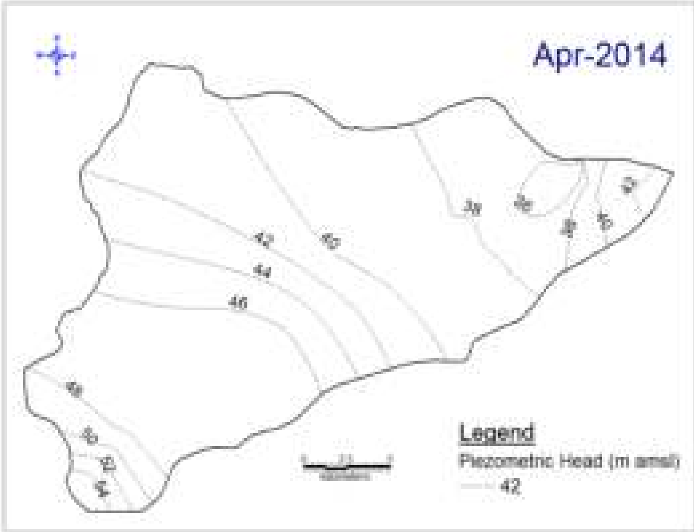
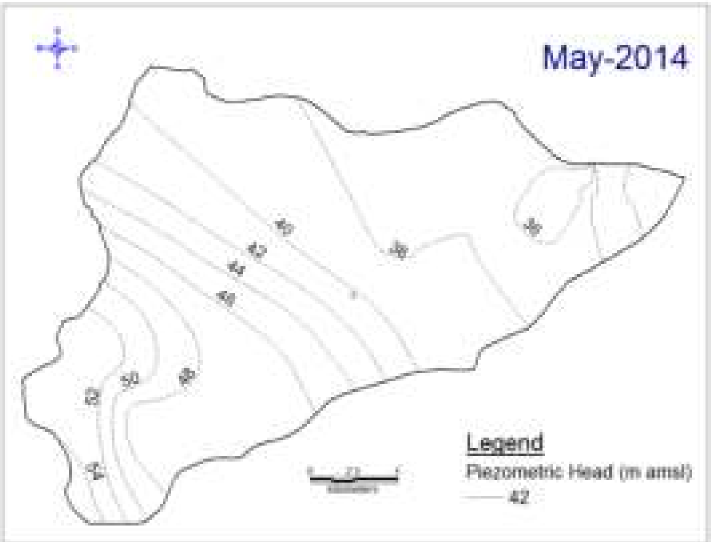
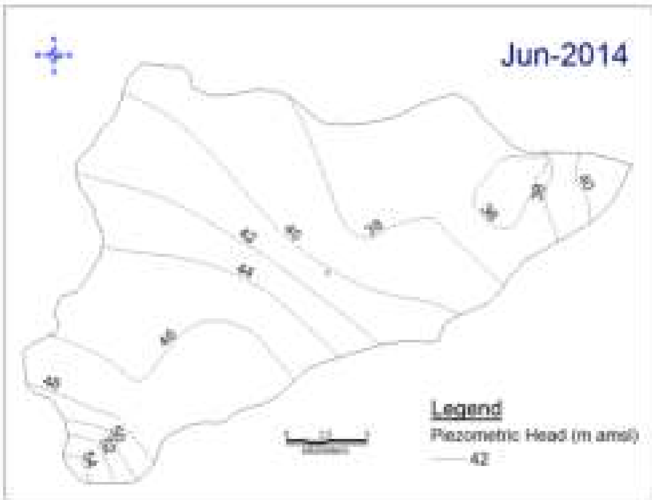
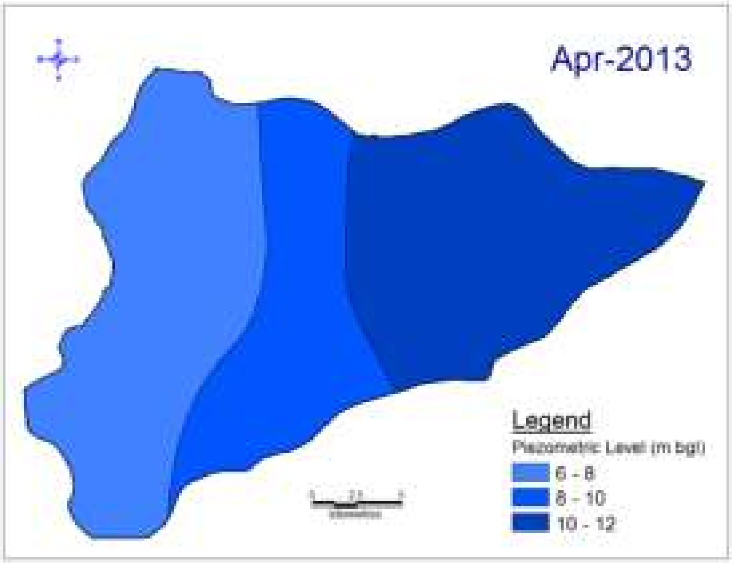
52
54
46
40
36
40
42
Legend
Piezometric Head (m amsl)
42

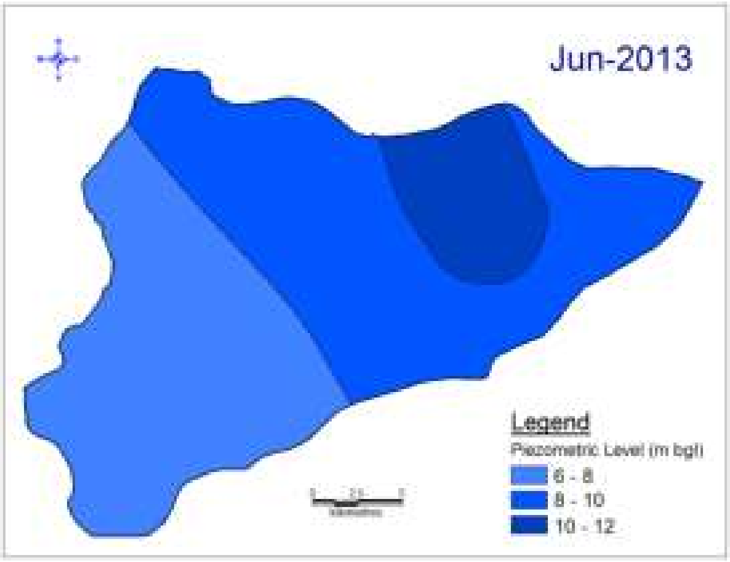

Apr-2014
Legend
Piezometric Head (m amsl)
42

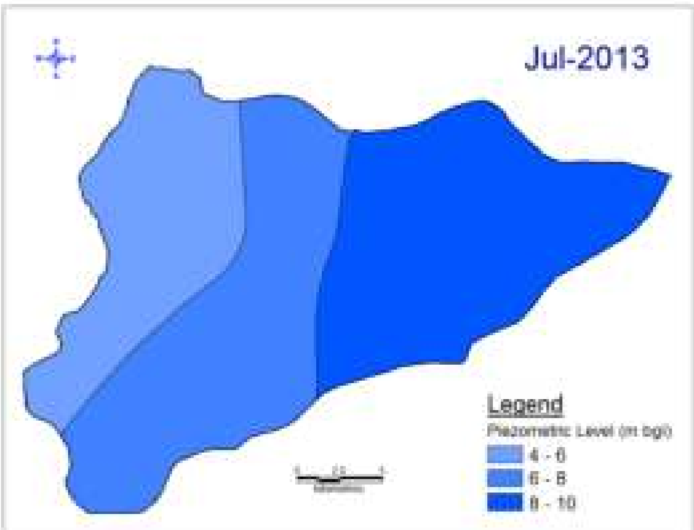

May-2014
Legend
Piezometric Head (m amsl)
42

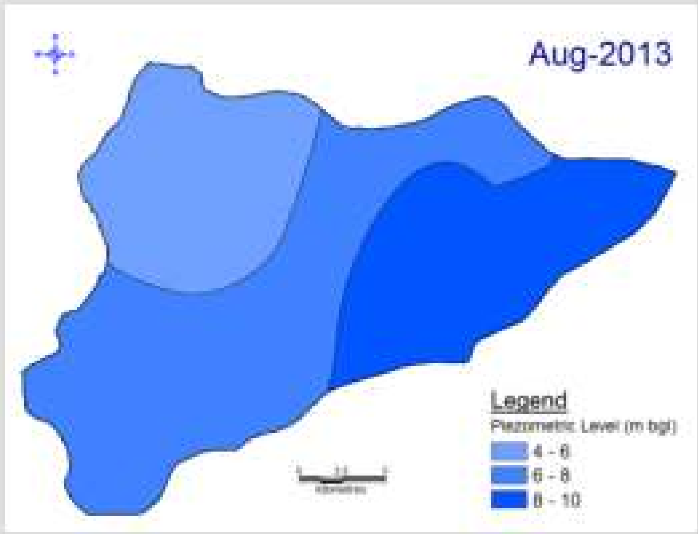

Jun-2014
Legend
Piezometric Head (m amsl)
42

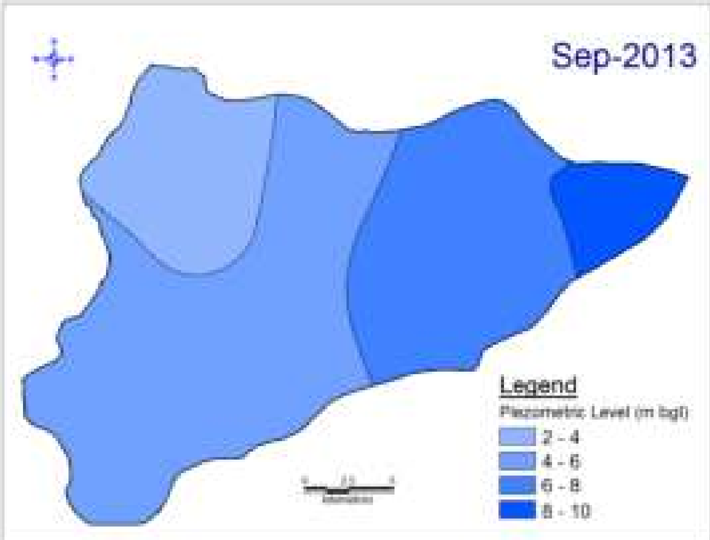
Annexure 3.8 (k): Month wise Depth to Piezometric level map (Aquifer-2)

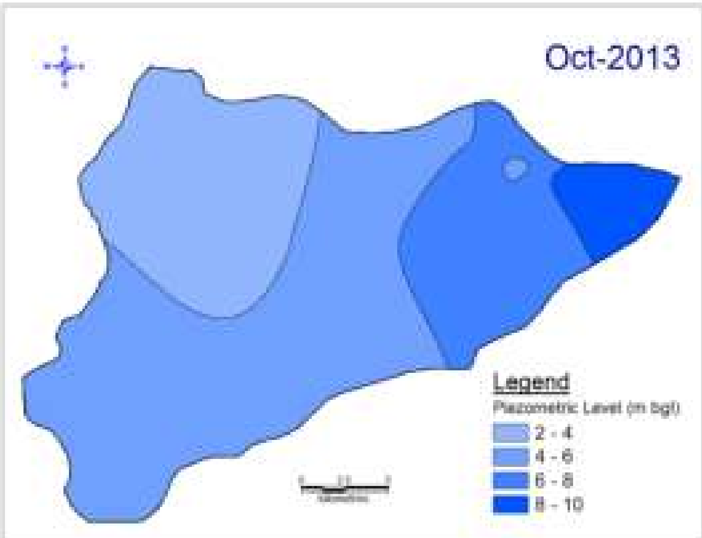


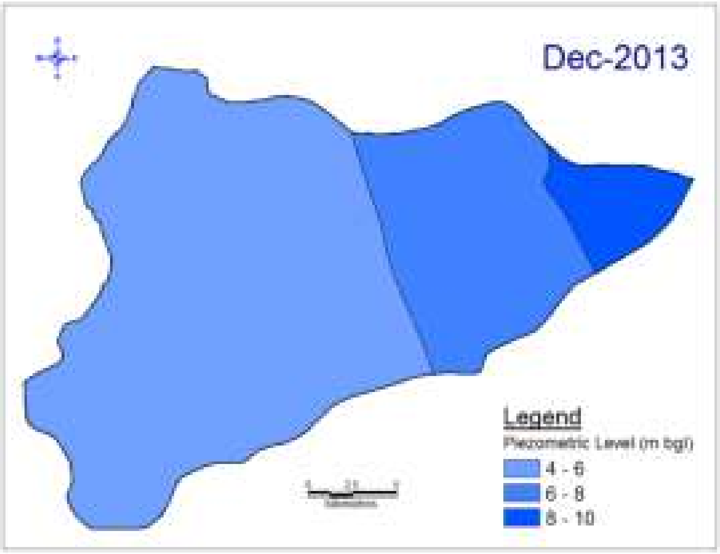


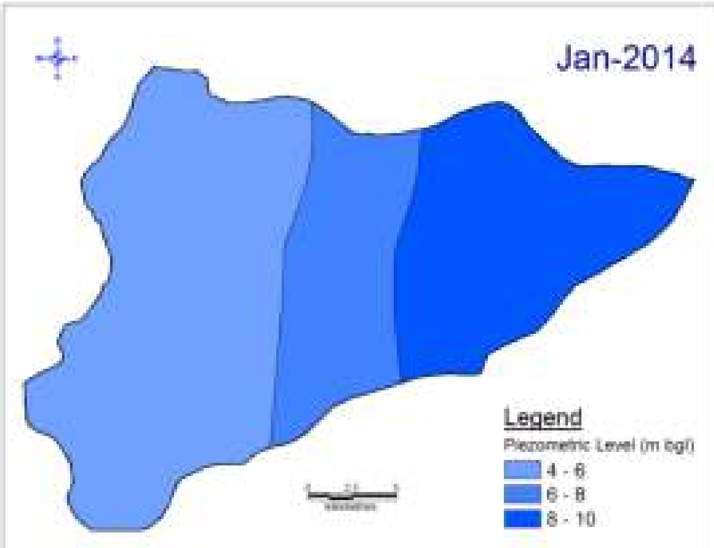


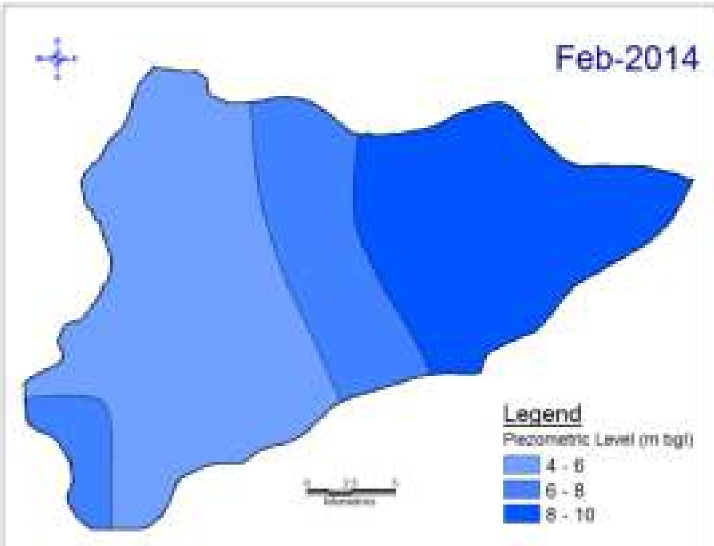

Aug-2013
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10

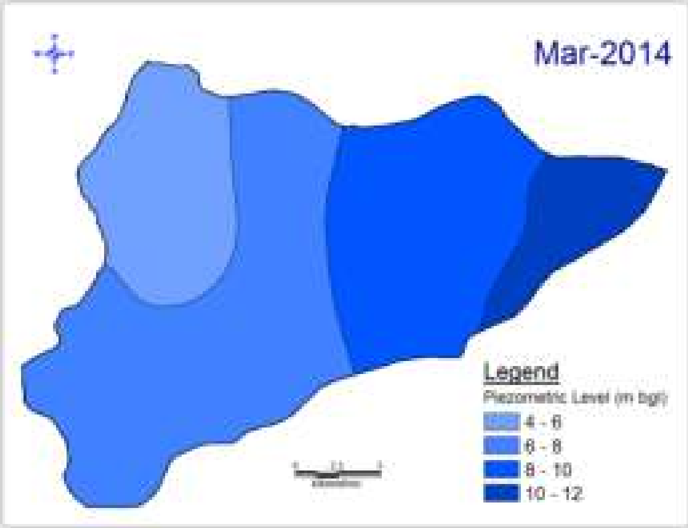

Sep-2013
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10

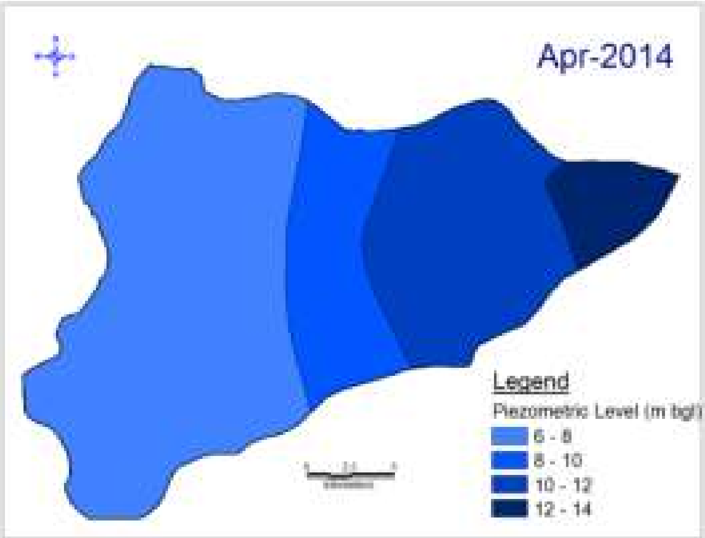

Oct-2013
Legend
Piezometric Level (m bgl)
2 - 4
4 - 6
6 - 8
8 - 10

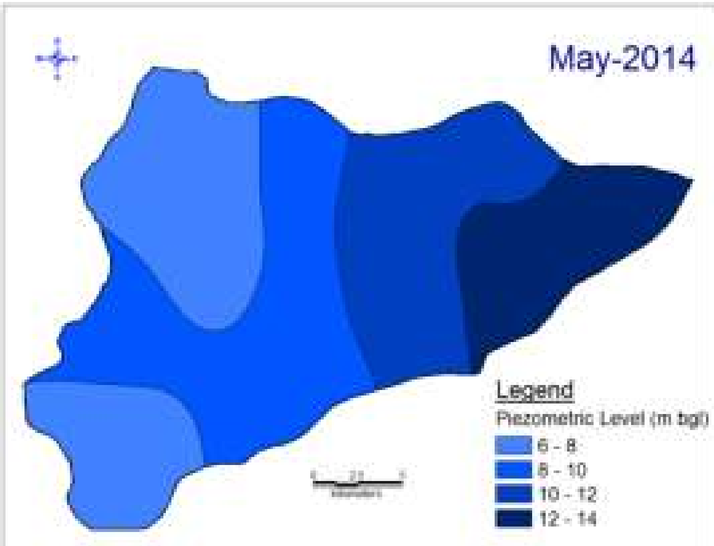

Dec-2013
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10

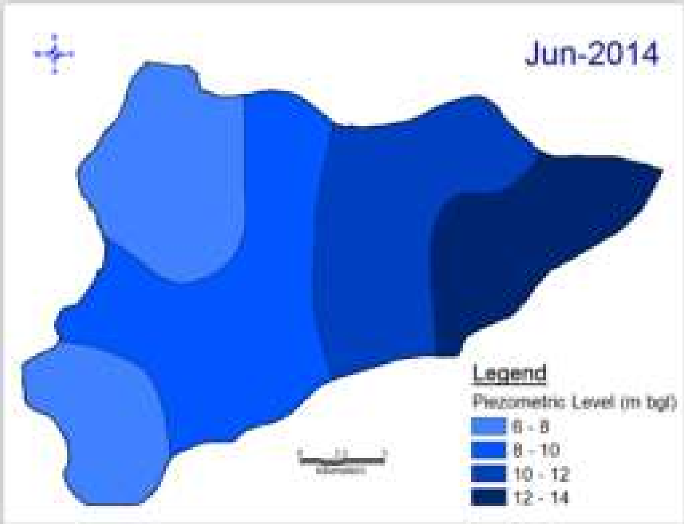

Jan-2014
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10


Feb-2014
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10

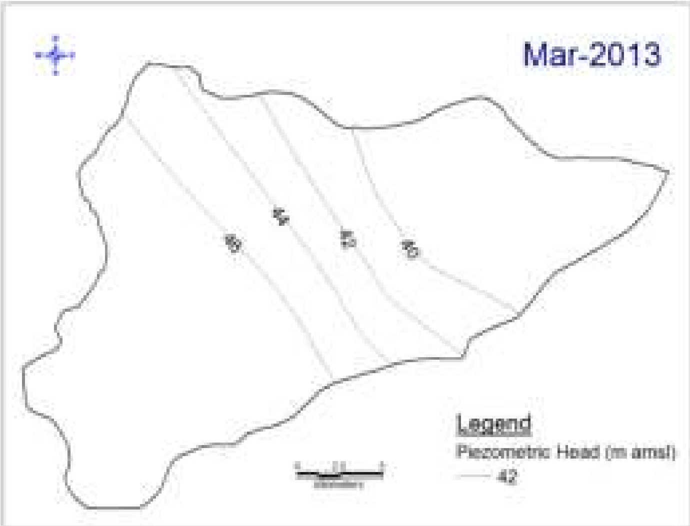

Mar-2014
Legend
Piezometric Level (m bgl)
4 - 6
6 - 8
8 - 10
10 - 12

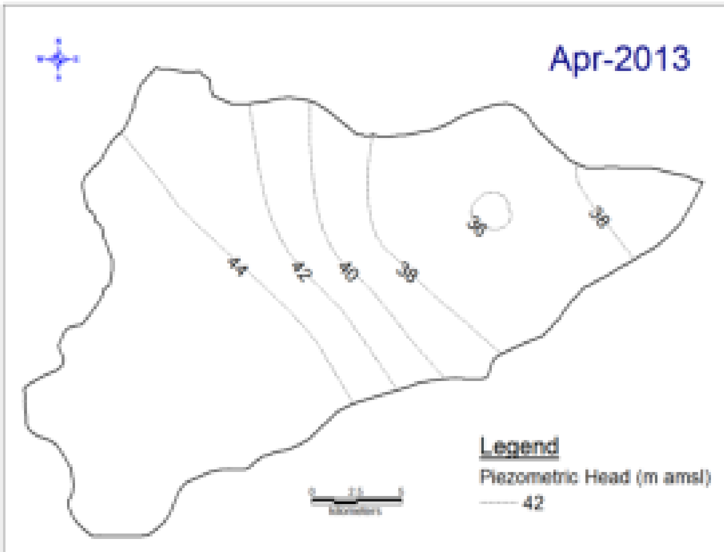

Apr-2014
Legend
Piezometric Level (m bgl)
6 - 8
8 - 10
10 - 12
12 - 14

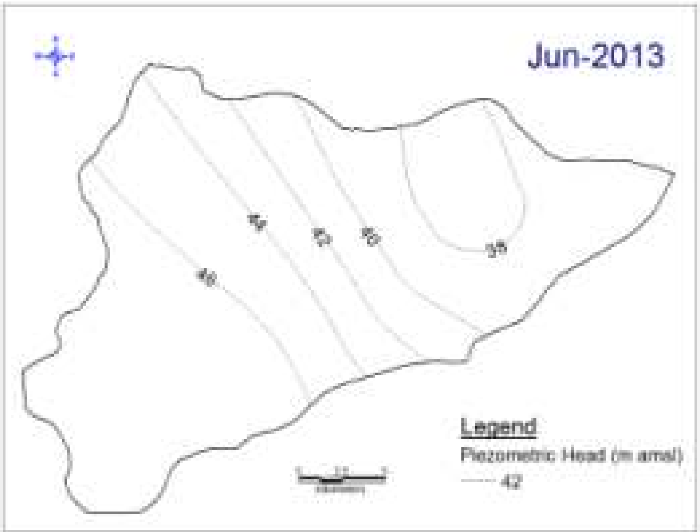

May-2014
Legend
Piezometric Level (m bgl)
6 - 8
8 - 10
10 - 12
12 - 14

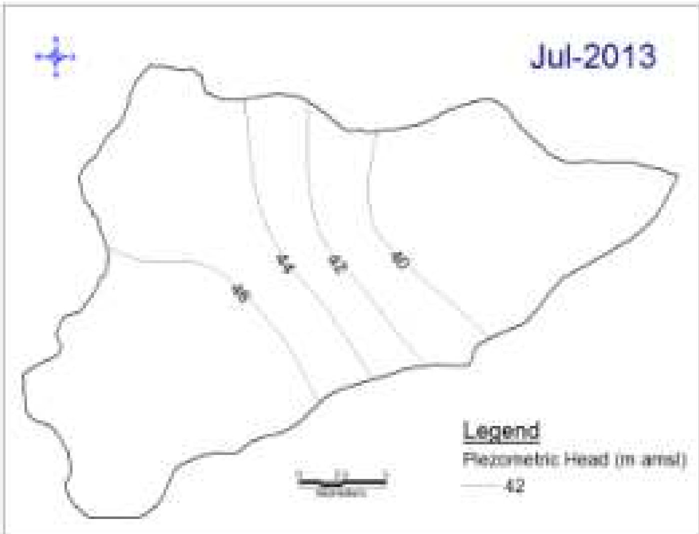


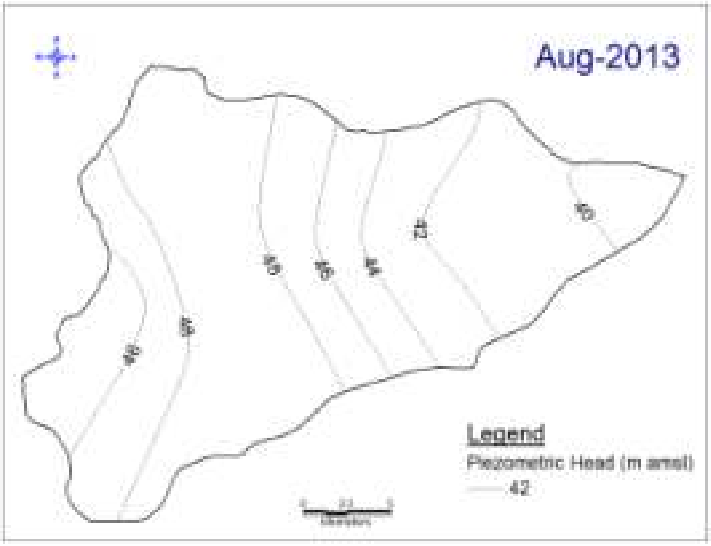
Annexure 3.8 (l): Month wise Depth to Piezometric head map (Aquifer-2)

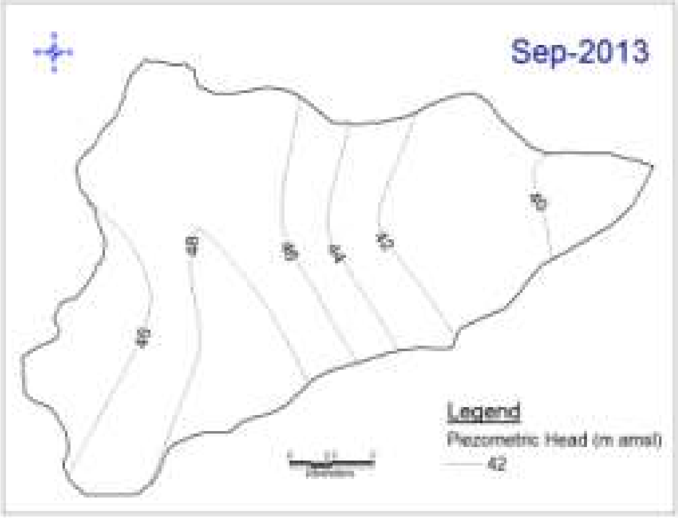


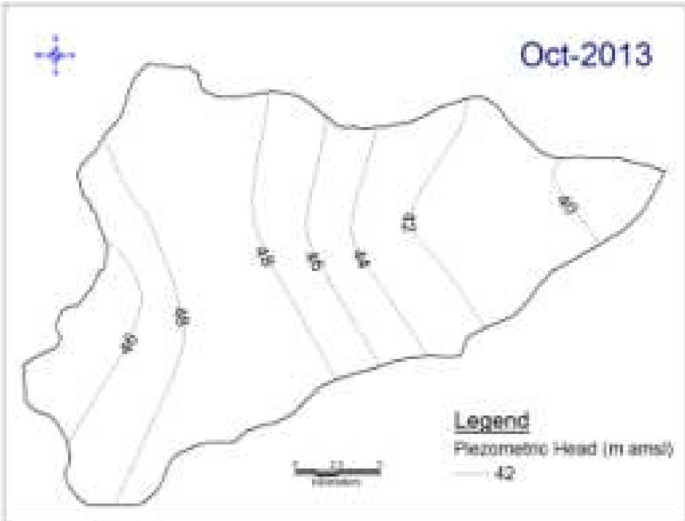


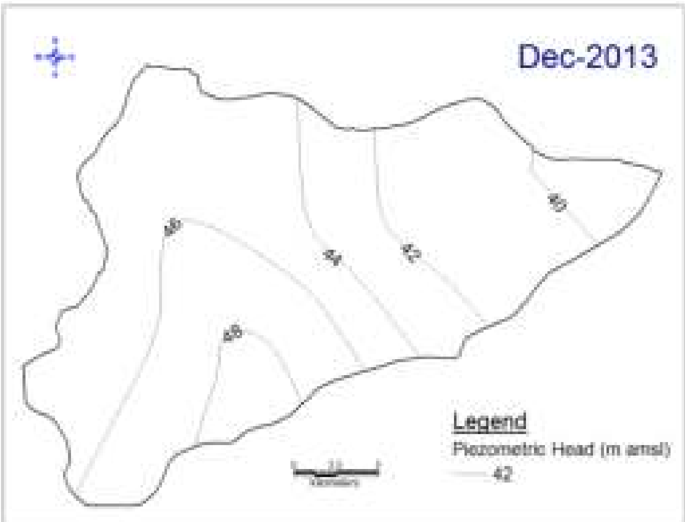

Jun-2013
44
42
40
38
46
Legend
Piezometric Head (m amsl)
42

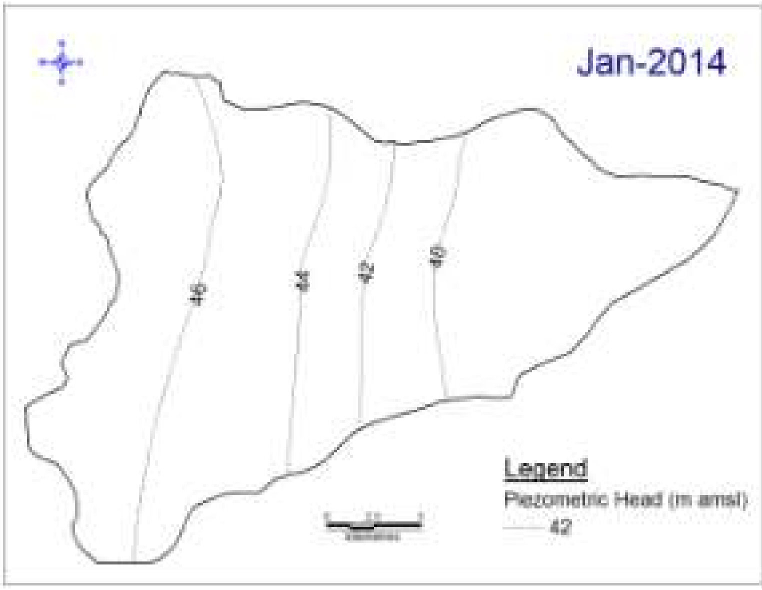

Jul-2013
44
42
40
46
Legend
Piezometric Head (m amsl)
42

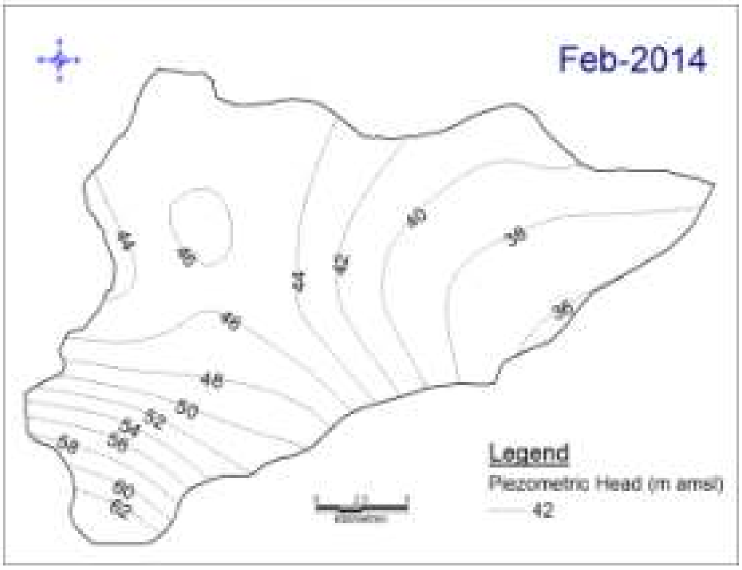

Aug-2013
48
46
44
42
40
46
48
Legend
Piezometric Head (m amsl)
42


Sep-2013
Legend
Piezometric Head (m amsl)
42


Oct-2013
Legend
Piezometric Head (m amsl)
42


Dec-2013
Legend
Piezometric Head (m amsl)
42


Jan-2014
46
44
42
40
Legend
Piezometric Head (m amsl)
42


Feb-2014
44
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44
42
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36
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48
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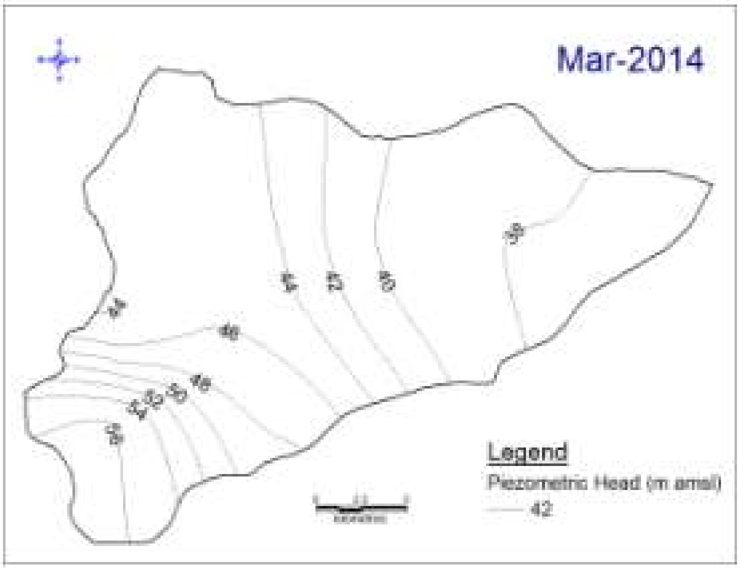
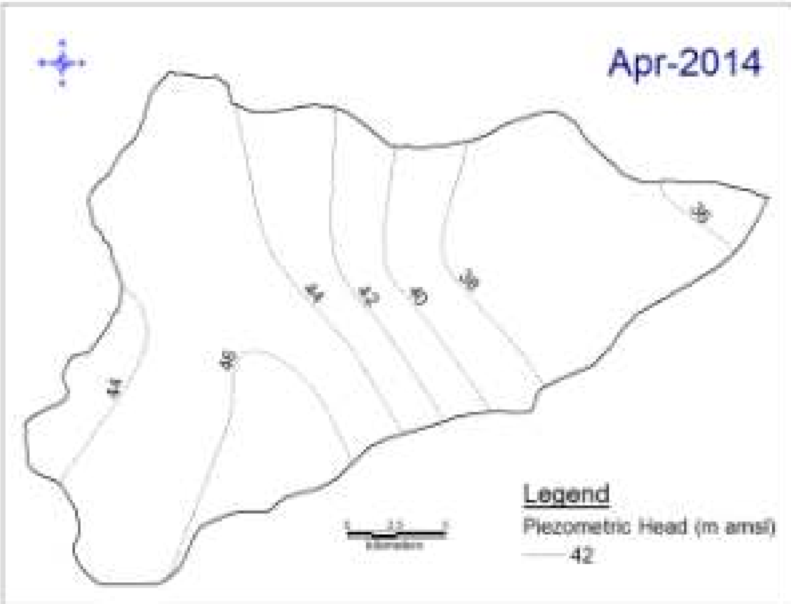
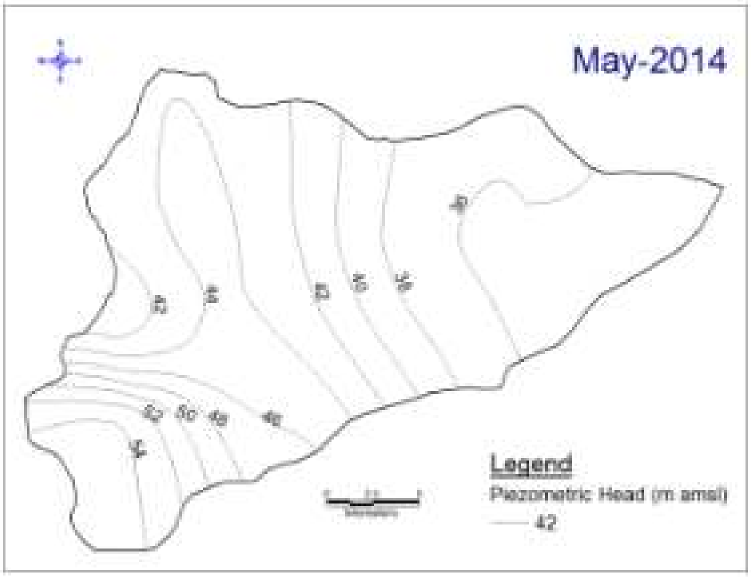
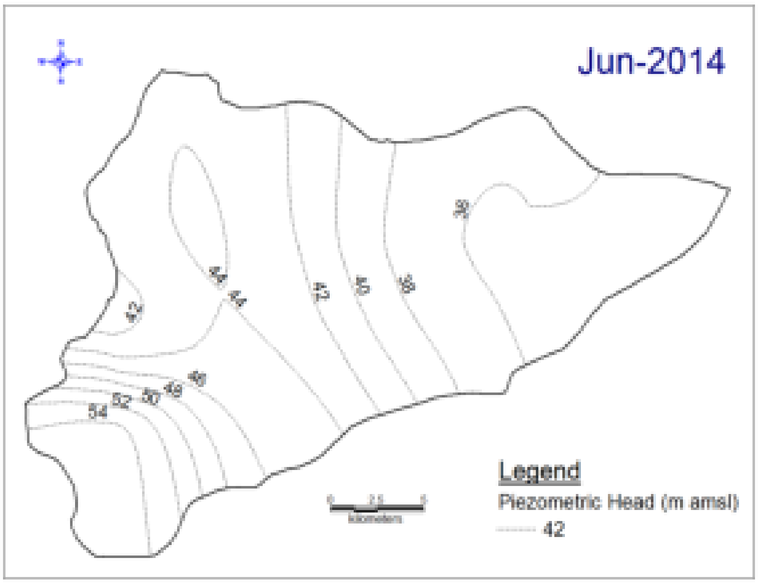
52
54
56
58
60
62
Legend
Piezometric Head (m amsl)
42


Mar-2014
38
44
42
40
44
46
48
56
Legend
Piezometric Head (m amsl)
42


Apr-2014
Legend
Piezometric Head (m amsl)
42


May-2014
Legend
Piezometric Head (m amsl)
42


Jun-2014
Legend
Piezometric Head (m amsl)
42

Annexure 3.9 (a): Location details of ground water sample collected for major parameter analysis (Dug wells)

Sl No.	Place	Block	Longitude (^{0}E)	Latitude (^{0}N)	Location	Total depth of dug well (m)
1.	Khazpura	Patna Sadar	85.08396	25.60363	Shiv Mandir Complex	12
2.	Soranpur	Phulwari Sharif	85.14691	25.58278	RHS of Anisabad-Fatua by pass road near Fatua 21 Km mile stone, inside the temple campus	10
3.	Karbighayia	Patna Sadar	85.15089	25.60078	Taposthan mandir, Near office of Hamraj Band Party	7.5
4.	Digha	Patna Sadar	85.08715	25.64349	In campus of Maa Sardha-Siddhi Mandir	14
5.	Lalbegnan	Maner	84.97678	25.65136	In the Rajkiya Prathmic Vidyalaya, Maner, TEM-18, Pashim Sherpur	11
6.	Ramnagar	Phulwari Sharif	85.051722	25.571833	RHS On Phulwari- Janipur road, Near Transformer and Devi Sthan	5.87
7.	Hulaschak	Phulwari Sharif	85.02658	25.53833	RHS On Phulwari- Janipur road, Near Shiv Mandir	6.16
8.	Gyaspur (Purvatola)	Maner	84.88964	25.62725	In the beginning of Village , Near house of Chote Chaudhary	7.92
9.	Gopalpur (Dhibrapur)	Maner	84.93958	25.61336	At the trijunction	8.25
10.	Bishambharpur	Bihta	84.88569	25.57775	Near chowk,Opposite to Hanuman temple, 10 m from main road	9.26
11.	Dariapur	Phulwari Sharif	84.92556	25.48033	RHS Khagaul-Naubatpur Road, Behind Hanuman Temple	8.86
12.	Snehi Tola, Naubatpur	Naubatpur	84.96131	25.50522	RHS Khagaul-Naubatpur Road, Just reaching to Naubatpur,Near Shiv Temple	7.3

Sl No.	Place	Block	Longitude (^{0}E)	Latitude (^{0}N)	Location	Total depth of dug well (m)
13.	Amahara	Bihta	84.86211	25.52892	RHS Bikram-Bihta Road, Near Rajendra Pustkalaya, Amraha. Owner Bablu Singh	6.4
14.	Faridpur	Naubatpur	84.98350	25.54875	LHS Shivala-Naubatpur road. Front of Kiran Niwas	7.35
15.	Charra	Naubatpur	84.942028	25.539861	LHS of Naubatpur -Bihta road. Near Sherawali Mandir and Hanuman Temple.	7.8
16.	Sadisopur	Bihta	84.917944	25.564583	RHS Sadisopur-Kanhauli road. Near House of Arvind Ram. In Sadispur Village.	10
17.	Chandmari	Danapur	85.017778	25.625084	A link road from Navlakha Mandir in Cantonment area. Leads to village at Devi sthan	11
18.	Nisirpura	Phulwari Sharif	85.09250	25.52972	In front of Sri lalan Paswan on Parsa Ganjpar road. 6 km from Parsa towards Ganjpar	12.8
19.	Etwarpur	Phulwari Sharif	85.12639	25.57500	In the campus of Ramjanki Mandir on Sipara Parsa road.	12
20.	Datiana	Bikram	84.866530	25.482380	RHS On Bikaram –Bihta road, 3 km frm Bikram towards Bihta 11Km Near Pillar. House of Budhan Mochi	7.60
21.	Darbeshpur	Maner	84.93958	25.65219	House of Sudhir Kumar LHS Danapur Maner Near Transformar	12.75
22.	Chhiyattar	Maner	84.8944	25.6654	Approach from Chiyattar more on Kachhi road about 1 km towards Mahabir tola and well locate adjecent to the Pipal tree, Samudayik Bhawan	6.2
23.	Tishkhora	Naubatpur	84.90058	25.52661	Inside the village Tiskhora and about 300 m from main road in the front of the house Ajit Kumar Ajad	12
24.	Sikariya	Bihta	84.837528	25.505167	1 km from sikariya more on way towards Bihta, in the	8

Sl No.	Place	Block	Longitude (^{0}E)	Latitude (^{0}N)	Location	Total depth of dug well (m)
					compound of Devi Sthan Mandir	
25.	Noniatola	Bikram	84.87040	25.4380	In the house of Late Bishun Sah, Near temple on Bikram-Aurangabad road.	10.8

Annexure 3.9(b): Location details of ground water sample collected for major parameter analysis (Aquifer 1)

Sl. No.	Location	Lat (^{0}N)	Long (^{0}E)	Depth (m bgl)
1	Khagaul	25.5793	85.0414	95
2	Kadamkuan	25.6127	85.1512	107
3	Kidwaipuri	25.6153	85.132	110
4	Bihta	25.558378	84.870875	90
5	Danapur	25.6358	85.0247	95
6	Korwan	25.5178	84.9416	100
7	Bahpura	25.6127	84.9085	95
8	Naubatpur(phed)	25.50153333	84.96436667	110
9	Amhara	25.53152	84.86051	100
10	Dariapur	25.57123333	84.99841667	90
11	Bikram	25.44667	84.85603	76
12	A.n.college campus	25.617	85.11	77
13	Naubatpur(SOW)	25.503	84.961	50
14	Khazpura	25.60363	85.08396	55
15	Garikhana	25.602577	85.045921	55
16	Soranpur	25.58278333	85.1469	50
17	Patna College	25.6214	85.16539	70
18	Karbighayia	25.600783	85.150886	60
19	Digha	25.643492	85.087146	65
20	Lalbengwan	25.651355	84.976782	79
21	Ramnagar	25.571833	85.051722	59

Sl. No.	Location	Lat (^{0}N)	Long (^{0}E)	Depth (m bgl)
22	Hulaschak	25.538333	85.026583	30
23	Akbarpur	25.511444	85.024194	61
24	Gyaspur	25.62725	84.88964	49
25	Gopalpur	25.613361	84.939583	61
26	Bishambharpur	25.57775	84.885694	52
27	Dariapur	25.48033	84.92556	55
28	Snehi Tola,Naubatpur	25.505222	84.961306	25
29	Amhara	25.52892	84.86211	40
30	Faridpur	25.54875	84.98350	55
31	Charra	25.5398611	84.94202778	30
32	Sadisopur	25.564583	84.917944	52
33	Chandmari	25.625084	85.017778	57
34	Nisirpura	25.529722	85.0925	53
35	Etwarpur	25.575	85.126389	40
36	Datiana	25.48238	84.86653	52
37	Darbeshpur	25.652194	84.939583	76
38	Chhiyattar	25.66536	84.89436	30
39	Chiyattar	25.65638889	84.8915	35
40	Tishkhora	25.52661	84.90058	40
41	Sikariya (Padri)	25.505167	84.837528	25
42	Nonia Tola	25.43797	84.8704	30

Annexure 3.9 (c): Details of locations of water sample collected for major parameter (Aquifer-2)

Sl. No.	Location	Lat (^{0}N)	Long (^{0}E)	Depth(m bgl)
1	Digha (AN college , Panitanki)*	25.6209	85.1102	181
2	Meethapur*	25.59549	85.12371	180
3	Phulwari*	25.5848	85.0875	162
4	Rajbhawan	25.6011	85.1056	160
5	Chudrana*	25.6429	85.05613333	173
6	Patna law college Mahendru*	25.6192	85.17538333	137
7	Sipara*	25.58426667	85.12886667	150
8	Maner*	25.64572	84.88767	170
9	Moriama	25.49164	84.86381	227
10	Simri	25.60656	84.905	196
11	Naubatpur(DEW)	25.503	84.961	178
12	Goriaasthan,Jibrakhantola	25.64297	84.93322	232
13	A.N.College campus	25.617	85.11	186
14	Bihta MI Campus	25.554	84.868	208

*Multiple aquifer tapped

Annexure 3.9 (d): Analytical results of ground water sample (Dug well)

Sl. No.	Place/ Block	Temp	Turb	pH	EC	TDS	TH	HCO_3	Cl	SO_4	NO_3	F	Ca	Mg	Na	K
1	Khazpura	28.00	1.00	6.72	960	624	408	540	113.20	4.27	0.95	0.48	80.16	50.54	18.22	3.76
2	Soranpur	27.00	1.00	6.61	1330	864.5	464	680	147.16	28.13	0.34	0.94	25.65	97.20	128.04	13.23
3	Karbighayia	33.00	1.00	6.92	720	468	292	300	53.77	7.25	0.44	0.92	54.50	37.90	65.97	28.86
4	Digha	28.00	2.00	6.81	1180	767	478	680	116.03	70.58	0.86	0.63	20.84	102.24	114.21	35.98
5	Lalbengwan	28.00	1.00	6.91	1000	650	482	780	339.60	152.70	0.11	1.14	16.03	106.47	138.21	13.56
6	Ramnagar	30.00	1.00	6.88	1300	845	440	640	166.97	51.59	0.37	0.66	20.84	94.28	141.91	10.48
7	Hulaschak	29.00	3.00	7.34	1030	669.5	332	720	50.94	8.45	0.18	0.69	59.31	44.79	95.43	61.82
8	Gyaspur	27.00	1.00	6.86	1250	812.5	876	560	147.16	78.64	0.65	0.71	24.04	198.28	109.46	22.35
9	Gopalpur	29.00	1.00	7.29	1650	1072.5	488	760	161.31	90.76	0.19	0.49	28.85	101.08	106.53	254.64
10	Bishambharpur	30.50	2.00	7.22	550	357.5	320	360	31.13	13.81	0.77	0.34	36.87	55.40	14.38	8.01
11	Dariapur	28.00	6.00	7.09	660	429	252	400	31.13	16.70	0.86	0.41	49.69	31.10	31.78	24.74
12	Snehi Tola,	29.00	1.00	7.06	1090	708.5	484	400	155.65	63.03	0.43	0.63	43.28	91.36	61.29	13.23
13	Amhara	28.50	1.00	6.91	1260	819	460	420	147.16	71.68	0.16	0.39	19.23	100.11	44.23	1.12
14	Faridpur	28.50	2.00	6.71	1400	910	364	580	200.93	63.62	0.39	0.61	32.06	69.01	81.76	83.71
15	Charra	30.00	1.00	7.07	830	539.5	372	460	73.58	6.76	0.63	0.73	44.88	63.18	33.27	3.10
16	Sadisopur	30.50	2.00	7.41	1540	1001	500	600	183.95	91.76	0.74	0.59	24.04	106.92	131.88	19.08
17	Chandmari	27.50	1.00	7.23	1540	1001	556	540	226.40	104.88	1.03	0.96	165.12	34.99	118.55	15.64
18	Nisirpura	30.00	1.00	7.09	770	500.5	288	340	93.39	30.81	0.44	0.54	105.81	5.83	114.63	14.66
19	Etwarpur	27.00	1.00	6.77	950	617.5	396	540	101.88	20.08	0.80	0.64	121.87	22.35	16.78	5.71
20	Datiana	28.00	1.00	6.50	470	305.5	232	240	104.71	11.50	0.37	0.48	72.14	12.63	27.15	22.89
21	Darbeshpur	26.00	1.00	6.97	1160	754	388	520	113.20	65.01	0.31	0.76	89.77	39.85	109.86	4.36
22	Chihattar	27.00	3.00	6.90	1940	1261	351	680	203.76	96.43	0.24	0.33	84.36	34.02	15.64	3.60
23	Tishkhora	27.00	1.00	7.01	1100	715	364	580	101.88	58.25	0.68	0.38	88.17	34.99	107.76	336.57
24	Sikariya (Padri)	29.50	1.00	7.07	380	247	220	240	28.36	14.51	0.77	0.49	56.11	19.44	12.22	2.76
25	Nonia Tola	28.50	1.00	7.50	1060	689	448	440	141.50	54.77	0.94	0.34	97.79	49.57	36.50	10.71

Temperature in ^{0}C, Turbidity in ntu, and EC in µmho/cm at 25^{0}C; except pH all others are in mg/l, TDS: Total Dissolved Solid, TH: Total Hardness

Annexure 3.9 (e): Analytical results of ground water samples (Aquifer-1)

Sl. No.	Place/ Block	Temp	Turb	pH	EC	TDS	TH	HCO3	Cl	SO4	NO3	F	Ca	Mg	Na	K
1	Khagaul			7.79	600	390	250.00	336.00	11.00	40.00		0.19	64.00	22.00	21.00	1.95
2	Kadamkuan			7.65	395	256.75	125.00	220.00	7.00	38.00			24.00	16.00	22.00	5.00
3	Kidwaipuri			8.20	490	318.5	205.00	275.00	14.00	26.00			40.00	16.00	20.00	7.00
4	Bihta			7.10	740	481	392.00	430.00	144.33	46.60		0.41	86.00	42.24	24.08	6.04
5	Danapur			7.23	870	565.5	456.00	490.00	22.64	8.25		0.58	51.20	79.70	18.30	6.33
6	Korwan			7.22	400	260	216.00	240.00	16.98	4.49		0.96	51.20	21.38	11.41	1.51
7	Bahpura			7.25	400	260	196.00	220.00	19.81	6.19		0.46	43.20	21.38	9.75	3.74
8	Naubatpur(Phed)			7.24	440	286	256.00	290.00	25.47	8.98		0.92	64.00	23.22	26.59	1.95
9	Amhara			7.22	380	247	224.00	250.00	19.81	5.94		0.61	44.80	27.21	17.04	7.66
10	Dariapur			7.14	310	201.5	228.00	260.00	16.48	2.79		0.66	49.60	25.27	9.71	2.41
11	Bikram			7.18	380	247	220.00	240.00	22.64	6.79		0.13	35.60	32.07	26.22	5.58
12	A.n.college campus			8.24	491	319.15	180.00	215.00	46.08	2.00			36.00	21.87	34.64	2.08
13	Naubatpur(SOW)			8.24	491	319.15	180.00	215.00	46.08	2.00	3.00	0.25	36.00	21.87	34.64	2.08
14	Khazpura			6.81	560	364	276.00	400.00	65.09	13.52	0.33	0.49	78.55	19.44	15.91	3.14
15	Garikhana	29.00	1.00	7.09	540	351	248.00	300.00	36.79	12.02	0.86	0.66	57.71	25.27	20.10	2.02
16	Soranpur	30.50	2.00	7.11	430	279.5	216.00	320.00	28.30	3.87	0.11	0.66	56.11	18.46	15.75	2.13
17	Patna College		1.00	7.01	490	318.5	240.00	340.00	11.32	69.89	0.63	0.58	40.08	34.02	42.98	65.91
18	Karbighayia	29.00	1.00	6.64	1240	806	484.00	660.00	166.97	3.87	0.96	0.48	43.28	91.36	30.00	2.50
19	Digha		1.00	6.87	600	390	280.00	420.00	39.62	11.73	0.56	0.46	43.28	41.79	19.64	2.37
20	Lalbengwan		2.00	7.16	510	331.5	264.00	320.00	39.62	8.84	0.72	0.58	81.76	18.46	17.70	1.88
21	Ramnagar		1.00	7.29	420	273	232.00	340.00	22.64	7.55	0.69	0.31	48.09	27.21	18.59	2.23

Sl. No.	Place/ Block	Temp	Turb	pH	EC	TDS	TH	HCO3	Cl	SO4	NO3	F	Ca	Mg	Na	K
22	Hulaschak	29.00	2.00	6.89	410	266.5	240.00	300.00	25.47	7.35	0.56	0.48	64.12	19.44	9.18	1.17
23	Akbarpur	28.00	1.00	6.90	430	279.5	240.00	320.00	25.47	3.38	0.47	0.71	41.68	33.04	9.95	1.36
24	Gyaspur		1.00	6.79	590	383.5	260.00	340.00	65.09	11.93	0.27	0.58	67.33	18.46	18.27	1.54
25	Gopalpur	28.00	1.00	6.99	430	279.5	244.00	360.00	19.81	3.18	0.33	0.48	31.47	35.96	15.77	2.70
26	Bishambharpur	28.00	6.00	6.97	430	279.5	256.00	360.00	39.62	4.87	0.18	0.69	51.30	29.16	12.95	1.83
27	Dariapur	28.50	1.00	6.86	490	318.5	248.00	360.00	25.47	5.46	0.62	0.86	57.71	61.23	55.97	56.49
28	S.T,Naubatpur		1.00	6.36	760	494	396.00	220.00	31.13	19.88	0.79	0.48	60.92	59.29	13.42	0.83
29	Amhara		5.00	6.28	360	234	224.00	220.00	5.66	2.98	0.88	0.46	62.52	16.52	9.36	2.60
30	Faridpur	29.00	1.00	6.86	460	299	228.00	360.00	19.81	1.59	0.19	0.68	48.09	24.32	17.02	2.12
31	Charra	29.50	1.00	7.10	630	409.5	360.00	300.00	22.64	4.87	0.19	0.63	68.93	45.68	11.52	1.44
32	Sadisopur	29.50	1.00	7.11	740	481	228.00	440.00	48.11	55.97	0.34	0.79	43.28	29.16	43.70	4.48
33	Chandmari	28.50	1.00	7.29	480	312	224.00	340.00	42.45	5.26	0.11	0.61	43.28	28.18	18.47	3.00
34	Nisirpura	28.00	1.00	7.33	480	312	164.00	360.00	33.96	3.18	0.84	0.69	48.09	10.69	252.15	34.40
35	Etwarpur	29.50	1.00	7.09	530	344.5	192.00	340.00	25.47	1.59	0.39	0.61	41.68	29.38	19.47	2.22
36	Datiana	26.50	1.00	7.31	410	266.5	216.00	280.00	28.30	3.47	0.54	0.73	48.09	23.32	14.42	1.22
37	Darbeshpur	27.00	2.00	7.32	430	279.5	180.00	340.00	28.30	2.68	0.86	0.84	36.87	21.38	16.67	1.78
38	Chhiyattar	28.50	2.00	7.25	330	214.5	168.00	300.00	16.98	3.57	0.75	0.28	54.50	7.77	10.06	1.17
39	Chiyattar	27.50	1.00	7.51	400	260	204.00	360.00	28.30	0.29	0.33	1.37	48.09	20.41	15.00	1.00
40	Tishkhora		1.00	7.40	370	240.5	172.00	300.00	14.15	2.58	0.24	0.63	57.71	6.80	10.84	1.37
41	Sikariya (Padri)	28.00	1.00	6.80	490	318.5	244.00	340.00	16.58	5.86	0.21	0.48	46.49	31.10	11.20	0.53
42	Nonia Tola	28.50	1.00	6.68	500	325	156.00	220.00	59.43	31.01	0.65	0.28	59.33	1.94	41.07	1.84

Temperature in ^{0}C, Turbidity in ntu, and EC in µmho/cm at 25^{0}C; except pH all others are in mg/l TDS: Total Dissolved Solid, TH: Total Hardness

Annexure 3.9 (f): Analytical results of ground water samples (Aquifer-2)

Sl. No.	Location	pH	EC	TDS	TH	HCO_3	Cl	SO_4	NO_3	F	Ca	Mg	Na	K
1	Digha (AN college , Panitanki)	8.52	430	279.5	140	67	20	2.3			32	15	30	2.3
2	Meethapur	7.85	450	292.5	150	20	21	1.9	1.2	0.2	24	22	25	2.3
3	Phulwari	7.77	460	299	165	232	14	1.8			38	17	26	1.6
4	Rajbhawan	7.7	423	274.95	170	256	11	0.9	0.9		44	15	28	2.3
5	Chudrana	7.13	440	286	252	290	22.64	4.73		0.49	70	18.24	13.42	2.16
6	Patna law college Mahendru	7.08	470	305.5	268	290	19.81	6.19		0.58	80	16.32	9.17	3.71
7	Sipara	7.13	420	273	256	280	16.98	6.19		0.01	77	15.36	18.62	4.55
8	Maner	7.24	390	253.5	102	180	33.96	2.42		0.58	41.6	19.44	14.54	2.41
9	Moriama	8.28	315	204.75	105	161.49	10.63	2	5	0.18	18	14.58	25.1	1.88
10	Simri (SEW)	8.28	498	323.7	185	301.35	7	3.02	2	0.12	48	15.84	28.29	2
11	Naubatpur(DEW)	8.18	429	278.85	150	264.45	7.09	2	0.28	0.38	36	14.58	32.6	2.78
12	Goriaasthan	7.74	556	361.4	180	292.8	17.7	3.2	0.2	0.64	16	34	34.9	3.3
13	A.N.College campus	7.82	365	237.25	95	189	31.9	6.3			26	7.3	34.4	4.3
14	Bihata MI Campus	8.23	340	221	120	166	14	3	7	0.21	20	17	28	2

Temperature in ^{0}C, Turbidity in ntu, and EC in µmho/cm at 25^{0}C; except pH all others are in mg/l TDS: Total Dissolved Solid, TH: Total Hardness

Annexure3.9 (g): Location details and analytical result (As & Fe analysis) of ground water sample (Dug well)

Sl.No.	Place/ Block	Iron (mg/l)	Arsenic (mg/l)
1	Digha	0.02	0.017
2	Snehi Tola	0.04	BDL
3	Datiana	0.02	BDL
4	khazpura	0.06	BDL
5	Chandmaari	0.06	BDL
6	Khaspur	0.03	BDL
7	Lalbengwan	0.27	BDL
8	Gyaspur	0.40	BDL
9	korhar	0.08	-
10	Sadisopur	0.01	0.003
11	Nisirpura	0.07	BDL
12	chihatar	0.08	BDL

Annexure 3.9(h): location details and analytical result (As & Fe analysis) of ground water sample (Aquifer- 1)

Sl. No.	Place/ Block	Source	lat (^{0}N)	long (^{0}E)	Depth (m)	Month/ year of collection	Iron (mg/l)	Arsenic (mg/l)
1	Nilkantha Tola 1	HP	25.6563	84.9019	29	Feb-13	0.9	0.024
2	Nilkantha Tola 2	HP	25.6572	84.9020	29	Feb-13	5.09	0.068
3	Sadikpur	HP	25.6502	84.9222	29	Feb-13	1.8	BDL
4	Gauraiya Asthan	HP	25.6515	84.9317	34	Feb-13	1.17	BDL
5	Darveshpur 1	HP	25.6536	84.9396	30	Feb-13	0.31	0.004
6	Darveshpur 2	HP	25.6524	84.9375	27	Feb-13	1.75	BDL
7	Vyapur 1	HP	25.6523	84.9478	37	Feb-13	0.25	BDL
8	Vyapur 2	HP	25.6543	84.9532	34	Feb-13	0.19	0.006
9	Lodipur	HP	25.6549	84.9596	34	Feb-13	0.47	BDL
10	Khaspur 1	HP	25.6533	84.9853	79	Feb-13	0.73	BDL
11	Khaspur Bintoli 1	HP	25.6522	84.9888	30	Feb-13	0.34	0.008
12	Khaspur Bintoli 2	HP	25.6526	84.9884	37	Feb-13	0.17	BDL
13	Khaspur Bintoli 3	HP	25.6527	84.9881	82	Feb-13	0.09	BDL
14	Chitnaawa 1	HP	25.6478	84.9942	85	Feb-13	0.12	BDL
15	Chitnaawa 2	HP	25.6463	84.9966	50	Feb-13	0.15	0.004
16	Chitnaawa 3	HP	25.6469	84.9960	55	Feb-13	0.04	BDL
17	Imlital 1	HP	25.6400	85.0514	50	Feb-13	0.07	0.002
18	Imlital 2	HP	25.6400	85.0514	70	Feb-13	0.02	BDL
19	NariyalGhat	HP	25.6432	85.0600	76	Feb-13	0.03	BDL
20	Ramjee Chak 1	HP	25.6507	85.0812	27	Feb-13	0.35	0.001
21	Ramjee Chak 2	HP	25.6513	85.0807	30	Feb-13	0.04	BDL
22	Ramjee Chak 3	HP	25.6507	85.0809	27	Feb-13	0.01	0.001
23	Bas Kothi 1	HP	25.6483	85.0982	60	Feb-13	1.51	BDL
24	Bas Kothi 2	HP	25.6481	85.0980	37	Feb-13	0.23	0.005

Sl. No.	Place/ Block	Source	lat (^{0}N)	long (^{0}E)	Depth (m)	Month/ year of collection	Iron (mg/l)	Arsenic (mg/l)
25	Garikhana	HP	25.5886	85.0434	55	Feb-13	1.56	0.008
26	Dariapur	HP	25.5712	84.9984	40	Feb-13	0.87	BDL
27	Nagwa	HP	25.5271	84.9725	46	Feb-13	0.78	0.001
28	Birpur 1	HP	25.5223	84.9728	45	Feb-13	0.7	0.002
29	Birpur 2	HP	25.5230	84.9730	45	Feb-13	1.66	BDL
30	Snehi Tola	HP	25.5052	84.9613	37	Jun-12	0.83	BDL
31	Gorakahri	HP	25.4609	84.8794	45	Feb-13	0.17	0.004
32	Nonia Tola	HP	25.4380	84.8704	30	Feb-13	0.15	BDL
33	Datiana	HP	25.4778	84.8629	51	Feb-13	0.39	0.008
34	Khazpura	HP	25.6036	85.0840	55	Feb-13	0.07	0.002
35	Chandmaari 1	HP	25.6251	85.0178	55	Feb-13	0.43	0.001
36	Chandmaari 2	HP	25.6256	85.0177	55	Feb-13	4.34	0.002
37	Chandmaari 3	HP	25.6253	85.0174	65	Feb-13	5.77	0.001
38	Khashpur 2	HP	25.6374	85.0074	50	Feb-13	0.01	BDL
39	Sherpur	HP	25.6557	84.9760	55	Feb-13	3.81	0.05
40	Lalbengwan 1	HP	25.6558	84.9685	70	Feb-13	0.44	0.038
41	Lalbengwan 2	HP	25.6514	84.9768	25	Feb-13	3.85	0.001
42	Darveshpur-3	HP	25.6548	84.9376	30	Feb-13	0.01	0.005
43	Darveshpur-4	HP	25.6543	84.9388	30	Feb-13	0.17	BDL
44	Gyaspur	HP	25.6272	84.8896	50	Feb-13	0.11	BDL
45	Korhar	HP	25.5954	84.8677	45	Feb-13	0.2	0.005
46	Bishambharpur	HP	25.5778	84.8857	52	Feb-13	0.24	BDL
47	Sodisopur 1	HP	25.5618	84.9157	52	Feb-13	0.19	BDL
48	Sodisopur 2	HP	25.5618	84.9157	27	Feb-13	0.27	0.003
49	Charra	HP	25.5399	84.9420	30	Feb-13	0.12	0.027

Sl. No.	Place/ Block	Source	lat (^{0}N)	long (^{0}E)	Depth (m)	Month/ year of collection	Iron (mg/l)	Arsenic (mg/l)
50	Hulaschak	HP	25.5395	85.0266	30	Feb-13	2.13	0.021
51	Nisirpura 1	HP	25.5297	85.0918	55	Feb-13	0.07	0.014
52	Nisirpura 2	HP	25.5297	85.0925	50	Feb-13	0.16	0.002
53	Boring Road 1	TW	25.6231	85.1145	107	Feb-13	0.21	0.021
54	Boring Road 2	TW	25.6231	85.1146	107	Feb-13	0.14	0.004
55	Digha	TW	25.6435	85.0871	107	Feb-13	0.22	0.008
56	Makdumpur Digha	TW	25.6454	85.0984	90	Feb-13	1.21	0.01
57	Hamidpur	TW	25.6423	85.1045	80	Feb-13	0.25	0.008
58	Kurji Balu Par 1	HP	25.6389	85.1009	75	Feb-13	0.64	0.005
59	Kurji Balu Par 2	HP	25.6389	85.1009	50	Feb-13	0.51	0.013
60	Kurji Balu Par 3	HP	25.6407	85.1016	50	Feb-13	0.42	0.072
61	Kurji Balu Par 4	HP	25.6391	85.1009	60	Feb-13	0.56	0.007
62	Kothiya 1	HP	25.6379	85.1108	60	Feb-13	0.4	0.005
63	Kothiya 2	HP	25.6397	85.1108	30	Feb-13	0.38	0.001
64	Maienpura 1	HP	25.6316	85.1181	75	Feb-13	0.5	0.004
65	Maienpura 2	HP	25.6314	85.1182	70	Feb-13	0.27	0.002
66	Gosai Tola 1	HP	25.6312	85.1168	50	Feb-13	0.15	0.002
67	Gosai Tola 2	HP	25.6314	85.1176	50	Feb-13	5.44	0.002
68	Gosai Tola 3	HP	25.6309	85.1171	55	Feb-13	0.2	BDL
69	Rajapur	HP	25.6237	85.1242	80	Feb-13	0.27	0.01
70	Sorangpur	HP	25.5828	85.1469	50	Feb-13	0.07	0.002
71	Clectriyet Ghat	HP	25.6209	85.1482	70	Feb-13	0.14	0.001
72	Darbhanga House	TW	25.6214	85.1654	110	Feb-13	0.07	0.01
73	Mahendru (Ambedkar Hostel)	HP	25.6157	85.1798	76	Feb-13	0.07	0.005

Sl. No.	Place/ Block	Source	lat (^{0}N)	long (^{0}E)	Depth (m)	Month/ year of collection	Iron (mg/l)	Arsenic (mg/l)
74	Chihhatar 1	HP	25.6574	84.8908	22	Feb-13	0.16	0.007
75	Chihhatar 2	HP	25.6669	84.8952	30	Feb-13	0.04	0.087
76	Chihhatar 3	HP	25.6627	84.8983	34	Feb-13	0.42	0.038
77	Mahavir Tola 1	HP	25.6679	84.9007	30	Feb-13	0.01	0.004
78	Mahavir Tola 2	HP	25.6679	84.9007	26	Feb-13	1.63	0.074
79	Ratan Tola 1	HP	25.6580	84.9074	34	Feb-13	1.46	0.003
80	Ratan Tola 2	HP	25.6580	84.9074	30	Feb-13	0.15	0.001
81	Ratan Tola 3	HP	25.6583	84.9095	30	Feb-13	0.42	0.076
82	Ratan Tola 4	HP	25.6581	84.9105	75	Feb-13	1.1	0.031
83	Karbigahiya	HP	25.6008	85.1509	60	Jun-12	0.83	BDL
84	Ramnagar	HP	25.5718	85.0517	59	Jun-12	0.97	BDL
85	Faridpur	HP	25.5488	84.9835	55	Jun-12	1.04	BDL
86	Sadisopur	HP	25.5646	84.9179	52	Jun-12	1.05	BDL
87	Chhiyatar	HP	25.6654	84.8944	27	Jun-12	0.32	BDL
88	Tiskohra	HP	25.5266	84.9006	40	Jun-12	0.36	0.001
89	Sikariya	HP	25.5052	84.8375	25	Jun-12	0.49	BDL
90	Dariapur chainpura	HP	25.4800	84.9300	50	Jun-12	0.01	0.005
91	Dariapur chainpura-1	HP	25.4800	84.9300	20	Jun-12	0.01	BDL
92	Patna college	HP	25.6214	85.1654	70	Jun-12	3.2	0.001
93	Akbarpur	HP	25.5114	85.0242	61	Jun-12	0.42	0.003
94	Gopalpur	HP	25.6134	84.9396	61	Jun-12	0.53	BDL
95	Bisambharpur	HP	25.5778	84.8857	52	Jun-12	0.34	BDL
96	Dariapur Mainpura	HP	25.5713	84.9983	55	Jun-12	0.77	BDL
97	Amhara	HP	25.5289	84.8621	40	Jun-12	0.59	BDL
98	Etwarpur	HP	25.5750	85.1264	40	Jun-12	0.04	BDL

Sl. No.	Place/ Block	Source	lat (^{0}N)	long (^{0}E)	Depth (m)	Month/ year of collection	Iron (mg/l)	Arsenic (mg/l)
99	chihatar-4	HP	25.6654	84.8944	40	Jun-12	1.37	0.013
100	Danapur	DTW	25.6325	85.0402	95	Jun-12	0.28	0.009
101	Korwan	DTW	25.5141	84.9444	100	Jun-12	0.27	0.01
102	Bahpura	DTW	25.6127	84.9085	95	Jun-12	0.48	0.008
103	Naubatpur	DTW	25.5015	84.9644	110	Jun-12	0.29	0.016
104	Amhara	DTW	25.5223	84.8636	100	Jun-12	0.24	0.005
105	Dariapur	DTW	25.5712	84.9984	90	Jun-12	0.31	0.002
106	Bikram	DTW	25.4467	84.8560	76	Jun-12	0.01	BDL
107	Phedcampus Bihta	DTW	25.5584	84.8709	90	Jun-12	0.01	0.001
108	Maner	HP	25.6457	84.8877		Jun-12	0.18	0.034

Annexure 3.9(i): location details and analytical result (As & Fe analysis) of ground water sample (Aquifer- 2)

Sl.No.	Place/ Block	lat (^{0}N)	long (^{0}E)	Iron (mg/l)	Arsenic (mg/l)
1	Chuadhrana	25.6419	85.056	0.15	0.019
2	Patna Law College	25.6192	85.175	0.01	0.023
3	Sipara	25.5843	85.129	0.01	0.025
4	A.N.College campus	25.6170	85.110	0.47	0.011
5	Simri	25.6066	84.905	0.009	BDL
6	Naubatpur	25.5030	84.961	0.06	BDL
8	Bihta MI Campus	25.5540	84.868	0.47	0.005
9	Moriyama	25.4916	84.864	0.72	0.008

Annexure 3.9(j): location details and analytical result (Hg, Zn & Mn, analysis) of ground water sample (Dug wells)

Sl. No	Location	Hg(ppb)	Zn(ppb)	Mn(ppb)
1	Digha	0.71	24.9	570.2
2	Lalbebwan	0.31	192.9	448.7
3	Gopalpur	0.15	70.9	90.9
4	Bisambharpur	BDL	30.3	48.9
5	Dariapur Mainpura	BDL	57.5	34.9
6	Amhara	BDL	71.7	9
7	Etwarpur	BDL	37.6	1367.9
8	chihatar	BDL	77.5	63.4
9	Noniatola	BDL	24.2	18.1

Annexure 3.9(k): location details and analytical result (Cr analysis) of ground water sample (Dug wells)

Sl.No.	Location	Cr (ppb)
1	Khajpura	BDL
2	Soranpur	0.6
3	Karbigahiya	BDL
4	Ramnagar	BDL
5	Hulaschak	BDL
6	Gyaspur	0.4
7	Snehitola	BDL
8	Faridpur	10.3
9	Charra	7.3
10	Sadisopur	2.8
11	Chandmari	5.6
12	Nisilpura	3.4
13	Datiana	0.3
14	Darveshpur	3.7
15	Tiskohra	3.5
16	Sikariya	4.1
17	Digha	17.8
18	Lalbebwan	14.4
19	Gopalpur	9.4
20	Bisambharpur	3.4
21	Dariapur Mainpura	6.8
22	Amhara	14.2
23	Etwarpur	15.7
24	chihatar	33.2
25	Noniatola	11.2

Annexure 3.9(l): location details and analytical result (Hg, Zn & Mn analysis) of ground water sample (Aquifer -1)

SL.	Location	Lat (^{0}N)	Long (^{0}E)	Source	Hg(mg/l)	Zn(mg/l)	Mn(mg/l)
1	Patna college	25.6219	85.1654	HP	0.001	0.1316	0.0427
2	Digha	25.6435	85.0871	HP	0.0003	0.0117	0.0267
3	Lalbebwan	25.6514	84.9768	HP	0.0002	0.0133	0.033
4	Akbarpur	25.5114	85.0242	HP		0.0112	0.1688
5	Gopalpur	25.6134	84.9396	HP		0.4386	0.0214
6	Bisambharpur	25.5778	84.8857	HP		0.017	0.2016
7	Dariapur Mainpura	25.5713	84.9983	HP		0.0618	0.005
8	Amhara	25.5289	84.8621	HP		0.0192	0.2391
9	Etwarpur	25.5750	85.1264	HP		0.1236	0.0325
10	chihatar	25.6574	84.8908	HP		0.092	0.667
11	Noniatola	25.4380	84.8704	HP		0.0144	0.0279

Annexure 3.9(m): location details and analytical result (Cr analysis) of ground water sample (Aquifer -1)

SL.	Location	Lat (^{0}N)	long (^{0}E)	Source	Cr (mg/l)
1	Khajpura	25.6036	85.08396	HP	BDL
2	Garikhana	25.5886	85.04342	HP	BDL
3	Soranpur	25.5828	85.14690	HP	BDL
4	Karbigahiya	25.6008	85.15089	HP	BDL
5	Ramnagar	25.5718	85.05172	HP	BDL
6	Hulaschak	25.5383	85.02658	HP	BDL
7	Gyaspur	25.6273	84.88964	HP	BDL
8	Snehitola	25.5052	84.96131	HP	BDL
9	Faridpur	25.5488	84.98350	HP	BDL
10	Charra	25.5399	84.94203	HP	BDL
11	Sadisopur	25.5646	84.91794	HP	BDL
12	Chandmari	25.6251	85.01778	HP	0.0024
13	Nisirpura	25.5297	85.09250	HP	0.0014
14	Datiana	25.4824	84.86653	HP	0.0041
15	Darveshpur	25.6522	84.93958	HP	BDL
16	Chhiyatar	25.6574	84.89077	HP	BDL
17	Tiskohra	25.5266	84.90058	HP	BDL
18	Sikariya	25.5052	84.83753	HP	BDL

SL.	Location	Lat (^{0}N)	long (^{0}E)	Source	Cr (mg/l)
19	Patna College	25.6219	85.16536	HP	0.0002
20	Digha	25.6435	85.08715	HP	0.0009
21	Lalbebwan	25.6514	84.97678	HP	BDL
22	Akbarpur	25.5114	85.02419	HP	0.0016
23	Gopalpur	25.6134	84.93958	HP	0.0018
24	Bisambharpur	25.5778	84.88569	HP	BDL
25	Dariapur Mainpura	25.5713	84.99828	HP	0.0048
26	Etwarpur	25.5750	85.12639	HP	BDL
27	chihatar	25.6574	84.89077	HP	0.0009
28	Noniatola	25.4400	84.87000	HP	0.0038

Annexure 3.11 (a): Questionnaire prepared in Hindi for draft sample survey to know about aquifer zone used ,crop grown and dependency on ground water for irrigation purposes in the area .

<u>सिंचाई कार्य हेतू भूजल दोहन का सर्वेक्षण फॉर्म</u>

1. नाम: 2. गाँव 3. ब्लॉक

4 स्थान :

5. क्या खेती करते है: (क) हाँ (ख) नहीं 6. अपनी खेती हैं: (क) हाँ (ख) नहीं 7. खेती होती हैं : (क़) केवल खरीफ (ख) केवल रबी (ग) केवल गरमा (घ) सभी (ङ) केवल खरीफ एवम रबी

8 फ़सले मुख्यतःहोती है;

(क़) खरीफ मे :

(ख) रबी :

(ग) गरमा:

9. सिंचाई के लिए मुख्यतः निर्भर है (क) भूजल पर (घ) नहर/नदी/ तालाब पर

10. यदि भूजल तो,सिंचाई का साधन? (क) कुआं (ख) अपना बोरिंग (ग) सरकारी बोरिंग (घ) दूसरे का बोरिंग

11. यदि अपना बोरिंग है तो ? (i) कब बना है : ___________ (ii) कितना खर्च लगा : ________ रुपया (iii) बोरिंग की गहराई कितनी हैं : ___________ फूट (iv) जाली कितना हैं : ___________ फूट (v) जाली किस गहराई पर दिया गया हैं: ___________ फूट पर / (vi) बोरिंग का व्यास: ___________ (vii). अपनी बोरिंग से कितना खेत सिंचाई किया जाता हैं: (क़) खरीफ के मौसम मे: _________ बीघा या कट्ठा (ख) रबी के मौसम मे : _________ बीघा या कट्ठा (ग) गरमा के मौसम मे: _________ बीघा या कट्ठा

(viii). अपनी बोरिंग सिंचाई हेतु कितने घंटे चलाते हैं:

(क़) खरीफ के मौसम मे: _________ घंटे (ख) रबी के मौसम मे : _________ घंटे (ग) गरमा के मौसम मे : _________ घंटे

(ix) पम्प चलाने हेतू उपयोग करते हैं: (क़) केवल बिजली (ख) केवल डीजल (ग) दोनों

(x) डीजल कितना लगता है : (क़)) खरीफ के मौसम मे: _________ लीटर/ घंटा (ख) रबी के मौसम मे: _________ लीटर / घंटा (ग) गरमा के मौसम मे: _________ लीटर/ घंटा

(xi) पम्प कितने हॉर्स पावर का हैं: _______एच.पी. (xii) ऊर्जा के लिए वार्षिक खर्च : ___________ रुपया

(12) यदि सरकारी बोरिंग है , तो (क) गाँव मे कितना बोरिंग है: (ख) क्या बोरिंग कार्यरत है: हा /नहीं (ग) बोरिंग नहीं चलने का कारण: (i) बिजली/ डीजल (ii) अन्य कारण

13. यदि अपना बोरिंग नहीं है ,तो सिंचाई के लिए स्रोत क्या है? (क) दूसरे का बोरिंग (ख) सरकारी बोरिंग

14. दूसरे के बोरिंग उपयोग करने के लिए क्या शुल्क देना परता है/ दूसरे को बोरिंग उपयोग करने के लिए क्या शुल्क लेते है : (क) हाँ (ख) नहीं

15. (क) यदि हाँ, तो प्रति घंटे कितना शुल्क देना होता है : (i) खरीफ के मौसम: ___________ रुपया / घंटा

(ii) रबी के मौसम मे: ___________ रुपया / घंटा (iii) गरमा के मौसम मे: ___________ रुपया / घंटा

हस्ताक्षर

Annexure 3.11 (b): Questionnaire prepared in Hindi for draft sample survey to know about aquifer zone used and dependency on ground water for domestic purposes in the area .

<u>घरेलू कार्य हेतू भूजल दोहन का सर्वेक्षण फॉर्म</u>

1. नाम: 2. गाँव 3. प्रखण्ड

4 स्थान : 5. परिवार मे सदस्यों की संख्या

6. आमदनी का जरिया: (क) कृषि (ख) नौकरी (सरकारी/ प्राइवेट) (ग) व्यवसाय

7.मासिक आमदनी: (क) 5000 रु. से कम (ख) 5000-10000 रु. (ग) 10000 रु. से अधिक

8. क्या जल के लिए अपना स्रोत है? (क) हाँ (ख) नहीं

9. यदि नहीं, तो स्रोत क्या है? (क) सरकारी नल/कुआँ (ख) किसी दूसरे व्यक्ति का नल / कुआँ (ग) सार्वजनिक जल बितरण स्रोत से (घ) नदी/ तालाब/नहर

10. यदि नहीं, तो घरेलू उपयोग हेतु जल के लिए वे कितनी दूरी तय करते हैं? (क) 100 मीटर से कम (ख) 100-500 मीटर (ग) 500 मीटर से अधिक

11. यदि हाँ, तो स्रोत क्या है? (क) ट्यूबवेल(बोरिंग)/ चापाकल (ख) कुआं

12. क्या श्रोतों की संख्या एक से अधिक है? (क) हाँ (ख) ना

यदि हाँ तो क्या है (क) ट्यूबवेल-ट्यूबवेल (ख) ट्यूबवेल-कुआं (ग) ट्यूबवेल(बोरिंग)-चापाकल

13. एक से अधिक स्रोत होने का कारण (क) गुणवत्ता (ख) कोई अन्य कारण

14. ऊर्जा के लिए वार्षिक खर्च

15. ट्यूबवेल की गहराई: _______________ फूट

16. ट्यूबवेल का व्यास:____________इंच

17. ट्यूबवेल में (क) जाली कितना है : ________________ फूट (ख) किस गहराई पर दिया गया है : ________________फूट

18. घरेलू व्यवहार के लिए जल की खपत (प्रति व्यक्ति प्रति दिन) :

(क) खाने-पीने के लिये:________ लीटर (ख) अन्य विविध कार्यो के लिये: _______ लीटर

हस्ताक्षर

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