Executive Summary

Rajasthan Ground Water Department (RGWD), Government of Rajasthan (GoR) is the nodal agency for implementing "Aquifer Mapping and Development of GIS based Database for Assessment of Village wise Groundwater Potential and Strategy for Development". European Union (EU), under its bilateral program provided the financial support for the project. On 16th November 2010, ROLTA India Limited signed the consultancy contract for execution of the same. The project is set to be completed in December 2012 with the submission of current report i.e., Final Project Report. This report incorporates the suggestions from the Department on 'draft of the final project report' submitted earlier.

Rajasthan being a water scarce State is strategically located in western part of India. Despite this, population of the State is on the rise, part of the land and water resource is affected by salinity and is often brackish in nature.

The initial part of the project required visiting the RGWD's circle and district offices for collection of historic data collected by the Department over a period of time, largely 1984 onwards. Various thematic maps, water level and water quality records, geophysical survey data and groundwater resource assessment reports etc., were collected during the visits that constituted base for definition of aquifers in the state. Rolta has systematically computerized all the relevant data using in-house tools that ensured quality of final data.

Key objective of the project was to assess the groundwater resources at the level of villages. Per state's groundwater policy water resources should ideally be managed by the end users, which is a Gram Panchayat. So unless the data at village level is available, the intended objective of the project cannot be met.

A consultative approach was adopted and we engaged the RGWD and EU in all steps of project execution that led to finalization of 15 basins and 2 sub-basins, 19 aquifers (excluding forests and hill areas).

The project being unique in its kind wherein GIS techniques for delineating aquifers in 3 dimensions were to be done while addressing strong hydrogeologic principles. Innovative approach was adopted for defining saturated and unsaturated zones in each well and finally defining such thicknesses per a particular date of water level measurement was designed. This has helped in subsurface aquifer mapping, delineating thickness of aquifer, artificial recharge planning and finally water resources in each unit area which was a 250m X 250m grid cell. The resources so computed were finally summed up for each village and other administrative boundaries, aquifers and basins.

The groundwater resources were computed in two parts wherein, the dynamic resource based on fluctuation zone and static resources further below the minimum water table depth were worked out. The total resources computed have been grouped differently and presented in respective sections later in the report. The Department should take note of the same and adopt a cautious and conservative approach while designing developmental projects.

Study of RGWD's resource assessment methodology was also undertaken as part of the project and a thorough review of the same in light of recent publications by CGWB, GIS approach and local conditions was conducted. The same is discussed at length in the Technical Reports and recommendations have been summarized later in this report.

With the intent of community level participation in groundwater management, web based application was also designed and implemented which allows villagers to enter groundwater level value and they in turn receive the groundwater balance in their village for drinking purpose so that in case of availability of surplus, they can use the same for other purposes. In addition, all the project output maps and data will be available to public for viewing which will help in raising awareness among common people about this precious but fast depleting groundwater resource.

Series of training sessions were undertaken for capacity building by transferring the knowledge of aquifer mapping using industry standard softwares. It is believed that the Department will reap the benefits of the knowledge and new softwares procured as part of EU funding to take the initiative forward.

All about the project activities, methodology adopted, available groundwater resources, river basins and sub-basins, aquifers, their mapping and presentation, analysis for village level resource assessment, web GIS, capacity building sessions are all compiled and presented as separate chapters and sections in this report. A dedicated chapter for recommendations and suggested action plan is presented along with suggestions for future focused studies by the department.

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List of Acronyms

ADP	Agriculture Development Programme
agl	Above ground level
BCM	Billion Cubic Meter
BDR	Basic Data Report
BGC	Banded Gneissic Complex
bgl	Below ground level
BIS	Bureau of Indian Standard
CE	Chief Engineer
CGWB	Central Groundwater Board
D	Domestic
DCB	Dug Cum Bore well
DHI	Detailed Hydrological Investigation
DKW	District Key Well
DSPC	Data Storage and Processing Cell
DS&T	Department of Science and Technology
DTW	Depth to Water Level
DW	Dug well
DWS	Drinking Water Supply
EC	Electrical Conductivity
EU-SPP	European Union State Partnership Program
EE	Executive Engineer
GEC	Groundwater Estimation Committee
GIS	Geographical Information System
GL	Group Leader
GoR	Government of Rajasthan
GoI	Government of India
GP	Gram Panchayat
GMS	Groundwater Monitoring Station
GWD	Ground Water Department
GPS	Global Positioning Systems
GSI	Geological Survey of India
GW	Ground Water
GWRI	Groundwater Resources Information

I	Irrigation
IGNP	Indira Gandhi Nahar Project
LAN	Local Area Network
M	Monitoring
MCM	Million Cubic Meter
mg/l	Milligram per liter
meq/l	Mill equivalent per liter
MP	Measuring Point
.NET	dot net Technology
NABARD	National Bank for Agriculture and rural development
NRSC	National Remote Sensing Centre
O&M	operation and maintenance
OW	Open Well
PHED	Public Health and Engineering Department
PRI	Panchayat Raj Institutions
PW	Public Well
QA	Quality Assurance
QC	Quality Control
RFP	Request for Proposal
RID	Rolta unique ID
RSC	Residual Sodium Carbonate
RSLDB	Rajasthan State Land Development Bank,
RWSRP	Rajasthan Water Sector Restructuring Project

SAS 300 [ABEM] – Brand name for geophysical resistivity measuring equipment

SAS 1000 [ABEM] – Brand name for geophysical resistivity measuring equipment

SHG	Superintendent Hydrogeologist
SOI	Survey of India
SRSAC	State Remote Sensing Application Center
SWRPD	State Water Resource Planning Department
TA	Technical Assistant
TDS	Total Dissolved Solid
TH	Total Hardness
TL	Team Leader
ToR	Terms of Reference

WADI VLF	Brand name for geophysical equipment
UNDP	United Nations Development Programme
UPTRON	Brand name for geophysical logging equipment
WL	Water Level
WLF	Water Level Fluctuation

1. Background and Overview

1.1. Background

Groundwater is a replenishable but finite resource and its availability in any region is driven by the balance between prevailing recharge and discharge conditions. Rajasthan, largely being a rainfall deficient area coupled with limited perennial surface water supply and ever increasing demand for fresh potable water, the groundwater is under constant stress leading to its depletion year after year. Indications of overexploitation of groundwater were showing up at many locations and shrinking groundwater reserve in terms of its quantity and quality is a potential threat. However, despite measures to identify strained groundwater locations and control overexploitation, in such locations through appropriate measures of regulation by the State and Union government agencies, indicators of depleting groundwater continued to show up and the trend went on expanding. For rapidly expanding urban, industrial and agricultural water requirement of the state ground water utilization is of fundamental importance therefore, reliable estimation of ground water resource is a prime necessity.

The strata that hold groundwater are concealed below the surface which poses difficulty in direct measurement of the volume of water contained in them and hence available for use. Indirect methods are therefore best adopted to estimate the same which often is an eye opener providing crucial inputs for effective groundwater management to the decision makers. The complexities of the processes governing occurrence and movement of ground water make the problem of ground water assessment somewhat difficult, mainly because not only enormous data is to be procured, but a multidisciplinary scientific approach is to be adopted for space and time location of ground water, in quantity as well as quality. Groundwater resource estimation is thus an integral part of planning, development and management of water resources.

A State Partnership Program is being implemented in the state of Rajasthan with assistance from the European Union (EU). The program involves both the surface water (SW) and ground water (GW) agencies of the State. In the same context a project was conceived by EU and after a systematic tendering process, Rolta India Ltd was awarded the work to perform consultancy services for "*Aquifer Mapping and Development of GIS based database for assessment of Village Wise Ground water Potential and Strategy for Development*" in the state (Project number F-1() SKE/EC-1(1) CS/GWD/JU/2010-11/1344).

The main focus of the project is computerization of the relevant archived data of RGWD, development of village level database on the GIS platform, delineation of aquifers, recommend and support RGWD in procurement of software and hardware for hydrogeologic studies by the department and capacity building of stakeholders, review of existing methodology of ground water resources assessment and suggest suitable technique for seasonal assessment, strengthen local institutions on emerging water crisis and ground water management. The outcome of this process leads to development of GIS based Integrated Ground water Information System for village level assessment of ground water resources and data updation at local level.

From hydrogeologic perspective, 19 regional aquifer systems (excluding reserve forest and hilly areas) are also demarcated (Fig.1) and studies on 3D aquifer delineation and resource assessment has been carried out on that basis. Rajasthan is divided into 14 river basins, one outside basin and two sub-basins within the major basins (Fig. 2). The advent of Geographical Information System (GIS) has added a much needed dimension to the 3D delineation of aquifers and estimation ground water resources mapping and management. It helps in integration of data from multiple sources, carry out integrated analysis to derive meaningful results.

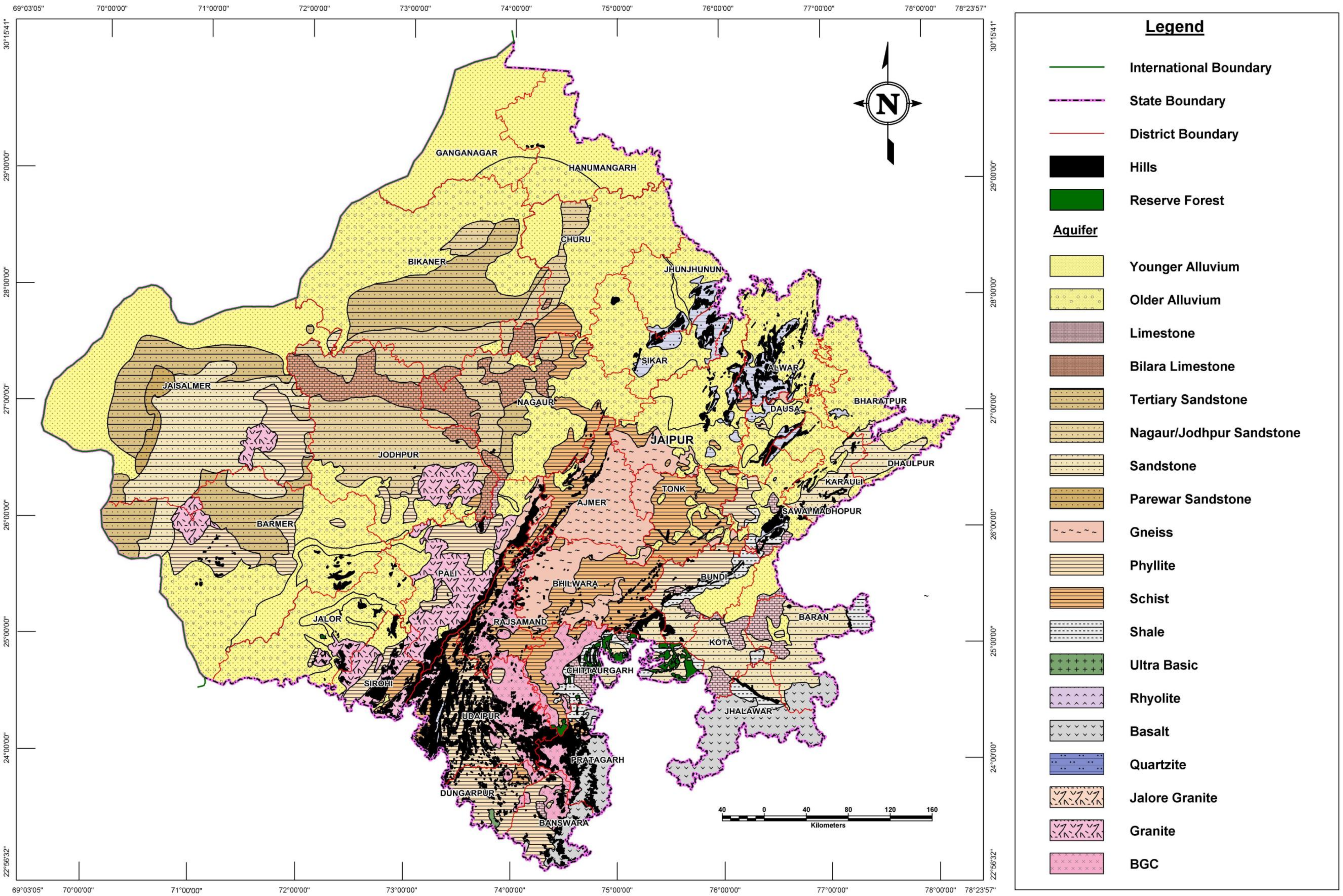


Figure. 1 : Aquifer Distribution Map of Rajasthan

Source: District wise Ground Water Potential Zone Map GWD, Rajasthan

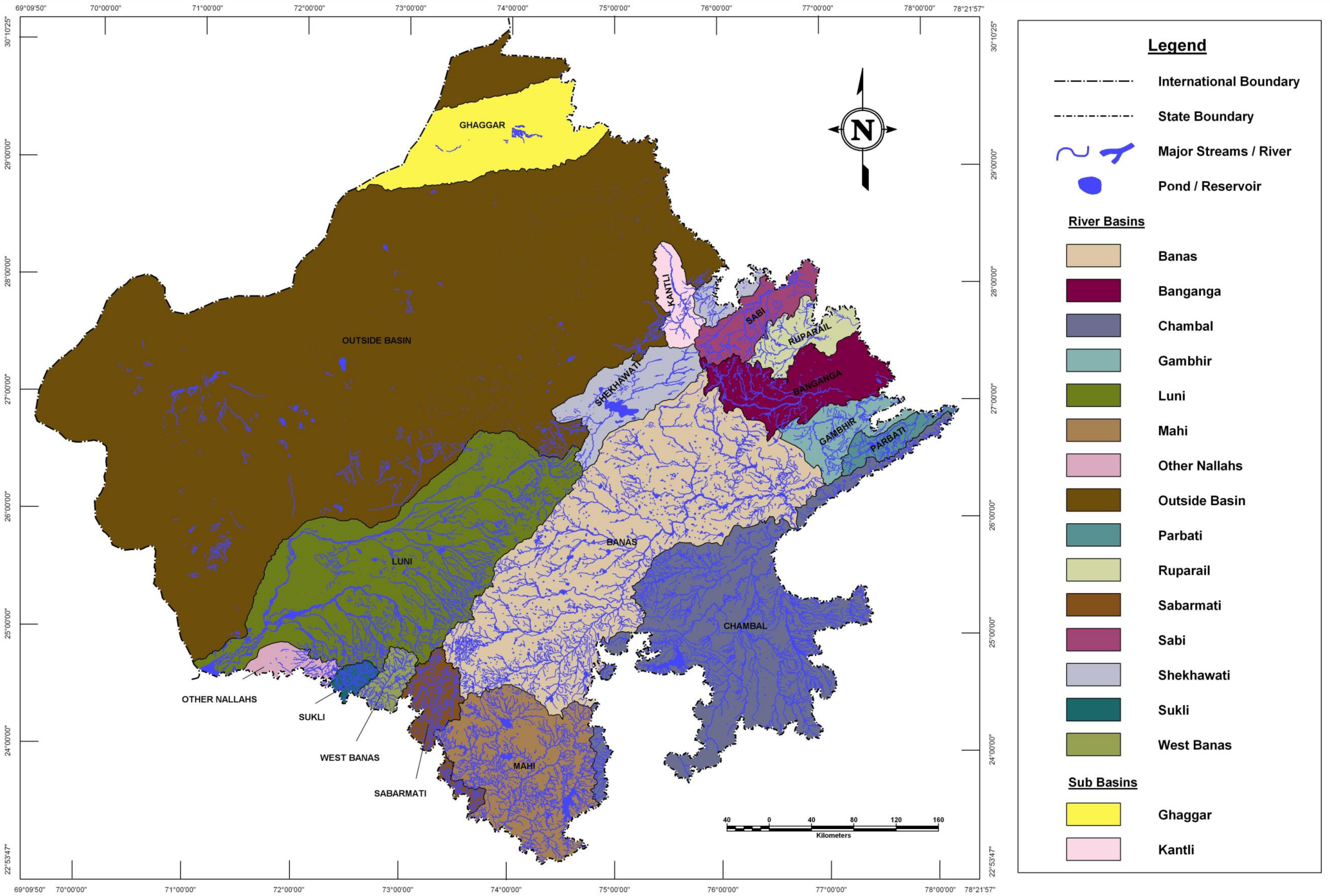


Fig. 2 : River Basin Map of Rajasthan

1.2. Overview

In the state of Rajasthan, surface water resources are meager and the entire state is principally dependent on groundwater. The problem is a consequence of low precipitation and hence low recharge to aquifers and high evapotranspiration. Annual rainfall across the state varies from more than 950 mm in the South-Eastern part to less than 200 mm in the North-Western part.

The rainfall is erratic and there is a large variation in the rainfall pattern in the state. Average annual rainfall of the state is 531 mm. The state has witnessed frequent drought and famine conditions in the past 50 years. Groundwater is not available in many parts even for drinking purpose. Sometimes water is being transported by trains, trucks and other means.

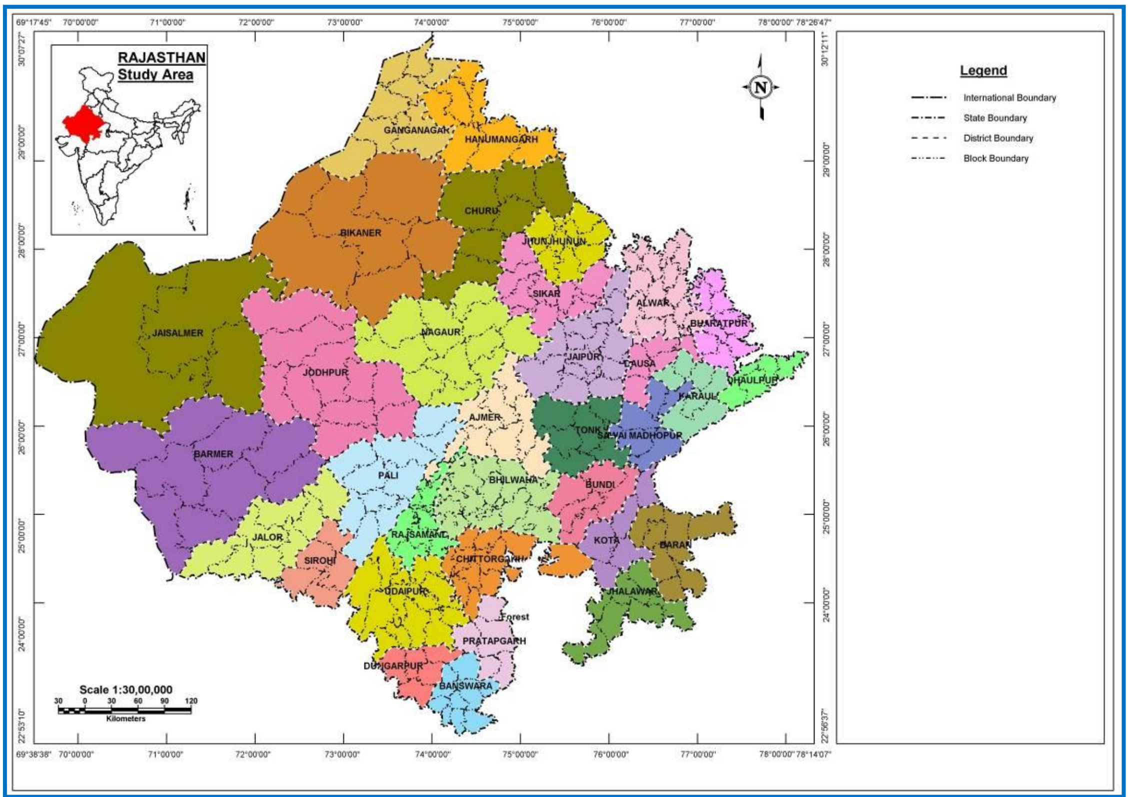


Fig.3: Administrative Boundary of Study Area

The increasing awareness of ground water management problems has resulted in a need for information on ground water quality and quantity so that remedial action may be taken in time to mitigate these problems or to prevent their re-occurrence in future.

Rajasthan state is categorized as the most water stressed states of the country as far as ground water is concerned. As per the latest estimates of ground water jointly carried out by the Ground Water Department of the state and CGWB, the scope for future groundwater resource development in the state of Rajasthan is very less. The year 2009 groundwater resource estimation report reveals that out of total 249 blocks in the state 138 blocks are categorized as Over-exploited, 26 blocks as Critical, 16 blocks as Semi Critical. Remaining 36 blocks which have been categorized Safe.

1.3. Objectives:

The State of Rajasthan is implementing multiple projects with assistance from the European Union. These were perceived to be 18 month long projects all running simultaneously, starting in November 2010 that involved the State Surface Water (SW) and Groundwater (GW) agencies. This will facilitate establishment of a firm GIS based hydrological database in the state, upgrade IT infrastructure and strengthen the technical capabilities of the state organizations. The broad objective of the project is to equip groundwater users / stakeholders with the necessary data, skills and knowledge to manage groundwater resources available in a sustainable manner. Also, the access to scientific data and knowledge will enable farmers to make appropriate choices and decisions regarding the use of groundwater resources and agricultural practices and actively participate in groundwater resource in their respective regions.

The key objectives of the current project:

1. Computerization of all the relevant groundwater related data (tabular and maps) collated by GWD and other agencies and bring them to one analytical platform,
2. Develop village level database on the GIS platform involving all sources of water including parameters related to ground water extraction and assessment,
3. Mapping and delineation of aquifers in three dimensions,
4. Capacity building and community level participation in real time data collection and planning development,
5. Review of existing methodology of ground water resources assessment and suggest suitable technique for seasonal assessment of the aquifer wise ground water resources,
6. Strengthen local institutions at the habitation and hydrologic unit level to bring on center stage discussions on emerging water crisis especially on groundwater,
7. Transform the perception of groundwater from private property to that of a “common good” (individual farmers take decisions for collective good),
8. Articulate and share information across hydrological units for crop planning.

1.4. Scope

In order to achieve the above objectives and based on the understanding of requirements of the assignment the scope of the work included:

1. Collection and collation of the ground water related data / information from State and central agencies for development of the GIS based database system,
2. Digitize Mapping of the aquifers at suitable scale for planning development and management of ground water at Panchyat / Community level through stakeholder’s participation,
3. Provide specifications for software, hardware, database/GIS tools and presentation/analysis

tools for developing GIS based databases and aquifer mapping for the State,

4. Depiction and analysis of the aquifer systems in 3 dimension at suitable scale using standard software's and preparation of the isopach maps showing thickness of the individual aquifers and their respective parameters,
5. Review of the existing methodology, practices and status of ground water resources assessment in the state and to suggest suitable technique for seasonal assessment of the aquifer wise ground water resources,
6. Carry out onetime assessment of groundwater resources, Aquifer Wise on suitable administrative/ hydrological units and standardize the appropriate technique / methodology for seasonal assessment of ground water resources using real time data by stakeholders,
7. Suggest mechanism for collection of required data / parameters for seasonal assessment of ground water resources and their regular updating at local level involving the end users,
8. Formulate appropriate strategies and methodology for strengthening local institutions and end users for ground water management,
9. Capacity building of staff/ officials and end users engaged in ground water development and management,

1.5. Deliverables

The deliverables were in terms of a series of technical reports and thematic maps on different scales that were to be completed by predefined deadlines spread over the project duration. Brief about them along with their contents is given below:

1. INCEPTION REPORT	Inception Report containing strategy for implementation and work schedule for various activities.
2. TECHNICAL REPORT - 1	About data gathering process that had formed basis for interpretation and analysis, their quantity, map scales and themes etc. along with its evaluation and our observations.
3. TECHNICAL REPORT – 2A	This report covered the compilation of inputs and preparation methodology for output maps. The report also contained recommendations related to Regional Aquifer System Analysis tools which is a set of softwares that would be required for the purpose along with recommendations for software, Hardware and Database required for Web GIS implementation.
4. TECHNICAL REPORT – 2B	Hardcopy GIS (1:50,000 scale) Map Prints on different themes viz. District Administrative, Ground Water Potential Zone and Geomorphology Maps.
5. TECHNICAL REPORT – 3A Part1	Report on study conducted on prevailing methodologies of ground water assessment, suggestion of modifications in methodology, organizational set up and processes adopted by GWD to assess groundwater resources.
6. TECHNICAL REPORT – 3A Part2	Detailed account of aquifer mapping outputs, statistics and

	distribution maps with emphasis on quality of water. The report was prepared basin wise for better depiction.
7. TECHNICAL REPORT – 3B	Report related to onetime assessment of GW Resource summarized aquifer wise and basin wise.
8. TECHNICAL REPORT – 4A	Village wise Apportion of groundwater resources both dynamic and static along with summary of quality of water in each village.
9. TECHNICAL REPORT – 4B	Capacity Building of staffs, officers and end users engaged in GW assessment and development. Also included training plan and modules based on requirement analysis.
10. TECHNICAL REPORT – 4C	Discussion and recommended approach for Seasonal Assessment of ground water resources at village level and how that would be implemented in Web GIS Application.
11. TECHNICAL REPORT – 4D	Documentation of appropriate strategy and action plan for strengthening local institutions and end users.
12. Draft Final Report	Draft Final Report
13. Final Report	Final Report

1.6. Brief Recap of Rolta's Implementation Approach

Following Rolta's standard implementation procedures, an execution plan was created and shared with management for approval. This plan consists of deliverables, dependencies, resources required, skillsets, timelines, travel plans, constitution of sub-teams with specific tasks etc. and appoint of one point contact, the Project Manager. Immediately after approval of plan, Rolta had opened a project office in Jaipur and appointed project coordinator for day to day liaisoning with client and maintain communication flow between client and Rolta main office in Mumbai.

Rolta adopts a consultative approach engaging with client on frequent basis for their opinions on key issues, seeking their consent and approvals before next step which ensures least amount of rework and a smoother workflow.

Inception report was submitted after mutual agreement on contents and timelines for interim deliveries. Later, teams dispatched for collation of input maps and data from different GWD and CGWB offices spread across the state. Mumbai back office had carried out the computerization of data, restructuring the data, preparation of standardized water level; water quality and basic data report formats that could be carried on a CD for ready reference. Redrawing of river basin During the process of implementation of the project, we were in constant touch with client's representatives and had gathered information regarding existing skillsets with them and the areas where training needs to be imparted in order to bring the RGWD staff handle GIS softwares, RASA tools, overlay analysis for derivation of different statistics, 3D aquifer delineation, presentation of data, maintain the all relevant databases pertaining to groundwater, update, manage and disseminate to through usage of modern tools and software. Accordingly, customized training modules were designed and training imparted to the identified teams of RGWD.

2. Approach and Methodology

2.1. Data Preparation

Data as such forms basis for any analytical study and this project is no different from those. Over a period of time, the agencies engaged in groundwater related studies at both state and central Government levels have collected wealth of data through their intensive and extensive field surveys and mapping through interpretation.

The initial step thus, was to develop an understanding of the data available with the agencies as well as to establish relationship between what they have vs what is required for undertaking the aquifer mapping and resource assessment at village level.

All the data was collected at the behest of the Chief Engineer, RGWD who issued the request letter for making available all the required data to Rolta. The letter was addressed to the Central Ground Water Board (CGWB), Public Health and Engineering Department (PHED), State Water Resource Planning Department (SWRPD), Survey of India (SOI). Initial discussion and planning for data collection began in consultation with DSPC, Jodhpur. It was decided that the data collection will be from the four Circles of GWD (Jodhpur, Jaipur, Udaipur and Bikaner) separately. Accordingly Rolta Team members visited GWD Superintending Hydrogeologist (SHG)'s offices at Jodhpur, Jaipur,

Input data available with the department consisted mainly of:

- Topographic maps,
- Hydrogeology Maps,
- Geomorphology maps
- Groundwater Potential Maps,
- Basin boundary maps
- Water level of key wells (year 1984 – 2010)
- Water Quality data,
- Monthly rainfall data,
- Geophysical survey data (Resistivity and VLF)
- Exploratory well data in the form of Basic Data Report (BDR),
- Published assessment reports of past years.

Largely, the data was available in the existing record format (data registers) in hard copy and some however, in soft copy.

The data collected from the CGWB key wells was in digital format for the water level and water quality. Apart from that, CGWB exploratory well detail, Daily rainfall data and Groundwater Assessment Report of 2009 was also collected. BDR data was however, available mostly in hard copies.

Besides, Groundwater Exploration Report of Western region and Basin Reports was provided by the EC – TA Team.

In addition, Ground Water Atlas of Rajasthan prepared by State Remote Sensing Application Center (SRSAC) has been procured from GWD. Geological Map has been procured from the Geological Survey of India (GSI). Census data of 2001 has procured from Census of India for village level information for the entire state of Rajasthan.

Table 2.1: Table on the different types of data collected and their details

S. No.	Types of Data	Format	Scale	Sources	Quantity
1	Base Map	Ammonia Print	1:2,50,000	GWD, Rajasthan	33
2	Hydrogeology Map	Ammonia Print	1:2,50,000	GWD, Rajasthan	33
3	Groundwater Potential Zone Map	Ammonia Print	1:2,50,000	GWD, Rajasthan	33
4	Geomorphology Map	Paper Map	1:5,00,000	Ground Water Atlas Rajasthan – SRSAC	33
5	Geological Map	Paper Map	1:250,0000	Geological Survey of India (GSI)	1
6	Basin Map	Paper Map	1:10,00000	State Water Resources Planning Department (SWRPD)	1
7	Toposheets	Paper Map	1:50,000	Survey of India (SOI)	570
8	Census Data (Year – 2001)	PDF	-	Census of India – Rajasthan	1
9	Elevation Data	Raster	90 meter	SRTM	Entire Rajasthan
10	GMS Water Level Data (Year 1984 – 2011)	Excel Sheets	-	GWD, Rajasthan	8091 GMS
11	GMS Water Level Data (Year 1969 – 2010)	MS Access	-	CGWB, Rajasthan	1570 GMS
12	Water Quality Data (Year 1984 – 2011)	Hard Copy	-	GWD, Rajasthan	26,788 Locations
13	Water Quality Data (Year 1984 – 2011)	MS Access	-	CGWB, Rajasthan	1301 GMS
14	Basic Data Report (BDR)	Hard Copy	-	GWD, Rajasthan	3260
15	Basic Data Report (BDR)	Hard Copy	-	CGWB, Rajasthan	1143
16	Exploratory Well Data	Hard Copy	-	CGWB, Rajasthan	1925
17	Geophysical Survey Data	Hard Copy	-	Hard Copy	1206 VES / 123 VLF
18	Rainfall Data (Year 1984 – 2010)	Excel Sheets	-	GWD, Rajasthan	229 Rain Gauge Stations

19	Rainfall Data (Year 1984 – 2010)	MS Access	-	CGWB, Rajasthan	292 Rain Gauge Stations
20	Ground Water Assessment Report – District (Year 1998 – 2011)	Hard Copy	-	GWD, Rajasthan	6 Reports
21	Ground Water Assessment Report – Basin (Year - 1999)	Hard Copy	-	GWD, Rajasthan	15 Reports
22	Ground Water Resources Planning – Basin (Year – 1998)	Hard Copy	-	Tahal Consultancy	15 Reports
23	Ground Water Assessment Report – Basin (Year – 1970 - 1971)	Hard Copy	-	UNDP / CGWB	2 Reports

2.2. Brief about data and Issues

In all, during annual pre-monsoon monitoring, samples of groundwater are taken from about 7,000 wells jointly by the State GWD (5,400) and the CGWB (1,373) and analyzed for 13 common parameters. In addition, the GWD determine Na% and RSC, while only the CGWB determine Fe, PO_4 and SiO_2.Although the basic salinity and fluoride data are still monitored adequately.

Based on the initial review of the data collected, the major observation was that the co-ordinates obtained from the hand held GPS were erroneous. It was also observed that there is no common reference for the monitoring wells and the water quality monitoring stations. In Groundwater Monitoring Stations data there were units for reduced level, total depth of wells and measuring points, including units for yield of wells have not been indicated. There are also mix between FPS (Foot Pound Second) and Metric systems of measurement. The same village names were spelt differently in different datasets and the same was persistent with block and district names. Continuous records for all the wells was unavailable, as some wells had gone dry after some years and new wells had to be added to the network from monitoring purpose.

Hence it was imperative to define a consistent database design in which all the different datasets can be accommodated and analyzed synchronously.

2.3. Non Spatial Data Entry Process

A series of data entry forms were designed for inputting the data pertaining to water level, water quality, BDR of expletory wells, geophysical data and rainfall into Oracle database.

A unique ID (RID) has been assigned to each sample entry for query and editing purpose. A replica of the provided hard copy by the GWD has been developed in the oracle. Intuitively selected checks were incorporated to each and every parameter and field to avoid errors in the manual entry. Each window could take a single sample entry and after successful entry of one sample into the database another new window would open for the next sample data entry to avoid any type of duplication and typological error. Updation, editing, searching and reset facilities were also used in the form.

The data received in soft cop for water level, water quality and rainfall for the years 1999 – 2010 from GWD was also migrated to Oracle.

Samples snap shots of data entry forms for water level, water quality, BDRs and Geophysical data developed in the Oracle have been shown below in the document:

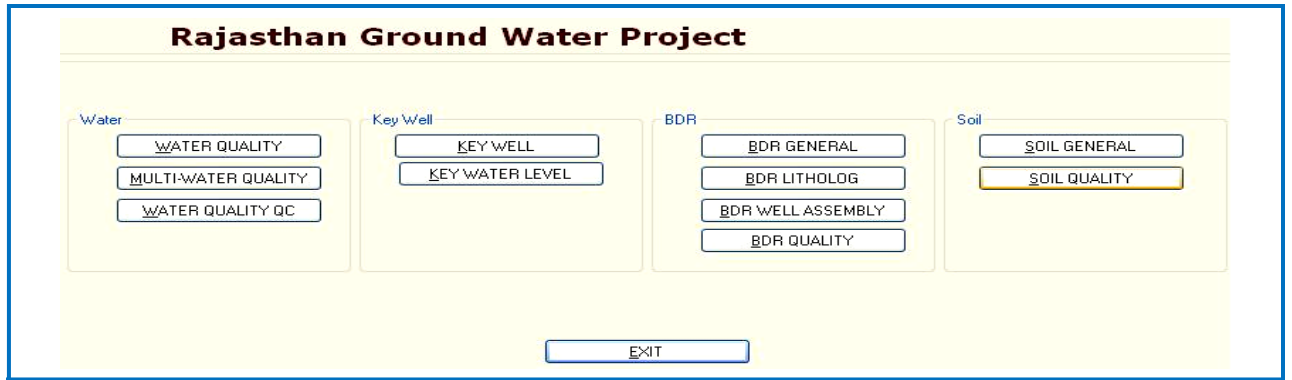


Fig.4: A snap shot of Main Data Entry Form

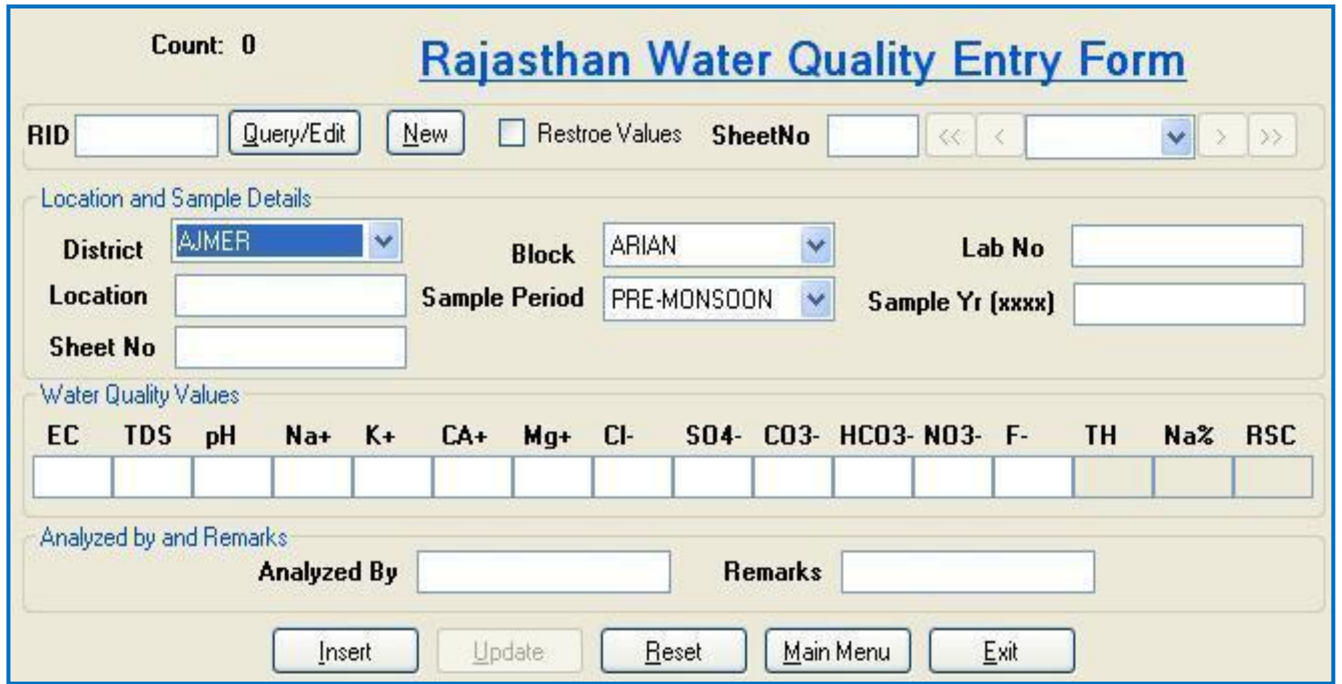


Fig.5: A snap shot of Water Quality Data Entry Form

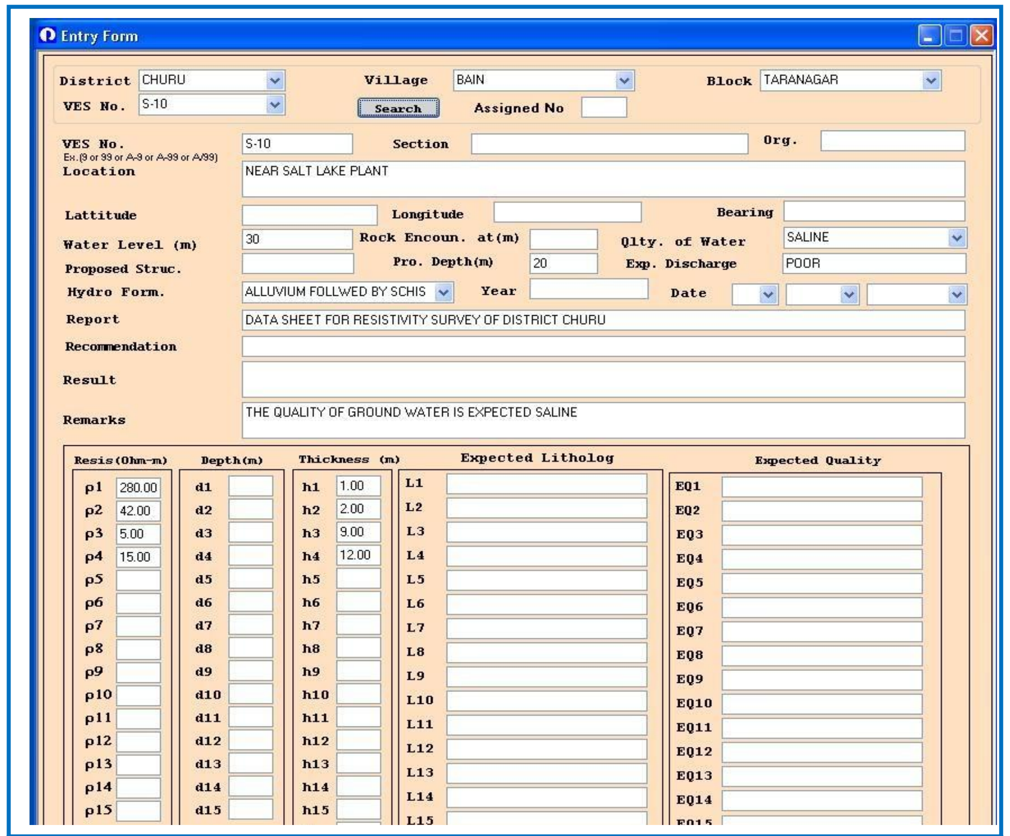


Fig.6: A snap shot of Geophysical Data Entry Form

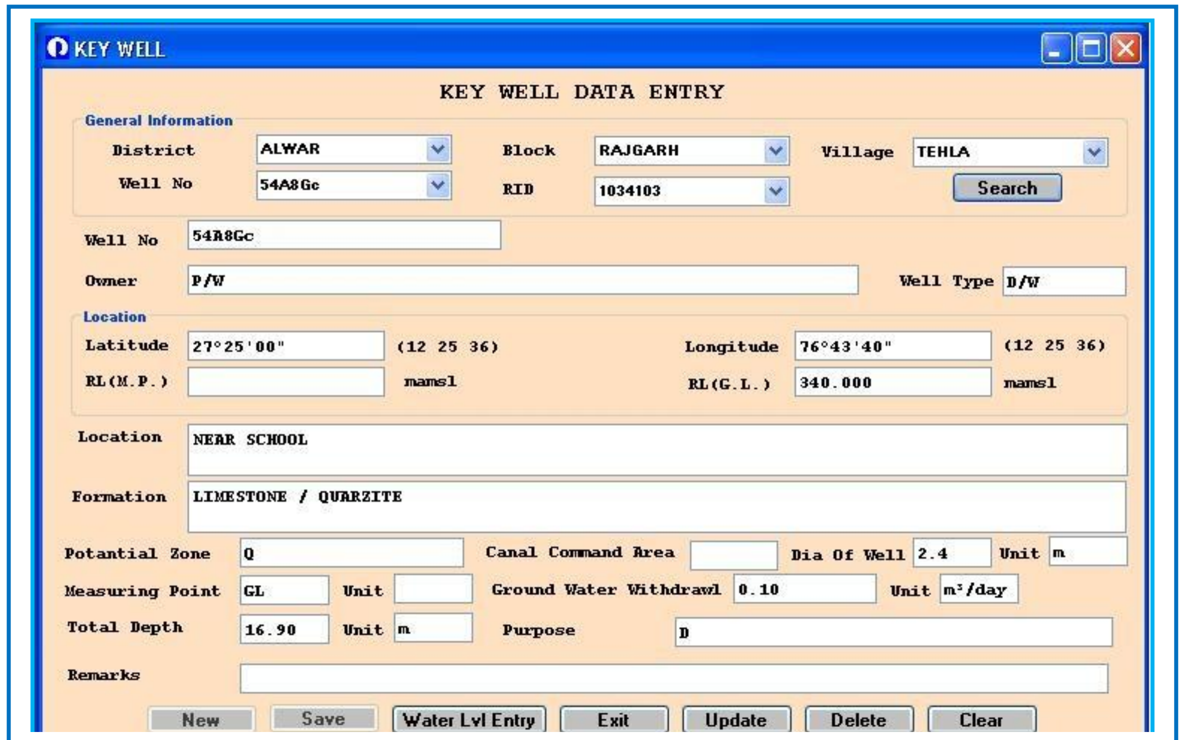


Fig.7: A snap shot of Water Level Data Entry Form

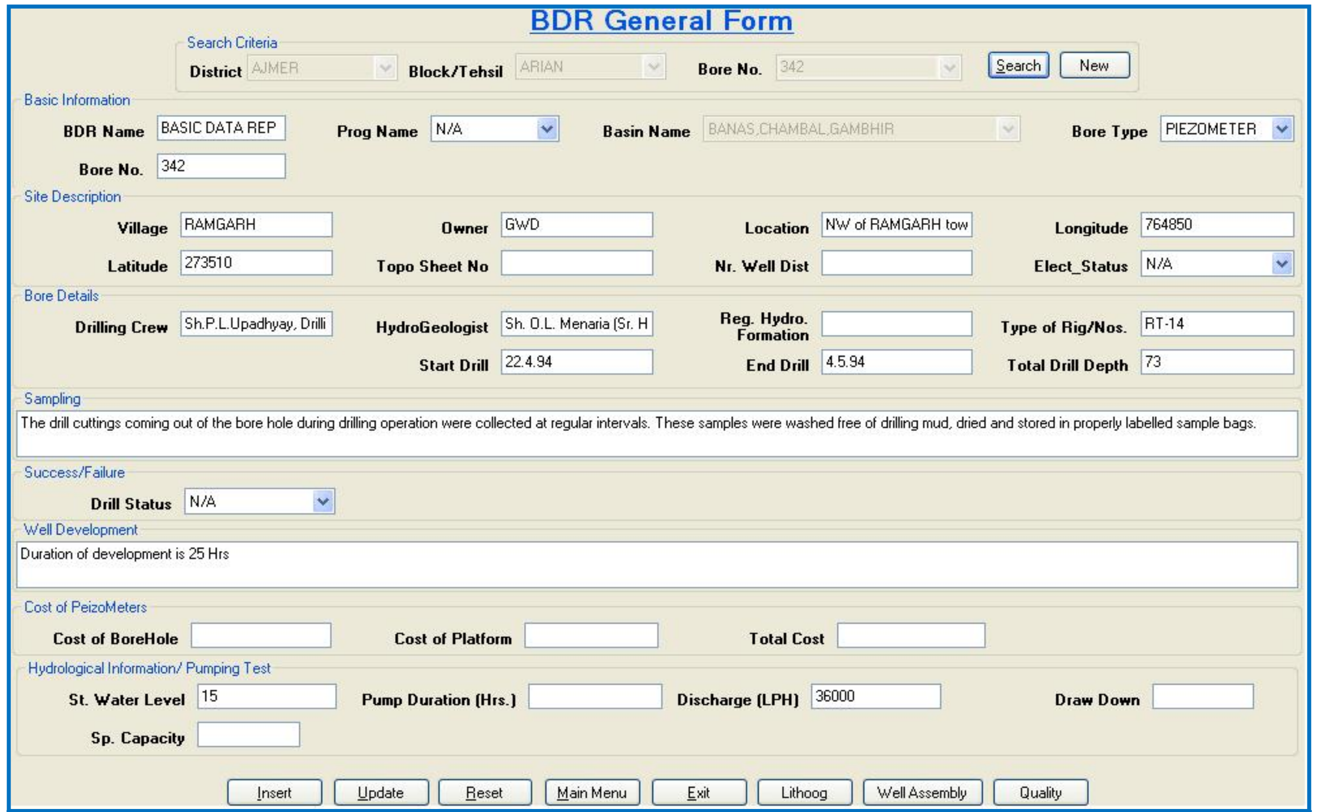


Fig.8: A snap shot of BDR General Form

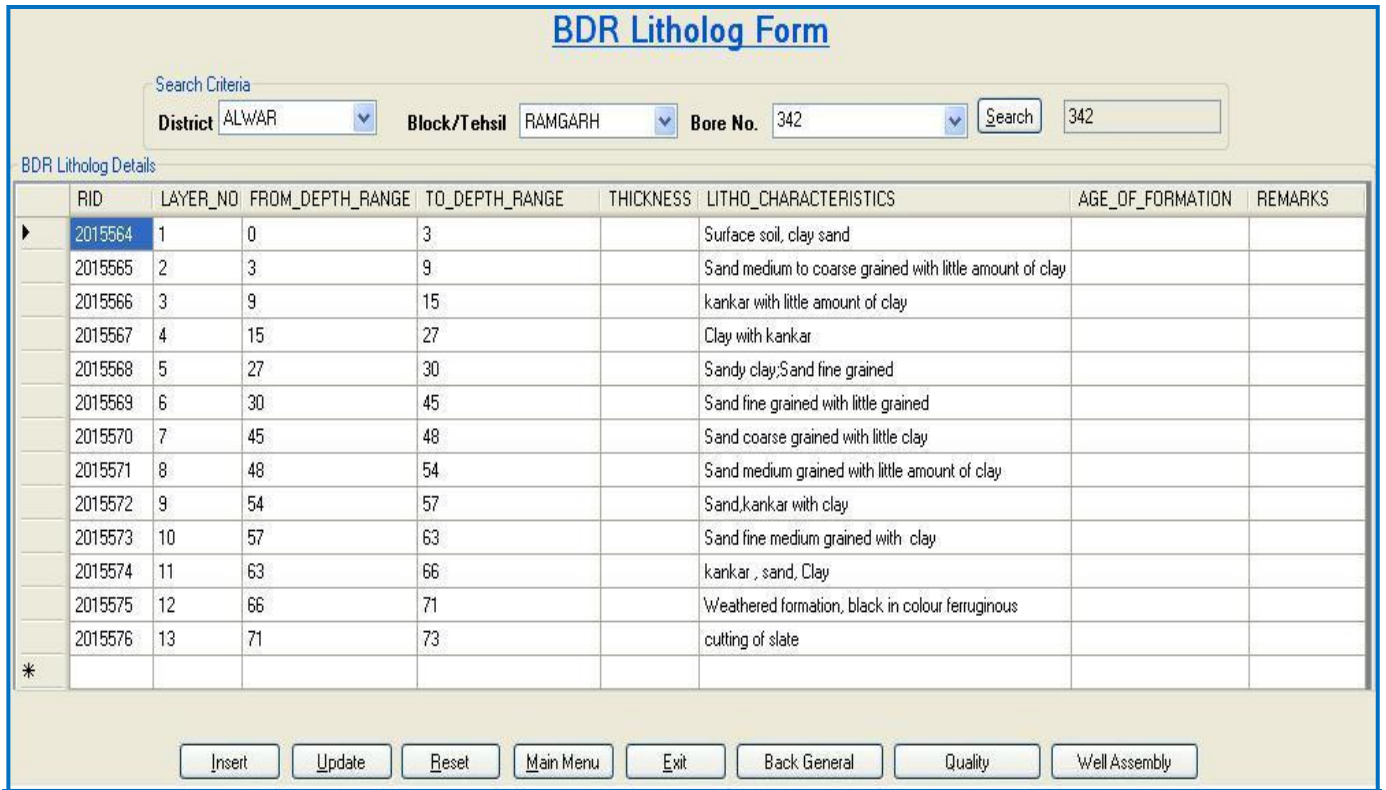


Fig.9: A snap shot of BDR Litholog Form

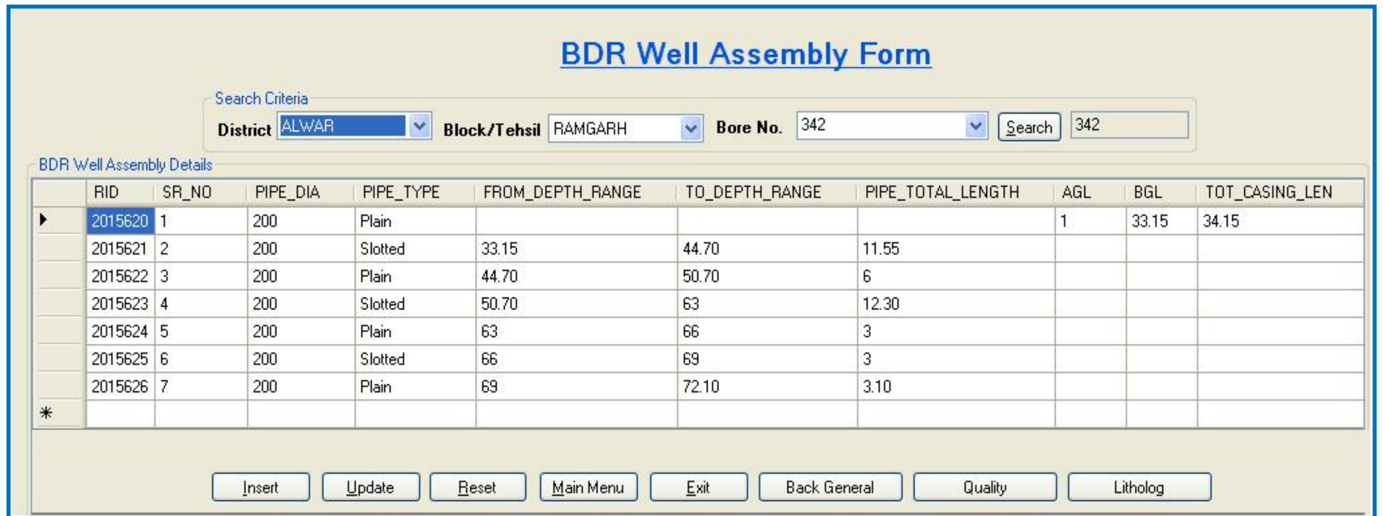


Fig.10: A snap shot of BDR Well Assembly Form

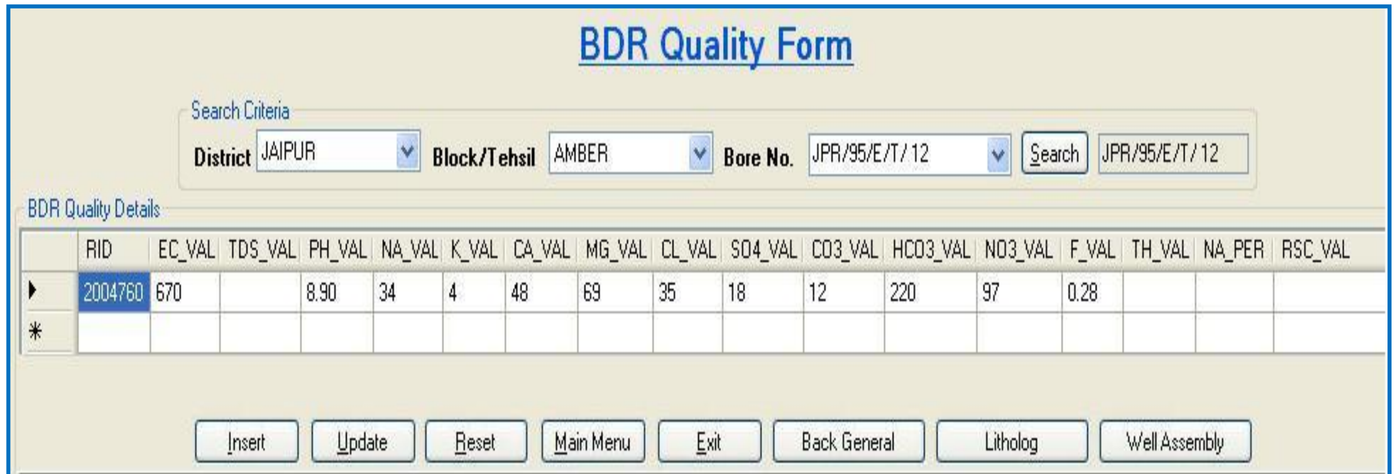


Fig.11: A snap shot of BDR Quality Form

Data Validation

Data validation ensures that every data value is logically correct and accurate. Rolta designed data validation into the application by using database constraints. Following two types of data validation, were mandatorily incorporated into the system:

- Data type validation
- Range checking

Data type validation verifies the entered data as to whether" It is alphabetic string?" or " Is the number numeric?" As an extension of simple type validation, range checking ensures that the provided value is within allowable minimums and maximums.

Rolta had incorporated checks in the database for data entry process to avoid

- Duplication of the records,
- Unnecessary spaces,
- Value ranges,
- Sample Year,
- Sample Period,
- Above Ground Level,
- Below Ground Level,
- Lithological thickness range, etc,

so that the system does not allow error records and also displayed the message to operator if there were duplicates and the matching record, so that operator could confirm by checking the data.

Report Generation

To bring these raw entered data into a presentable format, Crystal report was used. This report allows users to graphically design data connection(s) and report layouts. Crystal reports had been generated after incorporating all the hardcopy data entry in oracle data base and migration of the soft copy into oracle was complete. After data validation and QC/QA, the designing and programming was made using .net technology for the development of crystal reports.

Crystal reports were designed in such a way that exact replica of the provided hard copy could be printed. Different crystal reports have been generated for water quality, water level, rainfall and BDR of GWD.

Some of the representative data of water levels pertaining to key wells is presented in annexure A and recent data of past five years is mentioned them for ready reference.

Similarly, Rainfall data of past 10 years (2000 to 2010) is presented in annexure B, and arranged rain gauge station wise at block level.

2.4. Spatial Data Preparation

As mentioned in the input sources, the Department had several map sets prepared by scientists of GWD from time to time. Rolta had collected several hardcopy maps for the preparation of Geospatial data bases from the concerned State and Central Government Departments and the relevant ones for this project are listed below:

1. Rajasthan State Map (1:10,00,000 scale) 3rd edition 1999 – Source SOI
2. Blue prints of Base Maps with major road networks, railways, administration boundaries up to block level and major water bodies of 33 Districts – Source GWD
3. Blue prints of Hydrogeology Maps of 33 Districts – Source GWD
4. Blue prints of Groundwater Potential Zone Maps of 33 Districts – Source GWD
5. Geological Map and Geomorphology Map - Source Ground Water Atlas of Rajasthan
6. Basin Maps – Source WRD
7. Censuses Data of 2001 – Censuses of India
8. Water Level Data of Ground Water Monitoring Stations (GMS) of GWD and CGWB of 33 Districts – Source GWD and CGWB
9. Water Quality Data of GWD and CGWB for 33 Districts – Source GWD and CGWB
10. Basic Data Report (BDR) of 33 Districts – Source GWD
11. Monthly Rainfall data from GWD and Daily Rainfall data from CGWB – Source GWD and CGWB
12. Geophysical Exploration Data of GWD – Source GWD
13. CGWB exploratory well data – Source CGWB

To convert these maps into a Geographic Information System, these were subjected to a series of steps. The processes of Geospatial database creation are discussed in this section. Broad grouping is:

- Geocoding (assigning geographic coordinates) of non-spatial data related to rainfall, water levels, water quality, geophysical survey, borehole logs so that they can be analyzed together with other spatial datasets,
- Scanning, georeferencing, digitization and attribute assignment to different map themes.

Process Flow Diagram – Spatial Data Preparation

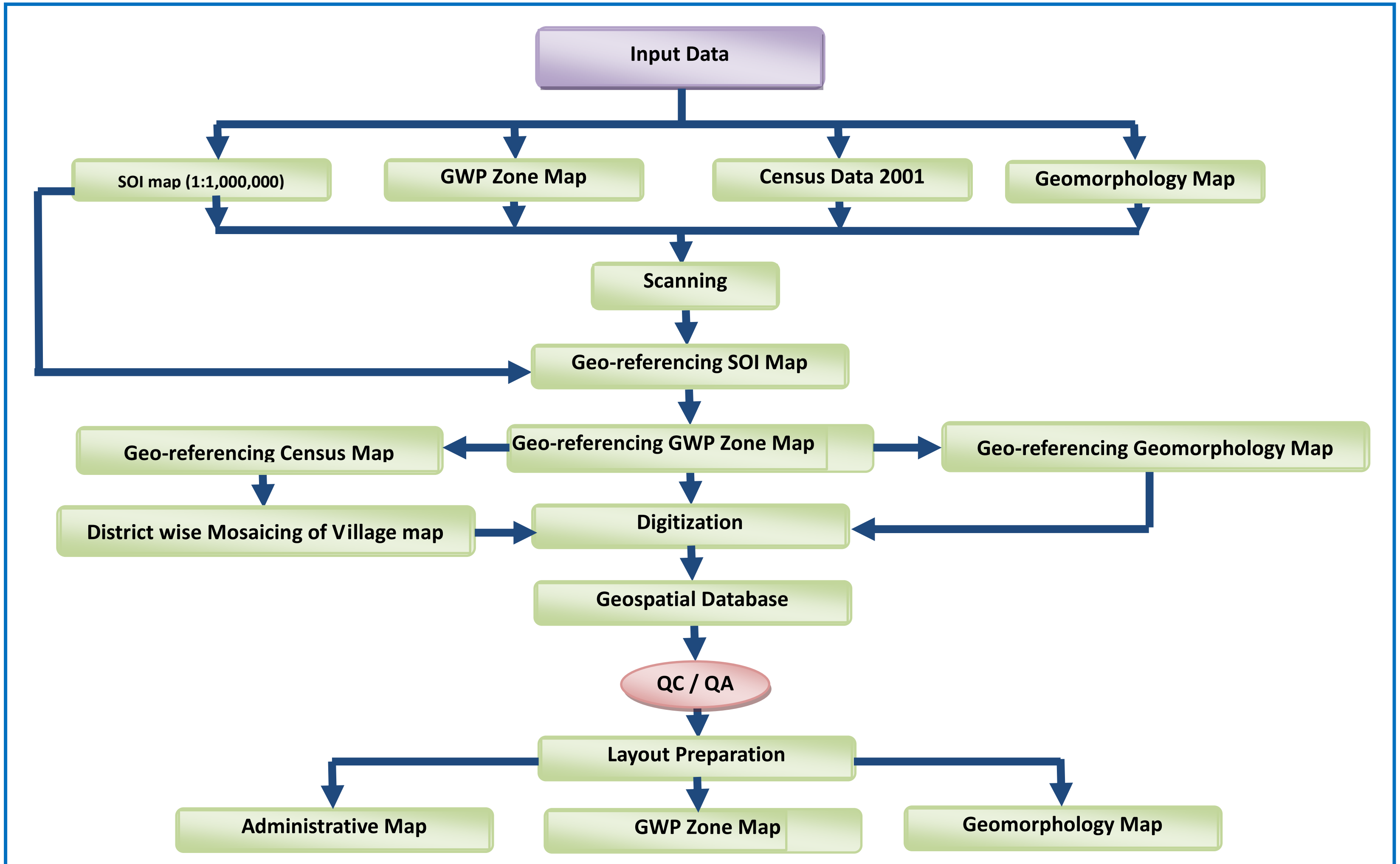


Fig.12: Process Flow Diagram - GIS Creation

Scanning of Hard Copy Maps

All the hard copy maps mentioned above were scanned before taking to next step. The scanning was carried out at 300 DPI resolution, colour mode for maps where details were clearly visible and 600 DPI on 24 bit colour mode was used for damaged or semi-legible maps where boundaries were indistinct. The scanning process followed for the scanning of input hard copy maps is as given below:

- Ensured that the digital scanned maps were free from any distortion/rotation and scale modification etc.
- Checking of scanned maps and verification with original maps was done simultaneously to remove if there were any discrepancies.
- The cleaning of the digital scanned maps was done by removing all unnecessary captured pest images. Raster Image has been de-skewed i.e., aligned perpendicularly and despeckled to remove noise to obtain the desired quality of scanned output. The process ensured that there are no line dropouts or stretched pixels.

Geo-referencing of topographic Maps

The Survey of India (SOI) Maps (State map and other topographic maps) with geographic coordinates printed on the corners of the map were assigned to the scanned SOI Map during geo-referencing process. There were up to 16 ticks / point locations present at grid intersections for which the coordinates was ascertained from the map (Fig. 13). Rolta professionals had carefully selected these ticks for using as Control Points (CPs) and ensured that they are uniformly distributed throughout the map for better output.

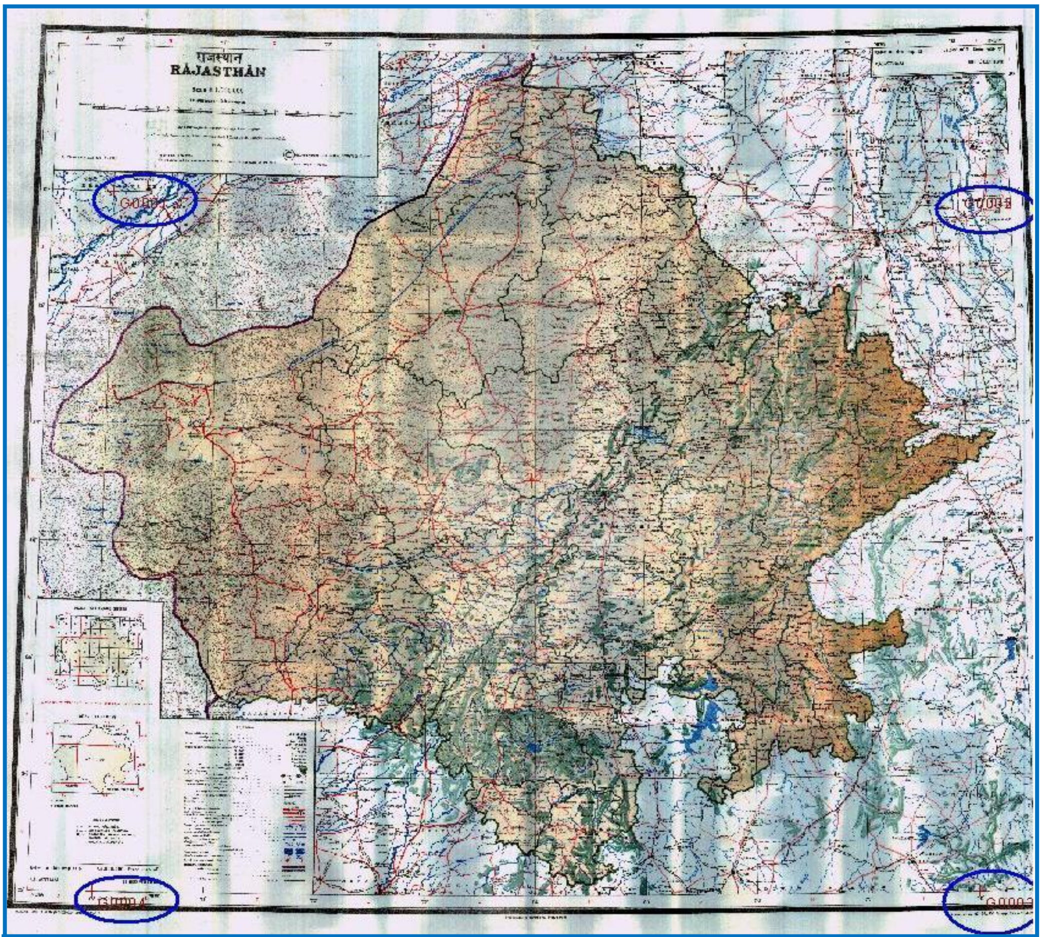


Fig.13: Geo-referenced SOI State Map

Following steps were adopted during Geo-referencing of the scanned SOI map:

- Importing the scanned SOI map in GIS environment.
- Conversion of scanned SOI map into desired file format.
- Finalization of Ground Control Points (GCPs).
- Recording values of coordinates from the map for selected GCP locations.
- Assigning coordinates to corresponding grid intersections (GCP locations).
- Ensuring to achieve the lease RMS error
- Selection of suitable transformation algorithm and projection parameters.
- Development of polynomial transformation and re-sampling of the map at specified pixel spacing and selected projection.
- Polyconic Projection and Datum parameters were considered for geo-referencing the map.

Geo-referencing of Other Maps

The District wise Ground Water Potential Zone Maps, Geology, Soil and Basin Map of Rajasthan have been georectified using geo-referenced SOI Map. Number of CPs on identified permanent features on the maps like road intersection, river, canal, etc. were used for geo-referencing, depending upon the length and area covered in each map sheet. For one secondary map, a minimum of four CPs (uniformly distributed on a map) were taken. As per availability, more than four CPs had been considered in order to achieve better rectification and transformation.

After identification of common Control Points (CPs) in secondary maps as well as in the SOI Maps, the CPs have been numbered as 1, 2, 3, 4 … and their respective X and Y values have been noted down from the geocoded SOI Map (Fig. 14). The GCPs selected for registration of secondary maps have been uniformly distributed so as to achieve least RMS error.

Following steps were adopted during Geo-referencing of the scanned secondary maps:

- Importing the scanned secondary maps in GIS environment.
- Conversion of scanned data into desired file format.
- Finalization of GCPs.
- Recording values of coordinates from the source data (SOI map) for selected GCP locations.
- Assigning coordinate values to corresponding GCP locations on the secondary maps.
- Selection of suitable transformation algorithm and projection parameters.
- Developing polynomial transformation and re-sampling of the raw map data at specified pixel spacing and selected projection.

Projection system

Rolta had adopted a single projection system i.e., UTM Projection and WGS84 Datum consistently for the Geo-referencing of maps throughout the project for all digital thematic maps.

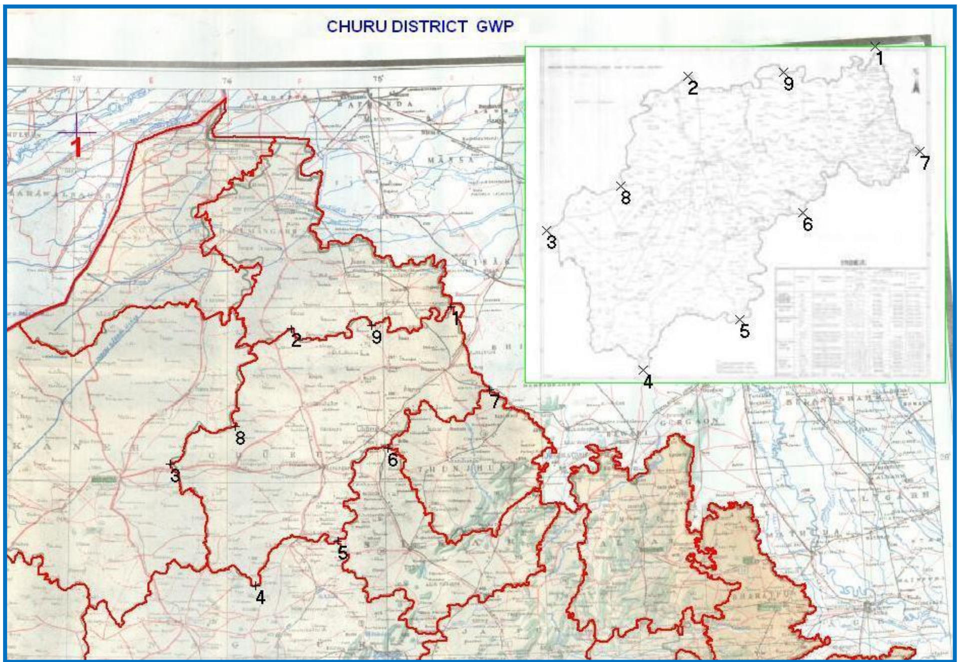


Fig.14: Sample Geo-referenced GWP Zone Map with SOI State Map

Digitization of Geo-referenced Maps

Once the above step of geo-referencing of all maps was completed, features like Administrative boundaries, Base map features (roads, rail, water bodies etc.), Ground Water Potential Zones, Geology, Soil and Basin boundaries were extracted from respective maps using standard GIS Software.

Before initiating the digitization of features, a database design was worked out in which decision was taken as to whether a feature to be captured as point, line or polygon along with the list of attributes to be attached with each feature type. Uniformity in layers, line type, color, units etc. has been maintained during digitization. The line / polygon features are vectorized in such a manner that the original shape of the feature is captured correctly and retained in its original form. While digitization unique IDs has been assigned to each feature and scale factors have been maintained accurately, so that output is in 1:1 source map scale. Hence the Digitized output has been exactly matched with the hard copy maps. Attribute data related to all the maps has been attached to the corresponding features during the attribute data attachment.

Mosaic / Edge Match of Vectorized Map

A seamless geospatial data (administrative map, ground water potential zone map and geomorphology map) for the entire state of Rajasthan was created by edge matching and merging the outer boundaries of each vectorized maps. After edge matching, the duplicate boundaries were eliminated to confine with one single boundary (Fig. 15). The features meeting this boundary was adjusted and cleaned so that dangles, overshoots or slivers were eliminated and feature geometry was maintained. During the edge matching process, it was ensured that the shapes of the features were maintained as the original.

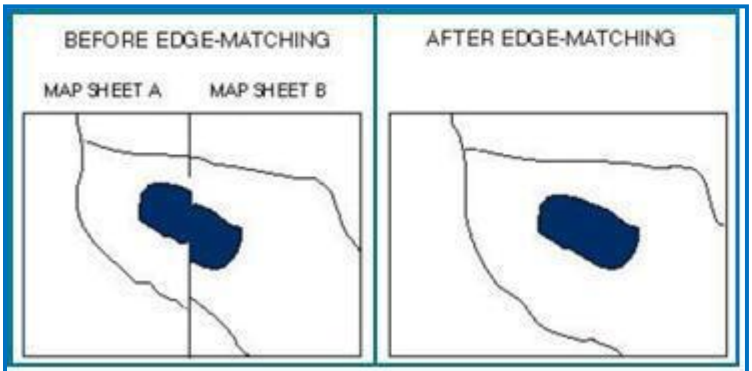


Fig.15: Sample Edge Matching with Adjacent Map

The relative positions of features on both sides of the boundary of maps were maintained. Care was taken where the boundary was represented as double line, like in case of rivers or roads where the double line had to be edge-matched without any slivers or gaps. After the edge matching process, each type of map for each category was prepared into one single map.

Topology Validation and GIS Creation

Topology validation and GIS Creation involved the removal of dangles, undershoots, overshoots, duplicate objects etc. All linear features were confirmed with planarity requirement, i.e., nodes are created at intersection of linear features after validation of geometry.

Generation of Administrative Map

The administrative boundary such as State boundary from SOI State Map of Rajasthan, District boundary from Blue print of Ground Water Potential Zone Map of GWD and Block and Village boundary from Census Map of 2001 respectively was captured.

The scanned Block boundary raster images of Census data was taken to the GIS environment. A seamless District wise data has been created by edge matching and merging the outer boundary of each raster block maps. After edge matching, the duplicate boundaries have been eliminated to confine with one single boundary.

The registration of district wise census data has been carried out using geo-referenced ground water potential zone map with the similar methodology explained in the section earlier and shown here in (Fig. 16 and 17).

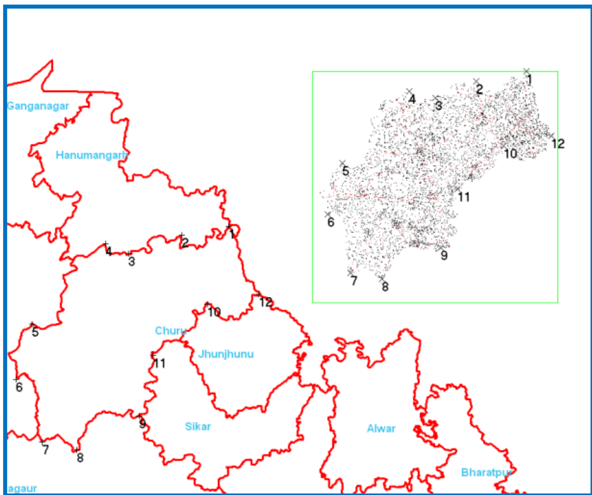


Fig.16: Sample District Census (Total mosaic) before register

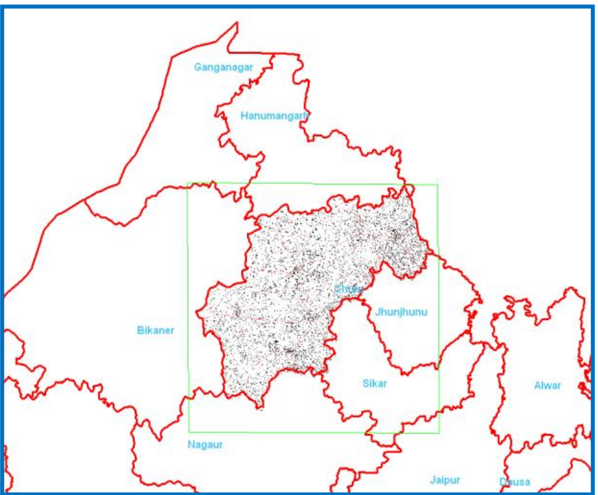


Fig.17: Sample District Census (Total mosaic) after register

Attribute Data attachment

Attribute data for each village was attached with the corresponding geometries. The census code and village name was incorporated in the respective spatial data base during digitization of village boundary. Other attributes such as block name / block headquarter, district name / district headquarter, population details and area had been incorporated in each village. Census code has been set as a primary key for linking the non-spatial data.

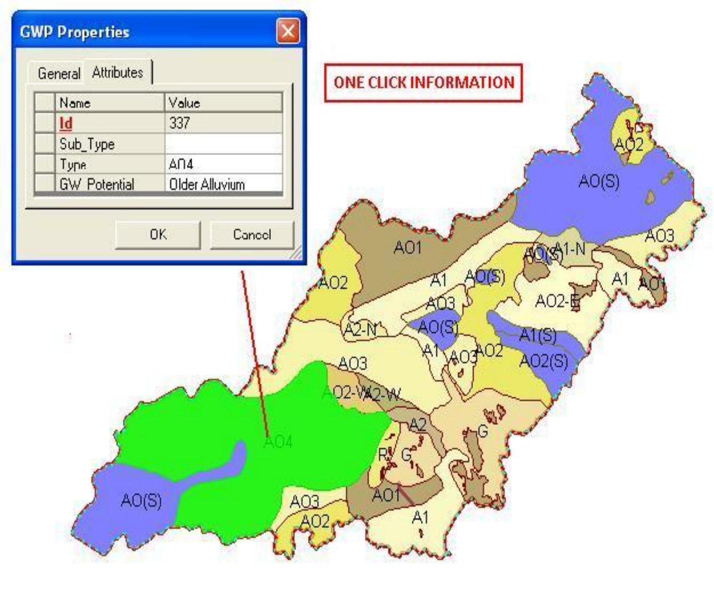


Fig.18: Linkage of Attributes with Spatial Feature

Geo-coding of Geospatial Database

Geocoding was done to bring the non-spatial data (such as water level, water quality, rainfall and BDR data) to a spatial platform. Each record of the non-spatial data contained a village name field which was used to correlate the non-spatial records to corresponding village name created as above. Later once the DGPS survey outputs became available, the water level data was transferred to their new locations using well ID as key field. Rainfall data was attached to Block headquarter points and water quality along with BDR data was attached to village centroids in absence of better reference information.

Preparation of Ground Water Potential Zone and Geomorphology Map

The geo-referenced district wise blue print ground water potential zone maps of GWD and district wise geomorphology maps from ground water atlas of Rajasthan has been imported into the GIS environment / software. These geo-referenced maps have been vectorized into point, line and polygon features. During digitization, minor attribute attachment to the features has been carried out with unique IDs. The heads up manual digitization techniques has been used to get high level of accuracy by avoiding omission / irregularities. The uniformity in layers, line type, color, units etc., during digitization was maintained. The Final output of this process would be to exact a replica of the paper maps in a standard shape (.shp) GIS format.

Global standards for symbology were adopted in the software and assigned to the particular features. The source for creation of symbology used in the ground water potential zone maps and geomorphology maps are from the blue prints of ground water potential zone map of GWD, ground water atlas and SOI state map.

Map Composition and Layout preparation

The final out put map has been created by superimposing all the digitized vector layers captured from SOI State Map - Administrative Map, Blue Print Ground Water Potential Zone Map of GWD – GWP Zone Map and Ground Water Atlas - Geomorphology Map. Rolta has developed routine check up to ensure that all map data elements comply with graphic representation required for digital data. All captured graphics were utilized for the concept of levels / layers, colors, and line codes to differentiate the various features and feature types as per the requirement. For the map indexing also Rolta has used appropriate cartographical information viz; symbols, naming conventions and abbreviations in the final layout. Sample state wide Geology and Geomorphology Maps have shown in the (Fig. 19 & 20)

Quality Control and Quality Assurance

Rolta is ISO – 9001:2008 certified company and we draw our philosophy of Quality upon achieving excellence in quality and consistency, in all products and services, through systematic review of operations. Accordingly, Geospatial data has been produced in the strict accordance with the GWD specifications. Each of the production steps was subjected to scrutiny through Quality Control and Quality Assurance (QC/QA) mechanism to meet the intended objective of outputs.

Some of the QC checks adopted for the project included the following:

1. Physical and logical accuracy of features captured.
2. Missing features
3. Interpretational errors
4. Edge matching of features across two adjacent map sheets,
5. Duplicate features through graphical verification
6. Undershoot and overshoot errors by Graphical QC routine developed.
7. Topological cleaning by using QC routines.
8. Attribute information against tables for attribute correctness
9. Verifying the database to graphic relationship
10. Verifying final Deliverables

Rolta had 4 levels of QA-QC mechanism as mentioned below:

1. **Automatic Check by using Software:** Rolta had used automatic software based checks for systematic errors. This software helps to reduce time in QA-QC and this has also delivered very good results.

2. **Manual check by Qualified Professional:** A plot of the map was taken and checked thoroughly manually. The errors, if there were any, pointed out by quality team were incorporated in the maps.
3. **Final Editing:** The Team leader, who has checked the maps on the computer, has to do the final editing.
4. **Client's feedback:** was also given due weightage and the modifications suggested by them were also incorporated.

Acceptance of data:

Once the data was entered for non-spatial tables and map digitization along with attribute assignment was completed, the same was shared in printed form with RGWD. RGWD in turn shared the outputs with its hydrogeologists who were either involved in collection of field data or had prepared the maps. The feedbacks received from them were recorded and attended to one by one. The final database thus was ensured that the maps are not only correct with input maps but also had been verified by client's team.

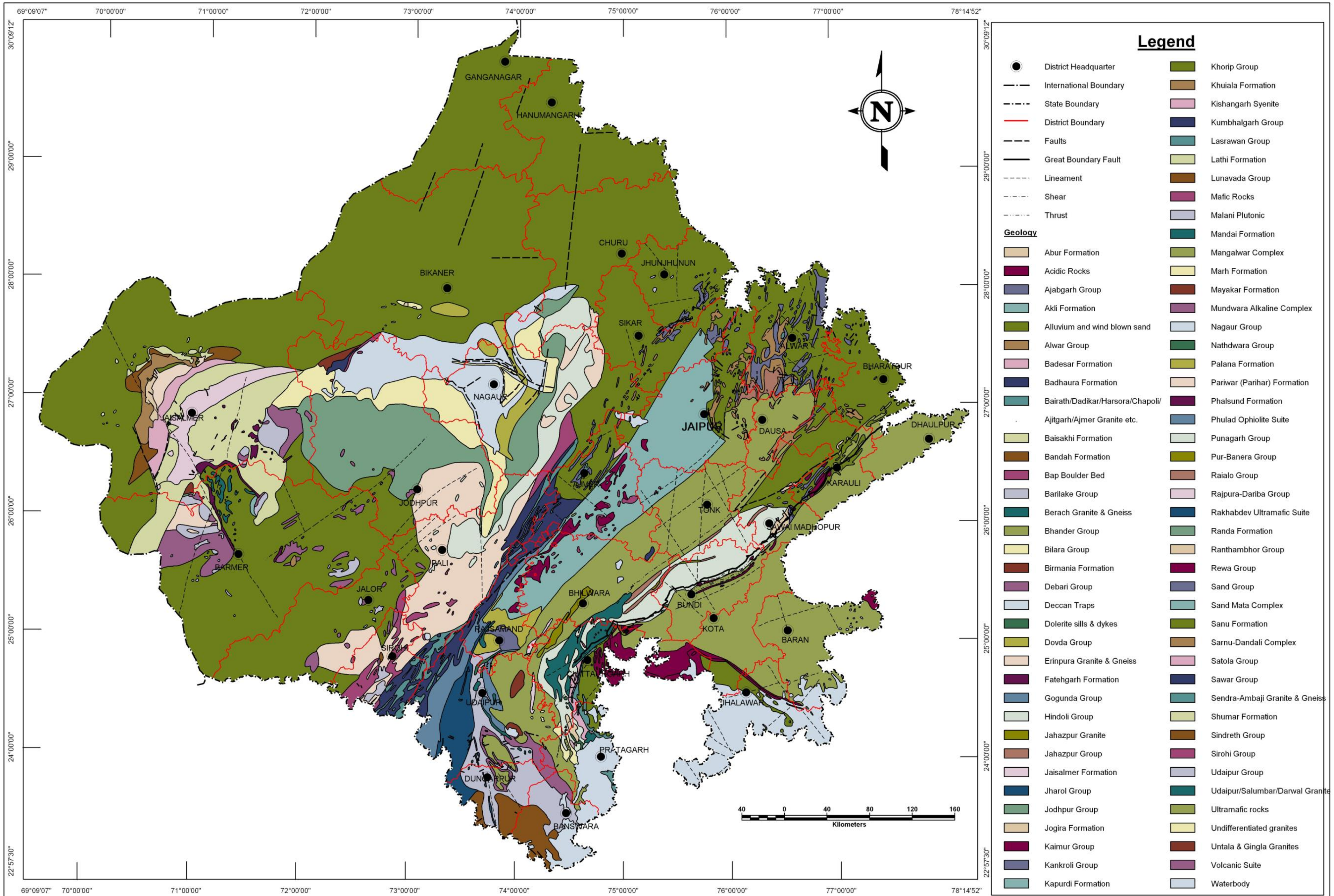


Fig. 19: Geological Map of Rajasthan

Source: Geological and Mineral map of Rajasathan - GSI
District Resource Map - GSI

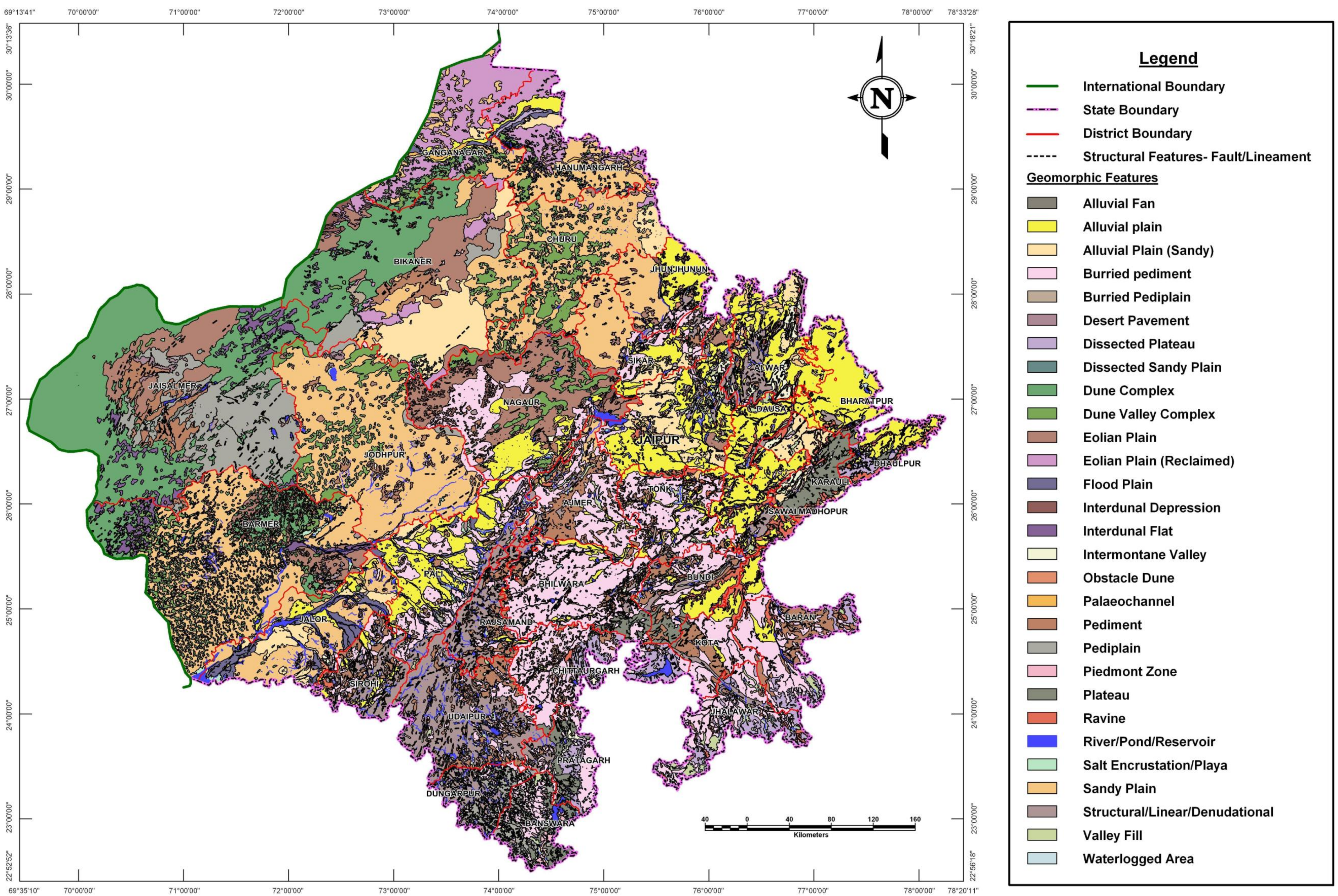


Fig. 20: Geomorphology Map of Rajasthan

Source: Ground Water Atlas of Rajasthan - SRSAC and GWD

2.5. Final data layers

Following the above approach, the data was organized into different feature types (point, line and polygons) and thematic layers. The important ones are given in the table 2.2, below. The data was arranged basin wise, aquifer wise and administrative boundary wise for different analytical purposes and from a presentation perspective.

Table 2.2: Final Data Layer

S. No.	Layer Name	Type	Feature Type
1	International Boundary		Line
2	State boundary		Polygon
3	District boundary		Polygon
4	Block Boundary		Polygon
5	Town boundary		Polygon
6	Village Boundary		Polygon
7	Gram Panchayat Boundary		Polygon
8	District Headquarter		Point
9	Block Headquarter		Point
10	Roads	National Highway	Line
		State Highway	Line
		Other Roads	Line
11	Railway	Broad Gauge	Line
		Metre Gauge	Line
		Narrow Gauge	Line
12	Streams		Line
13	Water Bodies	Pond/Lake/Reservoir	Polygon
14	Canals		Line
15	Major River Basins		Polygon
16	Kantli and Ghagar sub-basins		Polygon
17	Geology		Polygon
18	Geomorphology		Polygon
19	Structural Map	Fault	Line
		Lineament	Line
		Shear	Line
		Thrust	Line
20	Ground Water Monitoring Stations	Piezometers (RGWD)	Point
		Dug wells (RGWD)	Point
		Dug wells(CGWB)	Point
		Tube wells (RGWD)	Point
		Tube wells (CGWB)	Point
		Dug cum bore wells (CGWB)	Point
21	Exploratory wells	RGWD	Point
		CGWB	Point
22	Geophysical Survey locations	RGWD	Point
23	Water table elevation map (Pre Monsoon -2011)		Line
24	Depth to Water Table (pre-monsoon 2011)		Line
25	Water Quality Contour Map (Electrical Conductivity)		Line
26	Water Quality Contour Map (Chloride)		Line
27	Water Quality Contour Map (Floride)		Line
28	Water Quality Contour Map (Nitrate)		Line
29	Aquifers	19 aquifers + Hill + Forests	Polygon
30	Basin wise Aquifer Isopach maps (Unconfined aquifer)		Polygon
31	Basin wise Aquifer Isopach maps (Confined aquifer) - 1		Pdf
32	Basin wise Aquifer Isopach maps (Confined aquifer) - 2		Jpeg
33	Water table elevation map		Line
34	Saline Areas		Polygon
35	Topography (Digital Elevation Model)		Tif
36	Rangauge stations	CGWB	Point
		GWD	Point
37	Isohyetal map (year 2010)		Polyline

2.6. Aquifer delineation and 3D mapping

In the past, most ground water studies were conducted on area specific basis like surface watershed or were limited to boundaries of the administrative units that have generated limited information on regional geology, hydrogeology and ground water chemistry. These facts underscore the need for detailed study of the aquifer systems in the State of Rajasthan. Therefore, an exercise has been taken up for aquifer system analyses of the major aquifer systems to delineate the sub surface disposition of water bearing formations. This provides much needed information for aquifer management, planning and development of the ground water resources in the State.

The aim of the proposed Aquifer Mapping exercise is to define the sub-basin wise aquifer disposition, aquifer geometry, type of aquifers, water levels, hydraulic characteristics, and geochemistry of major aquifer systems which will form the base for planning and management of ground water resources. Various activities and steps undertaken for the aquifer mapping are briefly discussed below;

1. Preparation of administrative map upto village level of the State,
2. Preparation of drainage map with basins and sub-basins,
3. Preparation of geological map of the State,
4. Delineating and defining major aquifer systems in Rajasthan considering hydro-geological properties of the formations,
5. Collation and compilation of existing exploration data for analyzing the sub surface variations with vertical and lateral variation,
6. Collation, compilation and analysis of geophysical sounding data,
7. Further subdivision into various rock type / litho-units based on hydrogeological characteristics and order of superposition,
8. The aquifer delineation for Consolidated / Semi-consolidated formation and Un-consolidated formation,
9. Development of multi layered model for entire river basin depicting various aquifer systems,
10. Intersection of the aquifer thickness with water table elevation map to define saturated thickness of aquifers,
11. Preparation of 3D models, cross sections, panel diagram/ fence diagram, Isopach maps depicting aquifers including weathered / fractured zone in hard rock areas,

To develop these models and sections the data of ground water exploration, collected/received from GWD and CGWB is used, after it is analyzed, synthesized and reclassified manually after giving due consideration to hydro-geological aspects.

After preparation of data in software, and analyzing three dimensional dispositions of aquifers and their interrelationships, the intricacies in the subsurface and their location were noted down. The same were further reviewed with other published reports available with GWD and Rolta. Judicious decisions were taken in light of prevailing scenario and necessary modifications were made in defining aquifer disposition while presenting data in cross sections maps, spread across the basin.

While developing contours, 3D models, sections, etc. different interpolation techniques are used by the software to generate the outputs given in the subsequent chapters. Some of the techniques are detailed below.

2.7. Aquifer system Conceptualization

Once the exploratory wells drilled in a particular basin are shortlisted, they are simplified in a step by step manner by interpreting the driller’s findings of well material into lithostratigraphic columns. After the important formations are identified, then the next step is to overlay the lithologic boundaries with water table information of 2010 pre-monsoon levels (as derived from interpolation of monitoring well data at the exploratory well location) and identifying the actual saturated thickness in each well. This actually is the key step of all and finally leads to the actual aquifers in the area of study. Help from published reports and maps, was also taken in order to arrive at final aquifers. In some areas, a multi-aquifer system exists which is given due importance in the interpretations.

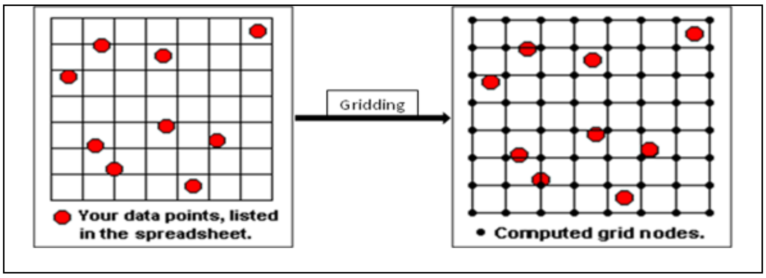
The interpreted lithologs are then ingested into Rockworks software for preparation of 3D maps and verification of the interpretations. One more step of refinement of aquifer interpretations is done and any changes in if required for achievement of lateral connectivity and contiguity of aquifers is addressed.

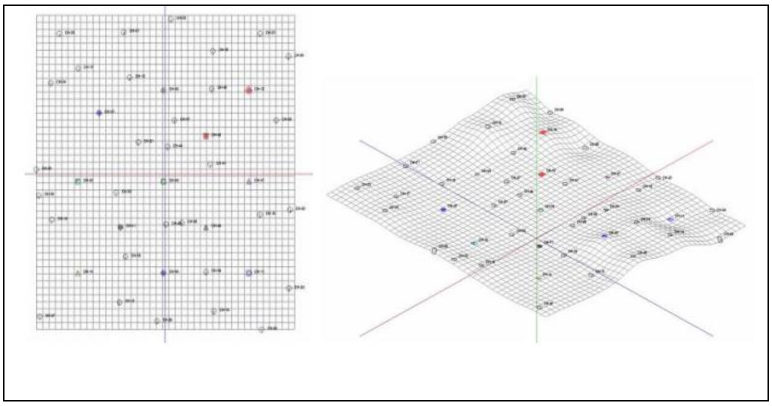
2.8. Presentation techniques

2.8.1. Contour mapping through gridding

Gridding is a process in which scattered, spatially-distributed data can be transformed into a continuous array or grid of numeric values. Data to be gridded can represent anything from topographic elevations to water quality parameters such as Electricity Conductivity or chloride etc., as long as the original data points have location coordinates (X and Y) and a measured "Z" value (like, elevation, depth or concentration. The locations coordinates must be in a Cartesian coordinate system.

It is also possible to create grid models of stratigraphic surfaces and aquifer surfaces using gridding process. Following picture displays a grid model. It is an array (grid) of imaginary lines that overlay the source data points. The images below show scattered borehole locations and an extrapolated grid model, displayed in plan view and as a 3D surface.





In the process of gridding, the program assigns a value to the grid line intersections, called grid nodes. A grid file is the computer file of numbers that contains the results of the gridding process. It contains a listing of the X and Y location coordinates of the regularly-spaced grid nodes and the extrapolated Z value at each node.

The program offers several methods to do this interpolation of a given data. Each operates differently, and each has strengths and differences (See "Gridding Methods" below).

Methods of interpolation:

There are several Methods to interpolate data of which **Inverse-Distance** interpolation method was adopted that uses a weighted average approach to compute node values.

Once regularly spaced gridded values are obtained, they are then converted into equal value regions or into contour/isolines to give best presentation of results.

The maps that were prepared using this approach are:

1. Depth to water table
    a. Average of pre-monsoon from year 2000-2009,
    b. Pre - and post - monsoon water table depth in year 2010

2. Water table change maps (post- to pre- monsoon in 2010),
3. Ground water quality maps (for EC, Chloride and Flouride),
4. Final isopach maps for different aquifers in the area and
5. Depth to bed rock map

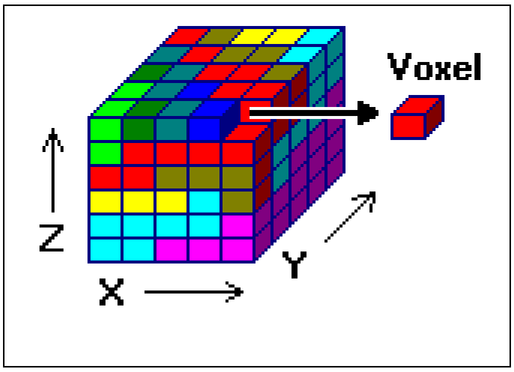
2.8.2. Isopach computation and 3D mapping using solid modeling

Voxel based approach

Solid modeling is a true 3-dimensional gridding process, in which a solid modeling algorithm is used to extrapolate G values for a fixed X (Easting), Y (Northing), and Z (elevation) coordinates. The G values can represent geochemical concentrations, geophysical measurements, or any other down hole or subsurface quantitative value.

The model tool creates solid models from X, Y, Z, and G data. It creates solid models from lithology data in the respective data tabs.

Once it knows the dimensions of the study area, the program divides it into three-dimensional cells or "voxels," their dimensions are automatically determined; alternatively, they can be user-determined. Each voxel is defined by its corner points or node. Each node is assigned the appropriate X, Y, and Z location coordinates according to its relative placement within the study area. A fourth variable, "G", which can represent grade of ore, Lithology, etc., here it may be the aquifer, is estimated based on the G value of the given data points.



There are several methods to perform the 3-dimensional interpolation of the data. Each operates differently, and each has strengths and differences

- **Inverse-Distance Weighting:** This method uses the Inverse-Distance modeling algorithm, which uses a weighted average approach to compute node values. This particular method offers user control over the horizontal and vertical weighting of the control points, as well as all-point versus directional searching for the control points to use in modeling.

Aquifer 3D models and fence diagrams were prepared using the above approach. It would be appropriate to mention here that a due representation to the 3D analysis is only possible when the data is viewed in computers as the model facilitates rotation, tilting and playing around with unique features like separation of horizons vertically and viewing three dimensional behavior of each layer individually, assigning colours of our own choice etc. whereas, hardcopy presentation of the same does not give that flexibility of impact.

2.8.3. Cross sections

The cross sections were largely prepared using manual methods and then converting them to electronic form using computers. The software had limitations in handling hydrogeologic boundaries while preparing cross sections and also the pinch and swell behavior of aquifers in alluvial formations were not being given due appreciation in software. Therefore, interpreted lithologs in Rockworks were plotted on paper and the aquifers materials in adjacent wells were connected using traditional methods and then the hydrogeologic boundaries (like hills) and major structural elements (faults and shear zones) were presented in cross sections by referring to other sources of information and indications present in the well data.

2.9. Dynamic Ground Water Resources Assessment

In the current project, the approach and methodology adopted for aquifer wise dynamic ground water resource assessment in Rajasthan is based on application of GIS based analysis within the framework of GEC 1997 methodology with value additions. The methodology followed by CGWB in the year 2011 for dynamic ground water resources computation of the country was also refereed. One time dynamic ground water resources was computed for the base year 2010 using the water level fluctuation for pre and post Monsoon water levels for the year 2010 only from GWD and CGWB GMS. Attempt was made to overcome the constraints and bottlenecks inbuilt in the GEC methodology through a semi automated process based approach to minimize the computational and assumptive errors.

The broad activities and steps followed are given below;

- ✓ Generation of a unified aquifer map of Rajasthan in GIS platform by delineating various aquifer units as exclusive map layer and integrating all the spatial / temporal ground water related data with aquifers
- ✓ Dynamic resources assessment was carried out for the base year 2010 and accordingly the ground water level fluctuation data of the observation wells of CGWB and GWD for year 2010 was considered
- ✓ Primary validation of water level and fluctuation data was made to eliminate any erroneous data, outlier / inliers or Non representative data. The pre and post water level fluctuation for the year 2010 was observed to vary between -15 to +64 m

- ✓ Further, the data was subjected to secondary validation using GIS based statistical tools in spatial domain using parametric methods to identified outliers or extremes in trends, after confirmation, the same was filtered from the data base to represent the true field conditions. The negative fluctuation values exceeding -2m was observed at isolated points and hence all such values were filtered, similarly it was also observed that positive fluctuation values exceeding 15m are very few in number and are at isolated points which are Non representative or erroneous data and hence those data were also filtered and eliminated from the computation of dynamic ground water resources
- ✓ GEC recommends a lumped approach of arithmetic averaging of water level fluctuation in spatial domain to arrive at single fluctuation value for the entire assessment unit. The arithmetic averaging of water level in spatial domain is constrained by the inherent assumption of linear variation in water level in space, which is strictly not valid due to in-homogeneities and anisotropy and hence do not represent the true ground condition. At the same time occasionally the impact of local stresses are ignored
- ✓ In the present exercise the distributed approach for spatial interpolation of water level was adopted through geo-statistical tools in GIS platform, the water level and fluctuation was computed on a regular grid of 250 m x 250 m which was then integrated to arrive at the fluctuation of individual aquifers units. The geo-statistical technique has advantage of incorporating spatial correlation through variogram models which overcomes the problem of in-homogeneities and outliers to larger extent. This value addition was brought the entire assessment more closer to the ground reality and eliminated any spatial discontinuities
- ✓ In general, the GEC recommended Water level fluctuation method was adopted for computation of rainfall recharge except in those aquifer units for which negative fluctuation was observed
- ✓ In the aquifer units for which negative fluctuation were observed, Rainfall Infiltration Method was adopted for computation of rainfall recharge
- ✓ Using the data of water level fluctuation, Rainfall, draft, rainfall infiltration factor and specific yield, Monsoon and Non Monsoon recharge was computed for each individual assessment unit within the 19 principled aquifer *(Assessment unit wise Specific yield and Rainfall Infiltration Factor (RIF) values are given in the annexure – C)*.
- ✓ In some of the aquifer segments where above data was not available, area weighted apportioning was done aquifer wise using the GIS tools

- ✓ The recharge from other sources such as form return seepage from surface water irrigation ground water irrigation, canal, tanks and ponds etc was used as lumped values as provided by the GWD, however aquifer wise are weighted apportioning was done wherever required
- ✓ Monsoon rainfall recharge using WLF Method was calculated after normalization with long term normal Monsoon rainfall
- ✓ Percentage of difference between normal rainfall recharge (RIF Method) and normal rainfall recharge (WLF Method) for Monsoon season was calculated to consider the accepted value
- ✓ To arrive at the total dynamic ground water resources availability, the rainfall recharge is added with the recharge from other sources both for Monsoon and Non Monsoon season for respective aquifer units
- ✓ The dynamic resources were computed for saline and fresh water separately
- ✓ The aquifer wise dynamic resources assessed through above process were further apportioned on area weighted basis for different hydrological and administrative boundaries (up to village level)

Limitations and Constrains – Dynamic

While estimating ground water recharge it is essential to proceed from a good conceptualization of different recharge mechanisms and their importance in the study area. Besides this conceptualization the objectives of the study, available data and resources, and possibilities of obtaining supplementary data should guide the choice of recharge-estimation methods. In addition, the inherent temporal variability of recharge has important implications for the measurement techniques adopted.

- ✓ Considering the data availability on different aspects for resource assessment and assuming a reasonably good distribution of monitoring network, the seasonal water level changes observed in the field represents the most dependable and consequential of all the inputs and output to the ground water reservoir. Hence in the present case in general the water level fluctuation approach was adopted for computation of monsoon recharge, recharge from other sources was further added to arrive at the total replenishable recharge to ground water. The choice of the method is also guided by data / parameters available as well as the recommended protocol by Government of India
- ✓ The local, intermediate and regional recharge components are very important while assessing the resources. Due to general data limitations, as far as possible these components was taken from standard literature and previous references of GWD / CGWB reports while

computing the resources using GEC97 methodology. Some of which relates to seepage from tank and canals, irrigated fields, return seepage from ground water and surface water irrigation , etc which was used as lumped values as provided by the GWD, however aquifer wise apportioning was done on area weighting approach wherever required

- ✓ While computing the rainfall recharge by water level fluctuation method, GEC recommends a lumped approach of arithmetic averaging of water level fluctuation in spatial domain to arrive at single fluctuation value for the entire assessment unit. The arithmetic averaging of water level in spatial domain is constrained by the inherent assumption of linear variation in water level in space, which is strictly not valid due to in-homogeneities and anisotropy and hence do not represent the true ground condition. At the same time occasionally the impact of local stresses are ignored
- ✓ In the present exercise the distributed approach for spatial interpolation of water level was adopted through geo-statistical tools in GIS platform, the water level and fluctuation was computed on a regular grid of 250 m x 250 m which was then integrated to arrive at the fluctuation of individual aquifers units. The geo-statistical technique has advantage of incorporating spatial correlation through variogram models which overcomes the problem of in-homogeneities and outliers to larger extent. This value addition has brought the entire assessment more closely to the ground reality and eliminated any spatial discontinuities.

2.10. Static Ground Water Resources Assessment

The methodology recommended by GEC for assessment of static ground water reserve is as below:

Static Ground Water Reserve (Cubic meter) = Thickness of the aquifer below the zone of water level fluctuation (m) x Areal extent of the aquifer (m^2) x Specific yield.

The parameters required in the assessment of static ground water reserve are areal extent of the aquifer, the thickness of the aquifer below the zone of fluctuation and specific yield.

The two important parameters are saturated thickness below the zone of fluctuation and specific yield. One of the crucial steps in the parameter estimation is working out the saturated thickness below the zone of fluctuation, the zone of fluctuation is considered as the deepest water level or pre-monsoon depth to water level of the year 2010.

In the present exercise, the thickness of aquifer below the zone of fluctuation was derived separately for alluvial as well as for hard rock aquifers based on the results of aquifer mapping. The alluvial formations generally represent a multi-aquifer system and hence essentially the thickness of granular zone need to worked out for different aquifers. In the present case the total thickness of saturated zone has been obtained from the spatially interpolated lithologs up to the depth of basement encountered in different areas. However, in the areas where the basement has not been encountered as per the available data the total saturated thickness was obtained up to the available depth of exploration or maximum 250 meter below ground level. In the aquifers made up of semi-consolidated and consolidated formations, the total thickness of saturated zone was worked out up to the total depth of 150 meter, considering that below this depth the possibility of encountering water yielding fractures are very less. This postulation is supported by the data of ground water exploration carried out in the state by various organizations in different aquifers underlain by hard rock. It was observed that in general the probability of encountering water yielding fractures below the depth of 150 meter is very remote.

The specific yield is another important parameter which has far reaching influence on the overall estimation. The readily available data is from the norms as provided in the GEC 97 manual. To further firm the aquifer wise specific yield values a thorough review of available reports / literature was made.

After detailed review of various parameters including specific yield data used against different type of aquifers in the state of Rajasthan and discussions with the State officials following decisions was arrived.

In the alluvial aquifers which are mostly constituted by unconsolidated sediments, the degree of compaction increases drastically with depth and reduces the overall porosity and specific yield of aquifer. In view of this, it was decided that for the aquifer below the zone of fluctuation, the specific yield values may be reduced to 7 % as compared to 10 - 15% used for the assessment of dynamic ground water resources.

The aquifers made up of hard rocks in general lacks primary porosity, the water is stored in secondary porosity produced by the joints, fractures and cracks other than the weathered portion. The degree of fracturing and the secondary porosity reduces drastically with depth and hence the dynamic and more so the static resources are not as potential as in alluvial aquifers. In these aquifers the ground water is mostly restricted to weathered and fractured zones up to limited depth, hence, the differentiation between dynamic and static resources has lost its significance. Keeping this in view, it was decided to take same values of specific yield for different aquifers as recommended by in the GEC norms for the dynamic resources assessment and the values used by the state ground water department for the assessment units. *(Assessment unit wise Specific yield values are given in the annexure –C).*

Limitations and Constrains – Static

The assessment of ground water reserve below the zone of fluctuation is generally based on the understanding of the lateral and vertical disposition of aquifer. The unconsolidated formation generally form multi-aquifer systems separated by aquitard / aquicludes and hence it is required to delineate the granular zones constituting the distinct aquifers. Similarly, the consolidated formations generally forming single aquifer system are made up of weathered / semi weathered and fractured portions of the underlying rocks constitute the aquifer system in the hard rocks. Hence aquifer mapping to establish the aquifer geometry is pre-requisite for assessment of static ground water reserve and total ground water resources availability.

- ✓ In the present exercise, the thickness of saturated aquifer below the zone of water level fluctuation has been taken from the aquifer mapping exercise completed within the project including delineation of aquifer layers, this exercise was carried out based on the limited data of ground water exploration carried available with CGWB and State Ground water Department. No additional data has been generated to fill the data gaps, spatial interpolation in a GIS platform was used suitably for delineating the vertical extent of aquifers
- ✓ In case of alluvial aquifers, the different granular zones (S1, S2 and S3) was identified by clubbing the sand /silt zones arrived from the point data of available litho logs, which has been then spatially interpolated to define the surface and demarcate the aquifer extent within the explored depth. The total thickness of aquifer in unconsolidated formation was arrived by summing up the granular zones
- ✓ The static reserve was computed separately for all the aquifers and depending upon the depth of occurrence, the specific yield values were suitably altered. In case of hard rocks, the thickness of wreathed zone as well as fracture encountered was arrived from the point data of ground water exploration which was then subjected to spatial interpolation to arrive at the effective thickness of fractured zones
- ✓ It is pertinent to mention that all the interpolation techniques was inherent limitations reflected in terms of interpolation errors within certain confidence interval. The interpolation error strictly depends upon the spatial correlation of the parameter being interpolated which is a function of spatial continuity of parameter, in the present case it is either thickness of granular zone or continuity of fractures. In unconsolidated formations the granular zone continuity can be spatially extended with greater degree of reliability and with high confidence interval , however in case of hard rocks, establishing the fracture continuity laterally or vertically has very high uncertainty level and hence the reliability of thicknesses arrived in case of hard rocks is comparatively less. Since , the present exercise is exclusively based on the compilation and integration of exiting data and no fresh data generation was involved, the uncertainty level in arriving the aquifer wise thickness of effective fractured zone is quite high which may lead to overestimation or underestimation of static reserve in case of hard rocks. In unconsolidated formations the assessment of static reserve are more reliable

- ✓ Aquifer mapping is a multidisciplinary approach for establishing the aquifer geometry and characterizing them with storage and transmission properties to qualify as an aquifer. Same geological formation occurring at two different geographical locations may form different type of aquifers. All the data generated through exploratory drilling or geophysical surveys has been integrated and validated with the pumping tests results to finally delineate the aquifer extent / disposition in horizontal and vertical dimensions and their characterization in terms of aquifer parameters,
- ✓ The specific yield values considered in the above estimation for different aquifers was provided by the State ground water department based on the GEC norms, the representativeness and accuracy of specific yield data pertaining to different layers could not be ascertained from the field tests as this was beyond the scope of the work. The inaccuracies in the specific yield data may lead to under or overestimation and hence it is recommended that, field studies may be undertaken to ascertain the accuracies in specific yield.
- ✓ Alternate methods for determination of specific yield such as water level hydrograph analysis using long term time series data, dry balance method, water balance approach etc may also be attempted to optimize the long duration pumping tests usually done for determination of specific yield
- ✓ Strategy planning for exploitation of static ground water resources from any area shall take adequate measures to avoid any adverse environmental impact such as ground water quality deterioration, irrecoverable decline in ground water level, land subsidence , reduced flow / drying up of surface streams / water bodies and dewatering of shallow fresh water lenses / perched aquifers.

2.11. Apportioning of static and dynamic resources at Village level

Approach and Methodology

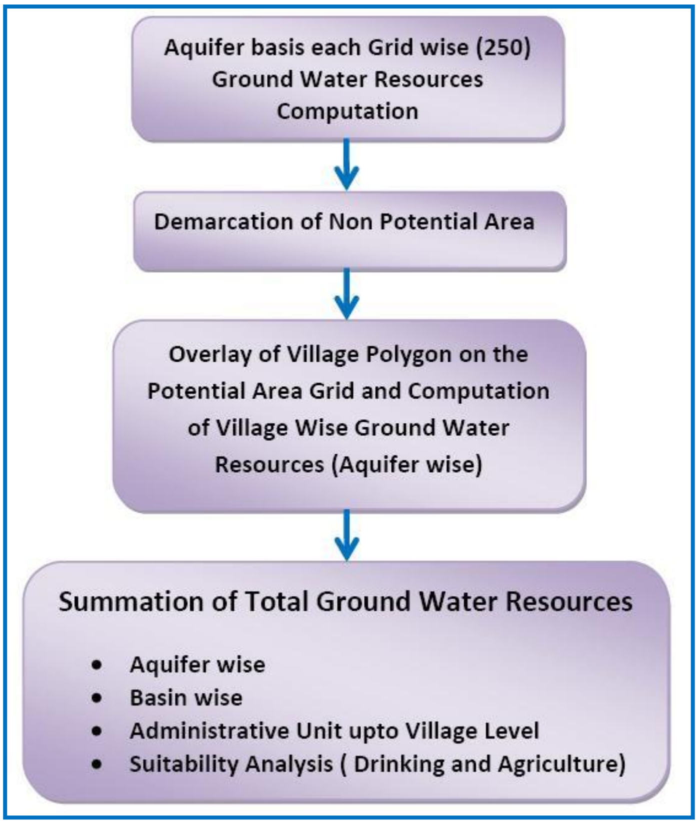
In the present exercise, maiden attempt was made to estimate the ground water resources basin wise adopting aquifer as a unit. Further, endeavor was made to evolve Spatially Distributed Recharge Estimation technique using Geo Spatial tools following the lumped water balance and area apportioning to arrive at the village wise resources. The geo-spatial tools inbuilt in to the standard GIS were used for spatial interpolations of parameters and for various computations. Different maps and their attributes were created in GIS platform to facilitate the estimation in line with the GEC recommendations, the methodology adopted is broadly lumped water balance approach based on the water level fluctuation and saturated zone technique.

In the first step the aquifers were delineated within the basin boundary and subsequently based on the lateral and vertical extent of the aquifer as well as saturated thickness (vertical extent between deepest water level and lower boundary of the aquifer) the ground water resources were assessed separately as Dynamic resources referring to the volume of water available within the zone of fluctuation and Static Reserve considering the lower bound of the aquifer indicating the total thickness. The approach and methodology followed to compute the dynamic and static ground water resources was already presented in previous chapters.

Broadly Water Level Fluctuation Method was adopted considering pre and post monsoon water level data of the year 2010. The area where there is lack of sufficient water level data and area with negative water level fluctuation, in that cases Rainfall Infiltration Method was adopted within the framework of GEC norm to calculate the dynamic ground water resources in a hydrological unit on the basis of aquifer. Similarly static reserve was also calculated on the basis aquifer mapping exercise and aquifer wise saturated thickness was derived by considering the year 2010 pre monsoon water level data.

Various thematic layers used in the present assessment and final to apportion the resources upto the level of villages includes administrative layers like District, Block, Gram Panchayat and finally village layers, excluding the above admin layers aquifer disposition, aquifer wise isopach map, water level fluctuation map, saturated thickness of the aquifer below the zone of fluctuation and the layer of specific yield values attached with the aquifer polygons. In addition, the layers depicting the spatial variation of ground water draft. All these layers were integrated in to GIS and geospatial tools was used for onetime assessment of aquifer wise ground water resources in a hydrological unit (Basin) and then area weighted apportion of the computed resources upto the village level on the basis of was carried out.

In the next step an integrated GIS and statistical analysis approach using Grid based resource apportionment and their further summarization at village level, was developed in fulfilling the unique requirement of resource computation at village level. Demarcation of non potential area (Hilly terrain) was also carried out to exclude from the resources assessment as per GEC norm, however if there are villages having population coming under hilly area still resources was computed. Multiple GIS and Non- GIS software were very effectively used to develop the methodology.



The village wise resources so obtained would form the basis for developing village wise ground water management plans taking in to account the total demand / utilization and availability of ground water and future scope for augmentation.

In addition to reporting the resources, attempt were made to integrate the ground water quality data created as part of this project and assess the available resources in terms of their suitability for different purposes (Human and livestock consumption and agriculture) based on standard norms.

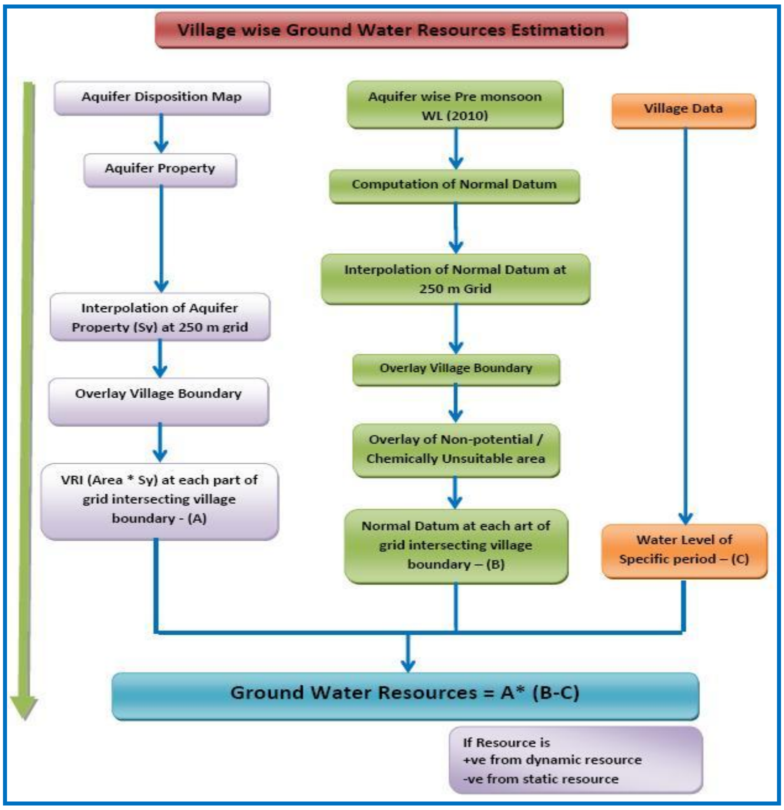
2.12. Computation of Village Resources Index (VRI)

In order to facilitate the assessment of ground water availability at village level by the local community, the Village Resource Index (VRI) was developed in GIS platform combining the aquifer extent, parameters (aquifer wise specific yield) and village area. In view of this it was proposed to adopt a simplified model for assessment of ground water availability in the dynamic zone using lumped water balance approach. The water level fluctuation between the specified periods would reflect the incremental availability of ground water over the period. Aquifer wise pre-monsoon (May / June) water level data for the period 2010 would form the normal datum for computing the dynamic resources. Any increment / decrement with respect to the normal datum would indicate the changes in ground water availability in the aquifer under reference. A distributed approach for spatial interpolation of water level was adopted through geo-statistical tools in GIS platform the water level was computed on a regular grid of 250 m x 250 m which was then integrated to arrive at the water level of individual aquifers units within the village.

Under this project a web based ground water information system has been developed for providing the information to the community on the reserve of their resources in their particular village. In context to this the computed VRI would play a vital role to calculate the reserve with minimum data inputs in a user friendly manner over the web application.

The developed Decision Support Tool (DST) would provide option for entering the village wise ground water level data measured from the wells for different periods. The fluctuation between the defined periods will be computed automatically in the DST. In the next step the Village Resource Index (VRI) already inbuilt in to the DST gets multiplied to the fluctuation resulting into change in ground water storage over the period under reference for the village.

In the backend of the developed application checks were fashioned using aquifer wise pre-monsoon (May/June) water level data and post-monsoon (Oct/Nov) from the year 1984 to 2010 were used for computing well wise minimum and maximum fluctuation which were then interpolated to derive fluctuation at 250 m interval grid. Separate interpolation was carried to arrive in each grid wise minimum and maximum water level fluctuation. This would provide the basis of validation for the input water level entered by the community into the DST.



In addition to the above demarcation of the non-potential area (hilly terrain) and chemically unsuitable area were demarcated in GIS environment. The suitability of ground water quality both for drinking and agricultural purpose were also defined and overlaid over the village polygon to aware the community related to the available water suitability for drinking purpose.

While computing the ground water availability between two specified period, the negative fluctuation in comparison to the normal datum would indicate the over utilization of dynamic resources and contribution from the static zone. Further, the positive fluctuation would indicate increment in the ground water resources in the aquifer under reference. The village wise demand of water for drinking uses was computed based on standard norms so as to allocate the available ground water resources.

The availability of ground water so computed for the village shall form the basis for planning the ground water development and management measures and for developing village wise ground water management plans taking in to account the total demand / utilization and availability of ground water and future scope for augmentation.

2.13. Artificial recharge potential mapping

Artificial recharge is the process by which infiltration of surface water in to ground water system is increased by altering natural conditions of replenishment. Due to ever increasing demand on water resources and depleting water table at alarming rates which ultimately harms the aquifer with respect to quantity and quality. To overcome these problems, artificial recharge of ground water is attributed high importance while preparing strategies of water management.

In this regard, unsaturated zone thickness for each well within alluvial areas and in unconfined aquifer was identified. The data was separated out for each river basin for preparing thickness zone maps. Pre monsoon water level of the year 2010 was taken for delineation of unsaturated zones. As the alluvial areas are having effective porosity to hold and transmit the water these areas may be treated as one of the productive zones for recharge. Out of 15 river basins only 11 river basins were identified where there was ample scope for recharge structure planning.

3. Aquifer Delineation and 3D Presentation

The Rajasthan can be divided into three hydrogeological units namely, unconsolidated sediments, semi-consolidated sediments and consolidated rocks. The unconsolidated sediments are of two types- alluvial sediments and aeolian deposits. The alluvial deposits are limited in extent to Barmer, Jalore and Jodhpur district, consisting of sand, clay, gravel and cobbles. Valley fills have been reported from Jhunjhunu, Ajmer, Bhilwara and Udaipur district. The aeolian sediments constitute one of the major aquifers in the east of Bikaner. Semi-consolidated formations include sandstones, limestones and Aur beds, covering Jaisalmer and Barmer districts. The consolidated rocks includes gneiss, granites, schist, phyllites, marble and Vindhyan sandstones, limestone, quartzite and basaltic flows, mostly restricted to eastern part of the State. The yield prospect is limited unless the well is located near major lineaments or any other weak planes. The ground water quality is in general poor (brackish to saline) at deeper levels.

The occurrence of ground water in the state is mainly controlled by the topographic and structural features present in the geological formations. The movement of the groundwater in hard rock areas is governed by size, openness, interconnection and continuity of structural weak planes while in unconsolidated rocks groundwater movement takes places through pore space between grains. Water table contour maps prepared for year 2010 (pre and post-monsoon) presented in Plates 18 and 19 depict behavior of groundwater in the state. Isopach map of Unconfined and Confined aquifer maps are shown in Fig. 21 and Fig. 22, and water bearing properties of different aquifers are described below.

3.1. Ground water in Alluvium

Ground water occurs under unconfined to semi confined and confined conditions in the unconsolidated formations consisting of sand, gravel, pebbles, cobles and boulders. In the state alluvium covers almost 30% of the geographic area. The area under alluvium comprises of Ganganagar, Hanumangarh, Churu, Bikaner, Jodhpur, Nagaur, Jhunjhunun, Alwar, Bharatpur, Sikar, Dausa, Jaisalmer, Barmer, Jaipur, Kota and Jalor districts. It is further divided into two groups i.e. Older Alluvium and Younger Alluvium.

Younger Alluvium

First Aquifer - The unconfined aquifer is the principal source of water but due to over exploitation it is likely to become dry soon. This aquifer covers almost whole Ganganagar and Hanumangarh district and major part of Jaipur district. This also occurs predominantly in North and West of Jaisalmer district, East of Churu district, in and around Talera and Keshorai Patan of Bundi district, Itawa and

Sultanpur of Kota district, Baran block of Baran district and some part in Jalor, Barmer, Sirohi, Rajsamand, Pali, Ajmer, Dausa and Jhununun districts.

The thickness of this layer ranges from less than 10m to 120m. The maximum thickness was encountered in and around Bhadra block of Hanumangarh district, Sindhari and Dhorimanna block of Barmer district and Bhinmal block of Jalore district. The ground water is fresh in shallow depth and in and around Canals and river/streams. As we go deeper the water quality is more brackish.

Second Aquifer - This aquifer covers almost whole Ganganagar and major parts of Hanumangarh district. Also occur predominantly in East of Churu district, in and around and some part in Jalor, Sirohi, Dausa, Jaipur, Barmer, Jaisalmer and Jhununun districts.

This aquifer group consisting of different sand and clay lenses at variable depths. The sediments of this group are less coarse than sediments of first aquifer and are admixed with kankar. The quality of water is reasonably fresh except in deeper aquifers. This aquifer is under semi-confined to confined conditions. The thickness of this layer ranges from less than 10 to more than 50m. The maximum thickness has been encountered near Sardar Shahar block (52m) of Churu district.

Older Alluvium

First Aquifer - The unconfined aquifer is the principal source of water but due to over exploitation this too is likely to become dry soon. This aquifer covers almost whole Jalor, Jhunjhunun, Sikar and Bharatpur district and major part of Alwar, Karauli, Dhaulpur, Sawai Madhopur, Dausa and Barmer district. Also occur predominantly in south of Jodhpur district, Central and East of Nagaur district, in and around Khajuwal of Bikaner district, and some part in Jalor, and Pali districts.

The thickness of this layer ranges from less than 10 to 120m. The maximum thickness was encountered in and around Bhinmal (more than 120 m), Jalor (110 – 120 m) and Chitawana (100 – 120 m) block of Jalor district. The ground water is saline in Bikaner, Hanumangarh and some part of the Jalor, Barmer Bharatpur and also in patches. In general, as we go deeper the water quality becomes brackish. In the rest of the area, the ground water is largely fresh.

Second Aquifer - This aquifer covers almost whole Jalor, Jhunjhunun, Sikar and Bharatpur district and major part of Alwar, Karauli and Barmer district. Also occur predominantly in the Central and East of Nagaur district, and some part of Dhaulpur, Dausa, Sawai Madhopur, Jalor, and Pali districts.

This aquifer group consisting of different sand and clay lenses at variable depths. The sediments of this group are less coarse than sediments of first aquifer and are admixed with kankar. The quality of water is reasonably fresh except in deeper aquifers and North-West Rajasthan area. The group is underlain by another clayey horizon, which is considerably thick at places and appears to be regionally extensive. This aquifer is under semi-confined to confined conditions. The thickness of this layer ranges from less than 10 to 150m. The maximum thickness has been encountered in Jaitaran block (149m) of Pali district.

Third Aquifer - This aquifer occurs in Deeg, Nagar, Kumher, Nadbai, Sewar and Weir blocks of Bharatpur district; Kathumar block of Alwar district and Mahwa block of Dausa district.

This group comprises of thin sand layers alternating with thicker clay layers and occurs at variable depths. The thickness of this layer ranges from less than 5 to 45 m. The granular material of this group is generally finer in texture. This aquifer group is under confined conditions.

3.2. Weathered and fractured zones in hardrock areas

Groundwater in the hard rocks occurs under water table conditions in the zone of weathering and fracturing, joints, fissures and bedding planes. When schists are intermixed with gneisses, they form better aquifers. The rate of recuperation is slow in gneisses and schist, it is comparatively faster in granites. Quartzites generally occur intercalated with phyllites and are well jointed. Ground water in phylites occurs mainly in fractures and cleavages. Carbonate formation are cavernous, wherever calcium content is high. The yield is high when the lenticular cavities along calc bands are saturated and interconnected.

Nagaur/Jodhpur sandstone - These aquifers mainly consist of medium to coarse grained sand, cemented with silica and ferruginous matrix. This sandstone is intercalated with siltstone and shale. The sandstones are hard, compact and from medium aquifer. Wherever, ground water occurs, it mainly occupies either void space between the adjacent grains (primary porosity) and in the secondary porosity zones. These aquifers mainly occurs in Mundwa, Ladnu, Jayal and Nagaur block of Nagaur district, Near Lunkaransar block, South eastern part of the Bikaner district and central part of the Jodhpur district. Ground water in these formations is under semi-confined to unconfined condition. Thickness of sandstone varies from 10 to more than 80 m. The maximum thickness was encountered in north of Balesar block and southeast of Osian block (82 m) in Jodhpur district. The ground water quality is in general brackish to saline, however in deeper aquifers it is good.

Tertiary Sandstone - This formation belong to lower Eocene to Palaeocene age comprises mainly fine to coarse grained sandstone, well sorted white to grey with some times pink tinge, poorly to moderately cemented, soft and friable. This aquifer mainly occurs in central part of the Bikaner district, north and northeast part of the Barmer district, northcentral part of the Jaisalmer district and some area in eastcentral part of the Nagaur district. The saturated thickness of this sandstone aquifer is 10 to 80 meters, and maximum thickness is encountered in northcentral part of Jaisalmer

(80 m). This aquifer is found to be under phreatic conditions. The ground water quality is brackish to saline in deeper aquifers except it is good.

Parewar Sandstone - This aquifer is mainly found near Sam block of Jaisalmer district only. The thickness of this sandstone aquifer is 10 to 30 meters. The ground water quality at shallow depths is good but is saline in deeper aquifers.

Sandstone – Sandstone is mainly found in Vindhyan and Trans-Aravalli-Vindhyan sequence covering part of Dholpur, Bharatpur, Karauli, Bundi, Jhalawar, Kota, Bhilwara, Chittaurgarh and Baran districts in eastern Rajasthan and in scattered form in Jaisalmer and Barmer of western desert plain. Thickness of this varies from 10 to more than 100 m. The maximum thickness i.e., 105m was found in east of Baseri block and near Dholpur block in Dholpur district. In general, the ground water quality is saline in western area but in eastern area the quality of ground water is good.

Bilara limestone - It is a very good and potential aquifer comprising limestone, dolomite and shale. It is cavernous at places and susceptible to solution activity which gives rise to high discharge in wells. These cover western and north-central part of Nagaur block, central part of Mundwa block, west central and eastern part of Jayal block, part of Ladnun block and north-central part of the Phalodi block, east and south-central part of the Bap block, eastern part of the Bilara block part of Bhopalgarh block in Jodhpur district. Thickness of this aquifer varies from 10 to more than 140m. The maximum thickness (147m) was found in the east of Phalodi block in Jodhpur district and east of Nagaur district. In general the groundwater quality is good however, is brackish to saline in deeper aquifers.

Limestone - Limestone aquifer covers major parts of the Antah block and some part of Atru and Baran block of Baran district and Nimbahera block of Chittorgarh district. Some small patches are also found in block Bonli and Khander in Swai Madhopur district, Khairabad, Sangod, Sultanpur, Itawa and Ladpura block in Kota district, Hindoli, Bundi, Talera block in Bundi district, Jaitaran and Sojat block in Pali district, Mandalgarh block in Bhilwara district and Begun block in Chittorgarh district. Thickness of limestone varies from 10 to less than 60 m. The maximum thickness was found in the north of Sojat block (54 m) in Pali district. The ground water quality is in general, good.

Shale - Shales intercalated with calcareous material generally forms poor aquifer. Shale mainly found in the Khander and Sawai Madhopur block of Sawai Madhopur district, central part of the Bundi district and almost half of Shahbad block of Baran district. It also spreads out in and around Bhainsrorgarh, Begun, Chittaurgarh, Nibahera, Bhadesar, Dungla and Bari Sadri block of Chittaurgarh district and Chhoti Sadri block of Pratapgarh district , some part of the Jhalarpatan, Manohar Thana, Bakani and Khanpur block of Jhalawar district and Sangod block of Kota district. The thickness of this layer ranges from 10 to more than 50 m. The maximum thickness was found in Bhadesar blocks (51m) of Chittaurgarh district. In general, the ground water quality is good.

Schist - Ground water in phyllite occurs under water table condition in joints, fissures and fractures. This aquifer is also quite susceptible to weathering top portion is invariably covered with thin clayey, the water bearing capacity of this formation is poor. Schist covered major part of the Tonk, Rajsamand and Bhilwara district and entire North-West part of the Ajmer district. It is asssociated with Delhi and Aravalli supergroup of rocks in parts of Ajmer, Jaipur, Bundi, Pali, Tonk, Udaipur and Chittaurgarh districts. Some small patches available in Bilara block in Jodhpur district, Pindwara, Abu Road block in Sirohi district and Aspur block in Dungarpur district. The thickness of this layer ranges from 10 to 100 m. The maximum thickness I.e., 90 to 100 m has been encountered in Bhim, Deogarh and Railmagra block in Rajsamand district and Pindwara blck of Sirohi district. In general, the ground water quality is good except the Sujangarh block in Churu district.

Phyllite - Ground water in phyllite occurs under water table condition in joints, fissures and fractures. This aquifer is also quite susceptible to weathering. Phyllite being compact in nature has poor water yielding capacity. The rate of recuperation is faster in comparison to mica-schist. It is associated with Delhi and Aravalli Supergroup of rocks in parts of Bundi, Sawai Madhopur, Pali, Sirohi, Udaipur, Banswara, and Dungarpur districts. It covers major parts of Banswara, Udaipur, Dungarpur and Bundi districts. The thickness of this layer ranges from 10 to more than 100m. The maximum thickness (101m) was found in Kherwara block of Udaipur district, in and around Dungarpur and Bichhiwara block of Dungarpur district. In general, the ground water quality is good.

Quartzite - The water-bearing unit of quartzite is highly ftractured and jointed. Intercalation of slates and phyllites is common. It covers Southwestt parts Jhunjhunun and central and southeastern part of Alwar district and central and northeast part of Sikar district. It is also spread in Weir block of Bharatpur district, Nadoti block of Karauli district, Chaksu, Bassi, Jamwa Ramgarh, Amber and Viratnagar block of Jaipur district and some part in Jhadol block of Udaipur district and Sawai Madhopur district. The thickness of this layer ranges from 10 to 80 m. The maximum thickness was found in Udaipurwati block (80m) of Jhunjhunun district. In general, the ground water quality is good.

Rhyolite - The rhyolites are partially impervious. They are sparingly jointed and weathered into a clayey impervious residuum reducing the water bearing capacity. The rocks have secondary porosity and the water yielding capacity of rock units diminishes with depth. It covers major part of Sankra block of Jaisalmer district. It also covers Barmer, Baytoo, Sindhari Charnan and Balotra blocks of Barmer district and central part of Luni and Mandor block of Jodhpur district. The thickness of this layer ranges from 10 to 45 m. The maximum thickness is found in Sankra (45m) block of Jaisalmer district. In general, the ground water quality is good.

Gneiss - Ground water in gneisses occurs under water table conditions in joints and fractures. It covers major parts of Bhilwara and Ajmer districts and also spreads in Dudu and Phagi block of Jaipur district, Raipur and Jaitaran block of Pali district. Small pockets of Gneiss are found in Bandikui block of Dausa district and Uniara block of Tonk district. The thickness of this layer ranges from 10 to more than 80 m. The maximum thickness was found in Kotri block (84m) of Bhilwara district. In general, the ground water quality is good.

Granite - Ground water occurs under water table condition in fractured and weathered zones. It covers major parts of district Pali and Sirohi and Jaswantpura block of Jalor district. Some small patches are also available in Raniwara block of Jalor district, Sakar block of Jaisalmer district and Sheo block of Barmer district. The thickness of this layer ranges from 10 to more than 100 m. The maximum thickness was found around Sumerpur block (110 m) of Pali district. The ground water quality is in general, good.

Jalor Granite - Ground water occurs under water table condition in fractured and weathered zones. It spreads in major parts of Bhopalgarh, Bilara, Mandor and Bawari blocks of Jodhpur district. The thickness of this layer ranges from 10 to more than 90m. The maximum thickness was found in South of Bawari, Bhopalgarh, Bilara, East of Mandor block (93m) of Jodhpur district. The ground water is fresh in shallow aquifers.

Banded-Granite Complex (BGC) - Groundwater is retained in weathered zones, fractures joints etc. Few intrusives are also found which have lower permeability. It spreads in major parts of Rajsamand, north and central part of Chittorgarh and East of Udaipur district. It also covers almost entire Dhariawad block and some part of Pratapgarh, Peepal khoont of Pratapgarh district, Ghatol, Banswara and Garhi block of Banswara district and Sagwara, Aspur and Dungarpur block of Dungarpur district. The thickness of this layer ranges from 10 to more than 100 m. The maximum thickness was found in and around of Mavli block (110 m) in Udaipur district. In general, the ground water quality is good.

Basalt - Basalt as aquifer occur in southeast part of the state covering almost entire Jhalawar and major part of Pratapgarh districts, eastern part of Banswara and southern part of Baran district. Ground water found in weathered, vesicular and amygdoloidal basalt. The thickness of this layer ranges from 10 to 70 m. The maximum thickness is found in Bakani block (69m) of Jhalawar district. In general, the ground water quality is good.

Ultra Basic – It is found in central part of Simalwara block of Dungarpur District only. The thickness of this layer ranges from 10 to less than 40 m. The maximum thickness (36m) was found in Simalwara block of Dungarpur district. In general, the ground water quality is good.

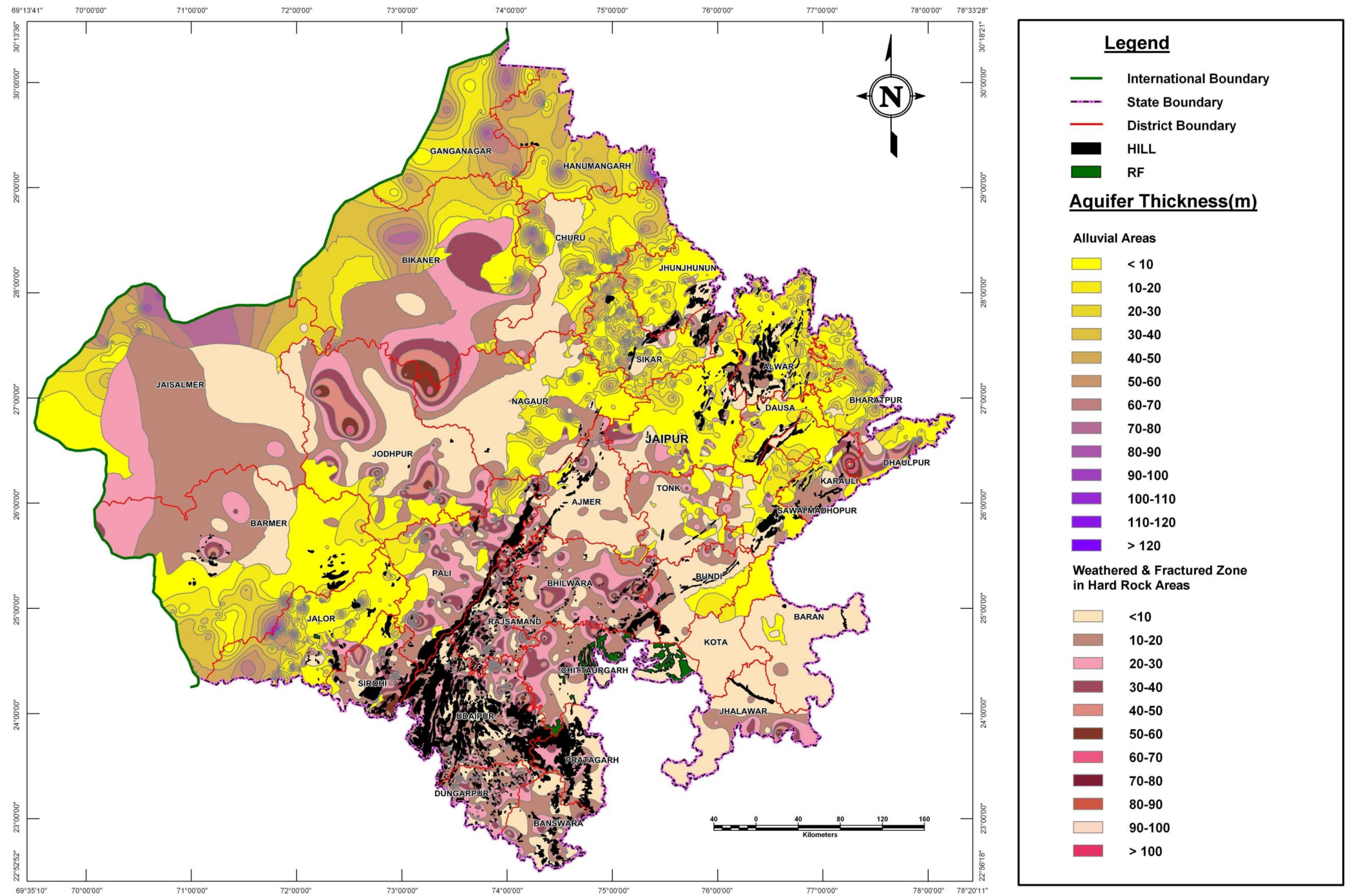


Figure. 21: Isopach Map of Unconfined aquifer in Rajasthan

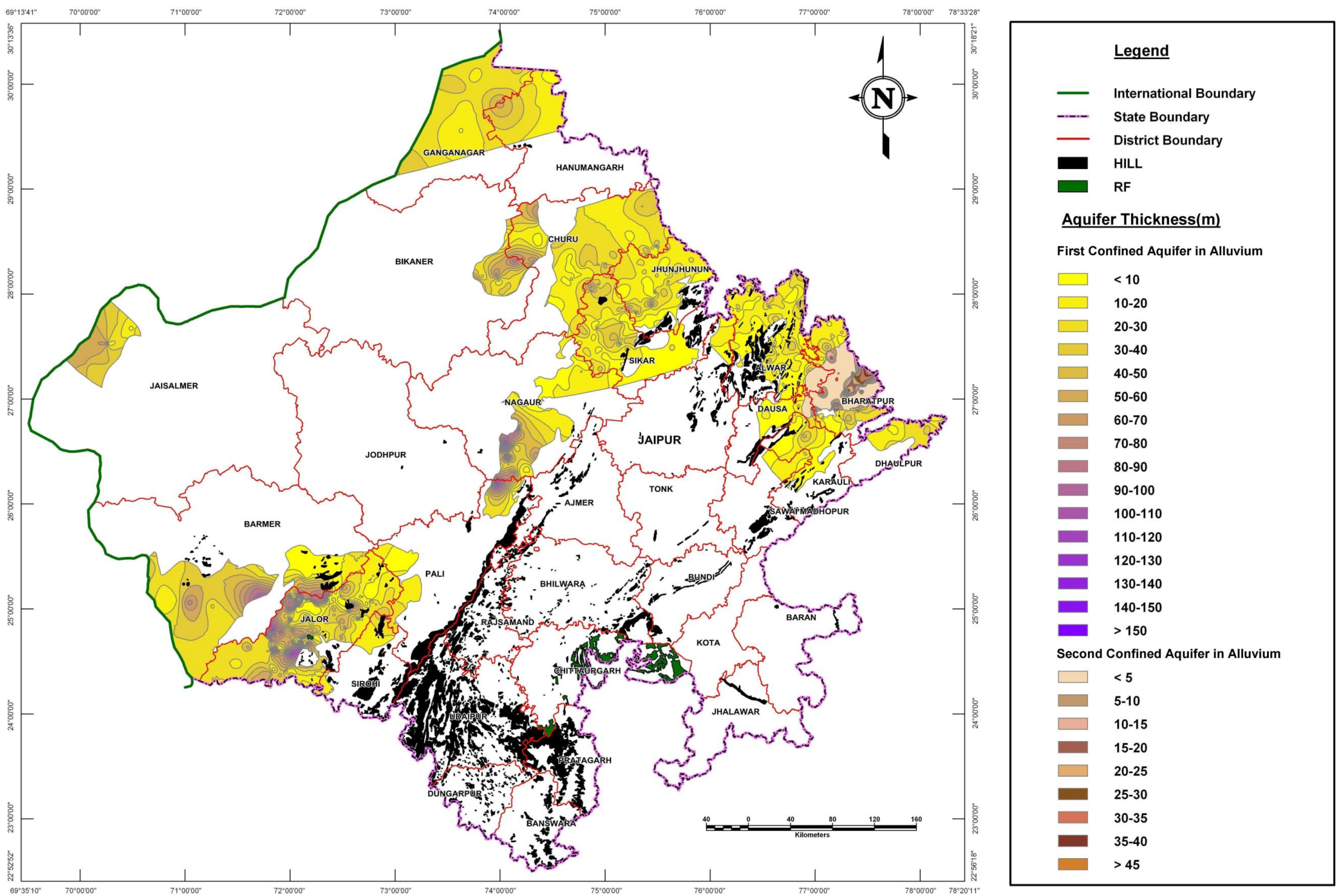


Figure. 22: Isopach Map of Confined aquifer in Rajasthan

3.3. Description of aquifers, basin wise

Sometimes, planning is done basin wise. Keeping that in mind, the aquifer statistics have been worked out per basin boundaries also. For the sake of convenience of reader, Basin wise summary is present in the pocket starting from Plate 1 through Plate 17. Each plate contains summary of a Basin, with Basin description on the left side and relevant maps adjacent to it for quick reading and visualization. Area wise statistics are also presented.

4. Ground Water Recharge Potential Assessment

A general assessment of possibilities for enhancing ground water replenishment by artificial recharge was carried out, with a view to identify the area where the hydrogeological condition appears to be suitable for large scale artificial recharge. River basin wise unsaturated thickness for recharge potential assessment in the alluvial area of unconfined aquifer along with electrical conductivity concentrations were presented in Fig. 23 to 33. The description of each basin has presented and discussed in the following sections.

4.1. Banas River Basin

About 80 percent area of the Basin is occupied by hard rocks comprising mainly granite, gneisses, schist, phyllite and quartzite. The transmissivity of these rocks is poor, static water level shallow, gradients steep and specific yield insignificant. Under such conditions, the artificial recharge prospects are practically negligible.

However about 20% area of Basin is occupied by alluvial formations. Most of the alluvial aquifers are small and scattered. The significant alluvial aquifers are located in the north, in and around the Jaipur city and Dausa district. The static water levels in the area were observed to be declining, water level is deep and specific yield is higher within the range of 10-20%. Such areas can be considered for artificial recharge planning. The unsaturated thickness ranged from 20m to 50m and the maximum thickness was found near Jhotwara of Jaipur district. Whereas almost rest part of the basin was identified with unsaturated thickness less than 10m with high saline zone especially in the Arain, Bhinay and Masuda block of Ajmer district, Bhopalsagar block of Chittaurgarh district and Shahpura and Hurda block of Bhilwara district. In these areas the potential for development of recharge structures is limited. Recharge potential assessment map has shown in (Fig. 23).

Ideally, the favorable areas for artificial recharge projects should have high transmissivity, favorable lithology with less clay and silt content and without hard pans and impervious layers above the saturated zones so as not impede percolation of water downwards. Therefore it is further recommended in alluvial formation, detailed hydrogeological investigations are required to locate favorable areas for implementation of artificial recharge projects.

4.2. Banganga River Basin

Suitable hydrogeological conditions for large scale artificial recharge have been identified along a stretch of River Banganga just upstream of the areas. The effect of artificial aquifer recharge in this site is expected to benefit much of the western part of the basin where the thicknesses of unsaturated zones were 10m to 30m. The maximum unsaturated thickness of alluvium was found in

Todabhim block of Karauli district. The map is presented in Fig.24.

It was noticed that artificial recharge is in fact already taking place here, by way of the inundation irrigation practice, where most of the water percolates down into the aquifer. However, special care and proper planning and control must be exercised in ground water utilization in the eastern plains of Banganga River Basin, because of the delicate balance between the fresh and the saline ground water.

4.3. Gambhir River Basin

Due to the geology, hydrogeology and ground water regime in about 25% of the Basin area occupied by hardrocks (mainly Vindhyans), the possibilities of incorporating artificial recharge as a large scale component in future conjunctive use of in this part of the Basin is generally rather very limited.

Alluvial Potential Zones cover about 75% of the total Potential zones area of the basin. The unsaturated thickness of alluvium restricted to unconfined aquifer ranges from 10m to 30m where as some isolated patches in alluvium was reported with unsaturated thickness upto 30m. The map has presented in Fig. 25. Saline zones were identified in the Rupbas block of Bharatpur district, where there may be possibilities to convert these saline zones to fresh water up to some extent by planning of artificial recharge structures.

4.4. Luni River Basin

About 60 percent of Luni River Basin area is occupied by hard rocks consisting of BGC, granite, gneiss, rhyolite followed by schist, phyllite, limestone and sandstone. Looking to the long term water level trend (1984-2010) most of the block falling in Luni River Basin had shown groundwater depletion in range of 2m to 10m. Out of 109 assessment units in the basin 49 are falling critical and overexploited category. Therefore it would be appropriate to go for small artificial recharge structures.

Potential zones area in alluvium is about 13,000 Sq.Km. This has moderate to good infiltration capacity (15-30%) artificial ground water recharge can be planned at suitable sites. The unsaturated thickness for recharge potential assessment in unconfined aquifer was found to be in the range of 10m to 60m. The maximum unsaturated thickness up to 60m was observed in isolated patches of Sayla block of Jalor district, Siwana blocks of Barmer district and in parts of Nagur districts. The map is presented in Fig. 26.

4.5. Other Nallahs

An area which appears to be suitable for artificial ground water recharge has been identified in basin of Other Nallahs located in the upstream reaches of the basin, where the availability of surface water which could be diverted to recharge sites is rather limited.

The unsaturated thickness for recharge potential assessment in this basin ranges between 10m and 40m. The effect of artificial aquifer recharge in this site is expected to benefit much of the central part of the basin where the thicknesses of unsaturated zones were 30m to 40m. The potential distribution map is presented in Fig.27.

4.6. Outside Basin

The hydrogeological conditions in several parts of the Outside basin appear to be suitable for large scale artificial ground water recharge but the water levels are quite deep coupled with lack of any significant river flows the actual prospects for large scale recharge become limited. The only option for recharging aquifers could be with the water of IGNP (Indira Gandhi Nahar Project) canal, which anyway is available year-round and needs no aquifer level storage by means of artificial recharge.

The unsaturated thickness for recharge potential assessment derived from the aquifer mapping exercise for Outside basin ranges between 10m and 100m. There are some isolated patches like Dungargarh, Nokha and Kolayat blocks of Bikaner district, where the unsaturated thickness of alluvium were found around 100m. The EC values were found to be more than 4000 µs/cm in most of the area of the basin, but in some patches, where the EC value is less than 2000 µs/cm is present in Bikaner, Jodhpur, Sikar, Jhunjhunun, Ganganagar and Hanumangar districts. The map is presented in Fig.28. With the introduction of canal system there have been perceptible changes in the ground water regime in its command area. There is a rise in water levels of the command area in his whole track of Indira Gandhi Nahar Project in the Outside basin.

4.7. Parbati River Basin

Transmissibility values in the older alluvium areas is high static water level is usually low and hydrogeological gradients are moderate. Infiltration capacity of the Alluvial deposits range roughly from 15cm/day to 25-30cm/day, depending upon the lithology, i.e. the clay and silt content. The artificial recharge prospects are also higher in the areas where surface water is available. Thus, in this area recharge of aquifer is suggested to not only improve the ground water reserve but also to improve the chemical quality. As several isolated places EC was found to be more than 4,000 µs/cm and unsaturated thickness of alluvium were reported 10m to 20m. These areas need to be considered for recharge structures after detailed hydrogeological investigation. The map is shown in Fig. 29.

4.8. Ruparail River Basin

Alluvial areas encompass about 85 percent of the basin area (Fig. 30) and rest of the basin is covered by quartzites. It had been noticed that the static water level is dropping in the alluvial zone, which indicates that artificial recharge in these regions might be attempted. The unsaturated thickness for recharge potential assessment in alluvial area of first aquifer was found to range between 10m and 40m. In the southwest part of the basin unsaturated thickness lies in between 20m to 40m. The aquifer in the east, southeast and in central part (Ramgarh block of Alwar district) of the vanishing Ruparail River course, constitutes a high salinity patch, similar to the one in the Banganga River Basin to the east and south; although artificial recharge in areas lying upstream of this patch may retard the process of deterioration and control the expansion of this zone westward.

Therefore, the prospects of using artificial aquifer recharge as a significant component of water resources management in Ruparail River Basin may be attempted on a small scale recharge projects in selected areas after due hydrogeological investigations.

4.9. Sabi River Basin

Older alluvium occupies about 80 percentage of the Basin (Fig.31) and rest of the parts of the basin covered by quartzites. The lower part of the basin appears to offer the option of incorporating artificial recharge as a significant element of conjunctive surface and ground water utilization in this basin. Transmissivity in this area are much higher, usually in the range of 10 to 20% i.e., almost on order of magnitude higher than that of hardrock. The infiltration capacity of the alluvial deposits ranges roughly from 15 cm/day to 30 cm/day, depending on the lithology, i.e., the clay and silt content

The unsaturated thickness for recharge potential assessment derived from the aquifer mapping exercise for Sabi basin ranges between 10m and 50m. There are some isolated patches like Srimadhopur block of Sikar district and Behror block of Alwar district where the unsaturated thickness of alluvium were found to be around 50m.

4.10. Shekhawati River Basin

Alluvial potential zones cover most of the area where agricultural activity takes place. In this region, the static water level is dropping in most of the potential zones, which support the chance of artificial recharge to be effective.

The Kantli sub–basin, the most important part of Shekhawati River Basin was considered most favorable area for artificial recharge system. The unsaturated thickness for recharge potential assessment is maximum in the area i.e., 60 m. Artificial recharge by means of injection of wells may be taken in deep water level areas in the Basin and spreading method can be taken as numerous small recharge grounds spread over in extensive region of the basin or a network of unlined canals can be considered.

The unsaturated thickness for recharge potential assessment derived from the aquifer mapping exercise for the basin ranges between 10m and 60m. The EC values of more than 4000 µs/cm was found between Makrana, Kuchaman block of Nagaur district, Parbatsar block of Ajmer and Sambhar block of Jaipur district. There are some isolated patches also available in the northeast and southwestern parts of the basin. The map is presented in Fig.32.

4.11. Sukli River Basin

The major part of the basin has occupied by granite followed by phyllite, only a small part in the southwest side has covered with younger alluvium. The unsaturated thickness for recharge potential assessment was found to be between 10m and 20m from aquifer mapping considering pre monsoon 2010 water level data. The aquifer recharge potential map in Fig.33.

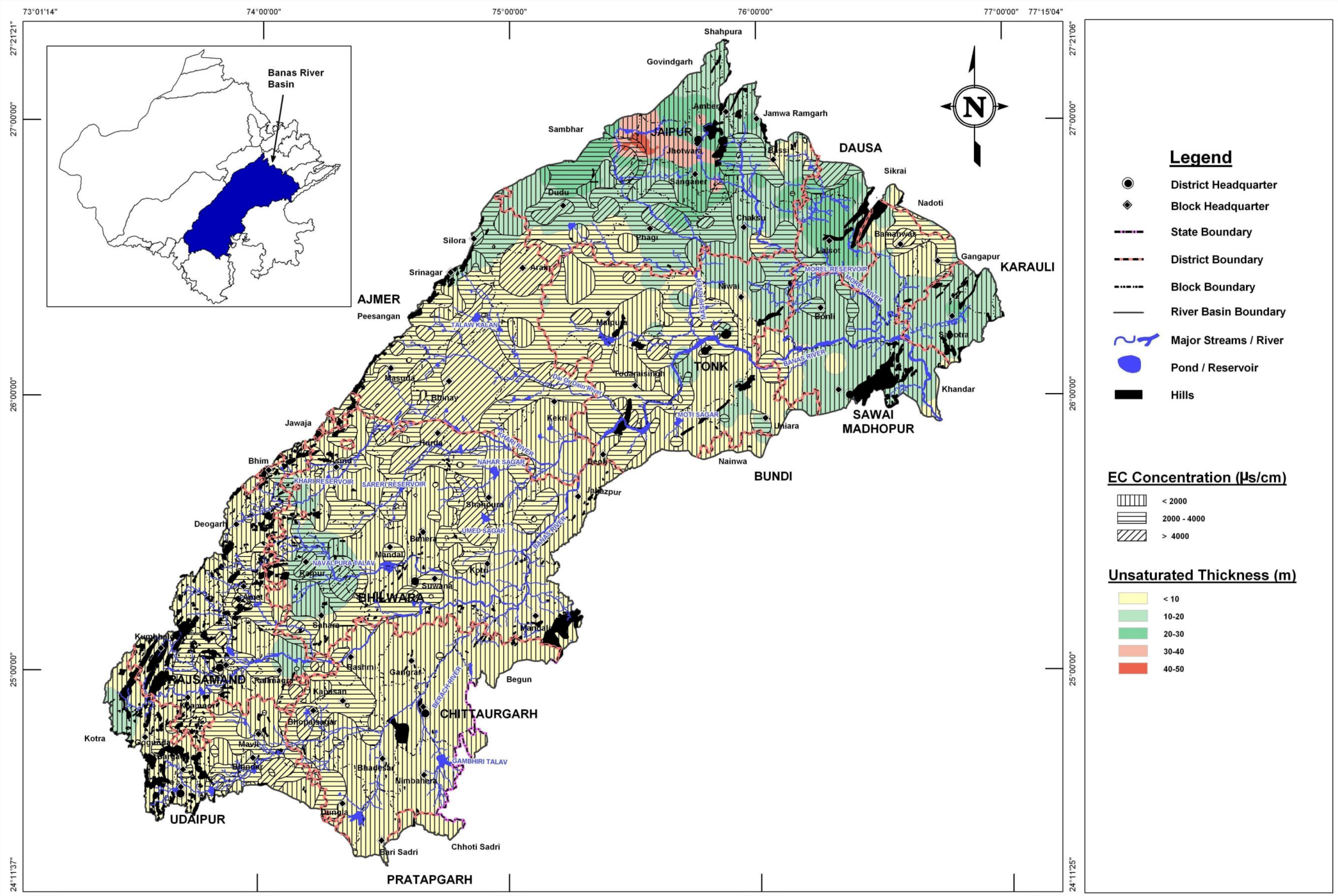


Fig. 23: Unsaturated thickness for Recharge Potential Assessment in Unconfined Aquifer of Banas River Basin

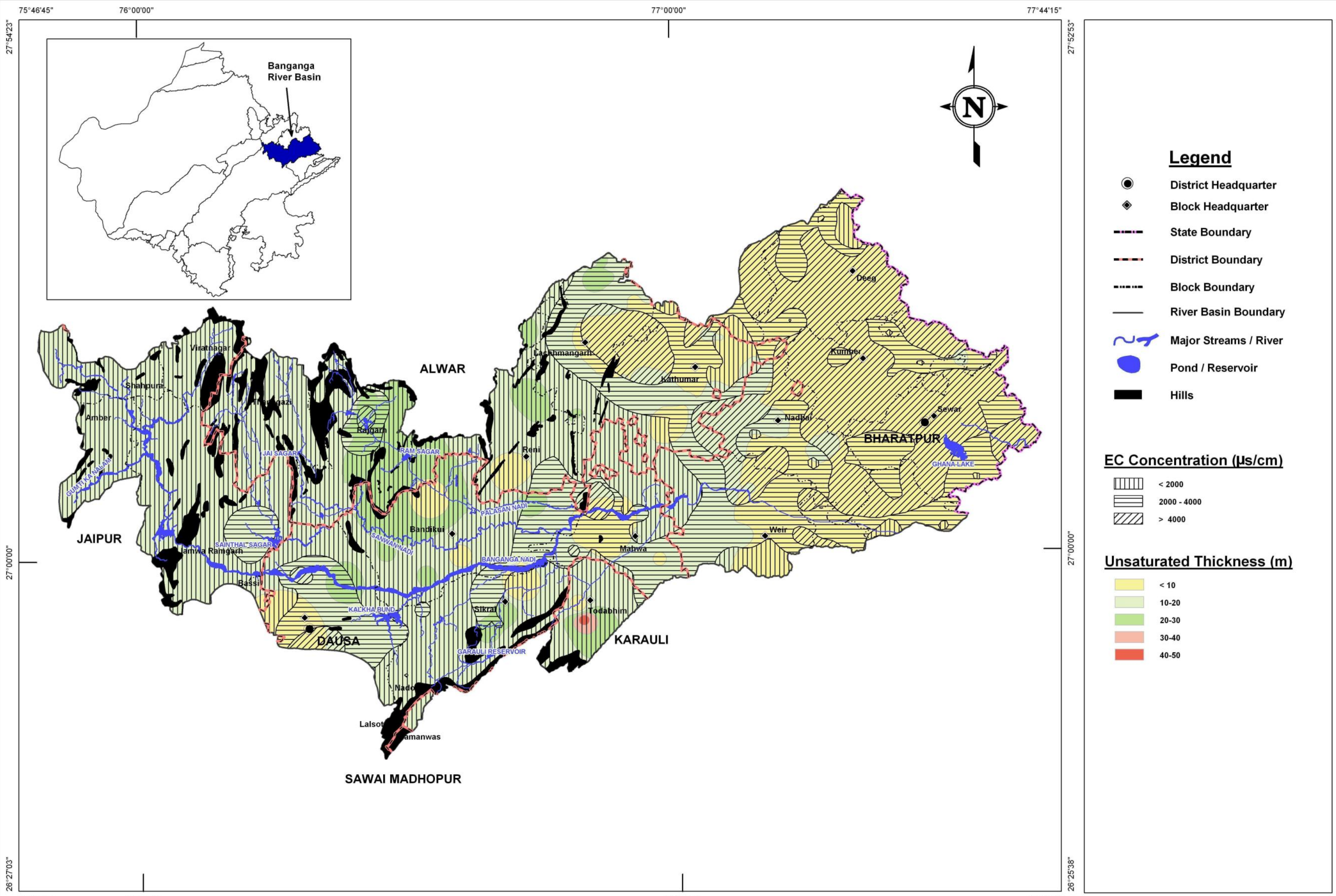


Fig. 24: Unsaturated thickness for Recharge Potential Assessment in Unconfined Aquifer of Banganga River Basin

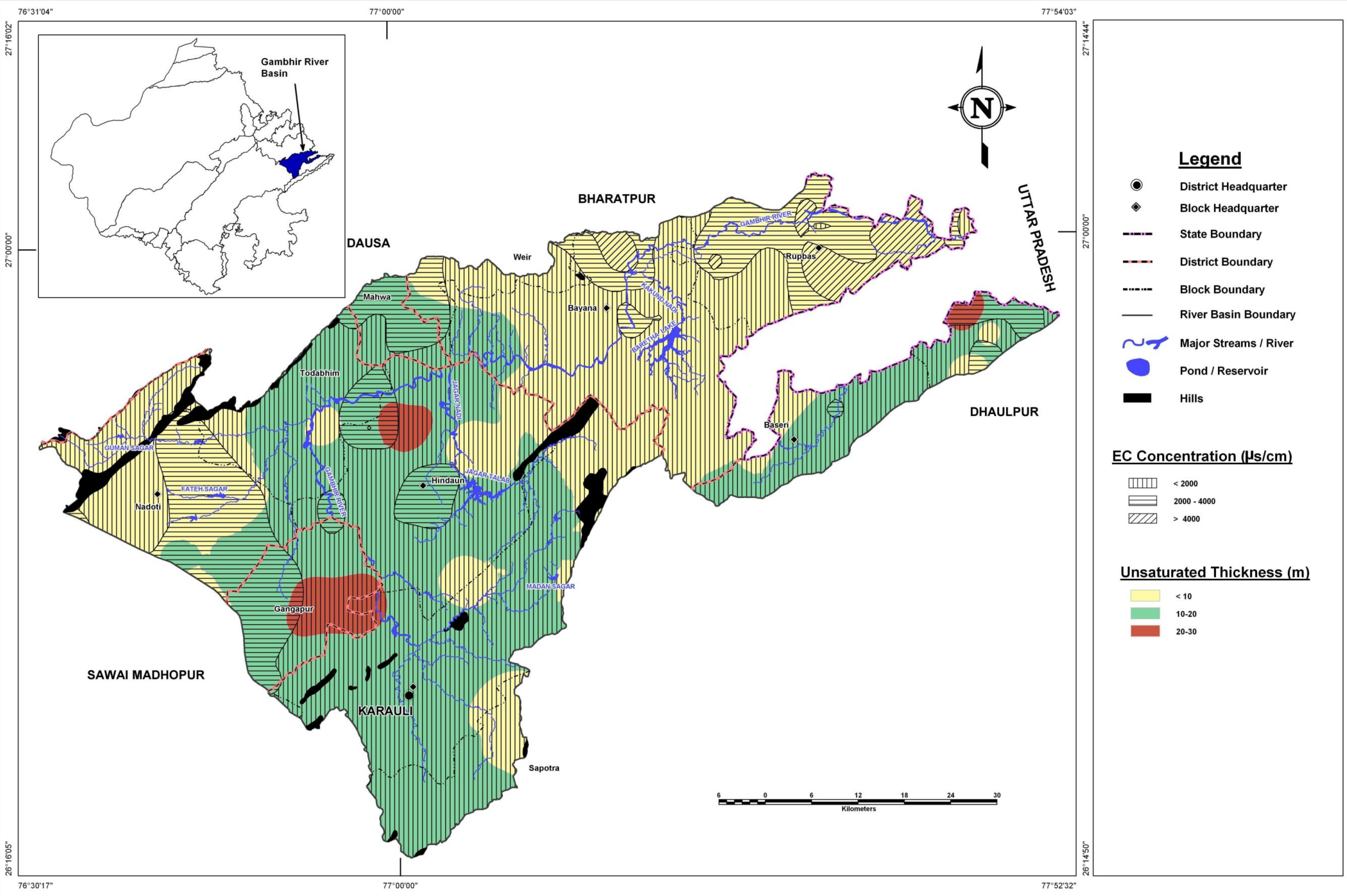


Fig. 25: Unsaturated thickness for Recharge Potential Assessment in Unconfined Aquifer of Gambhir River Basin

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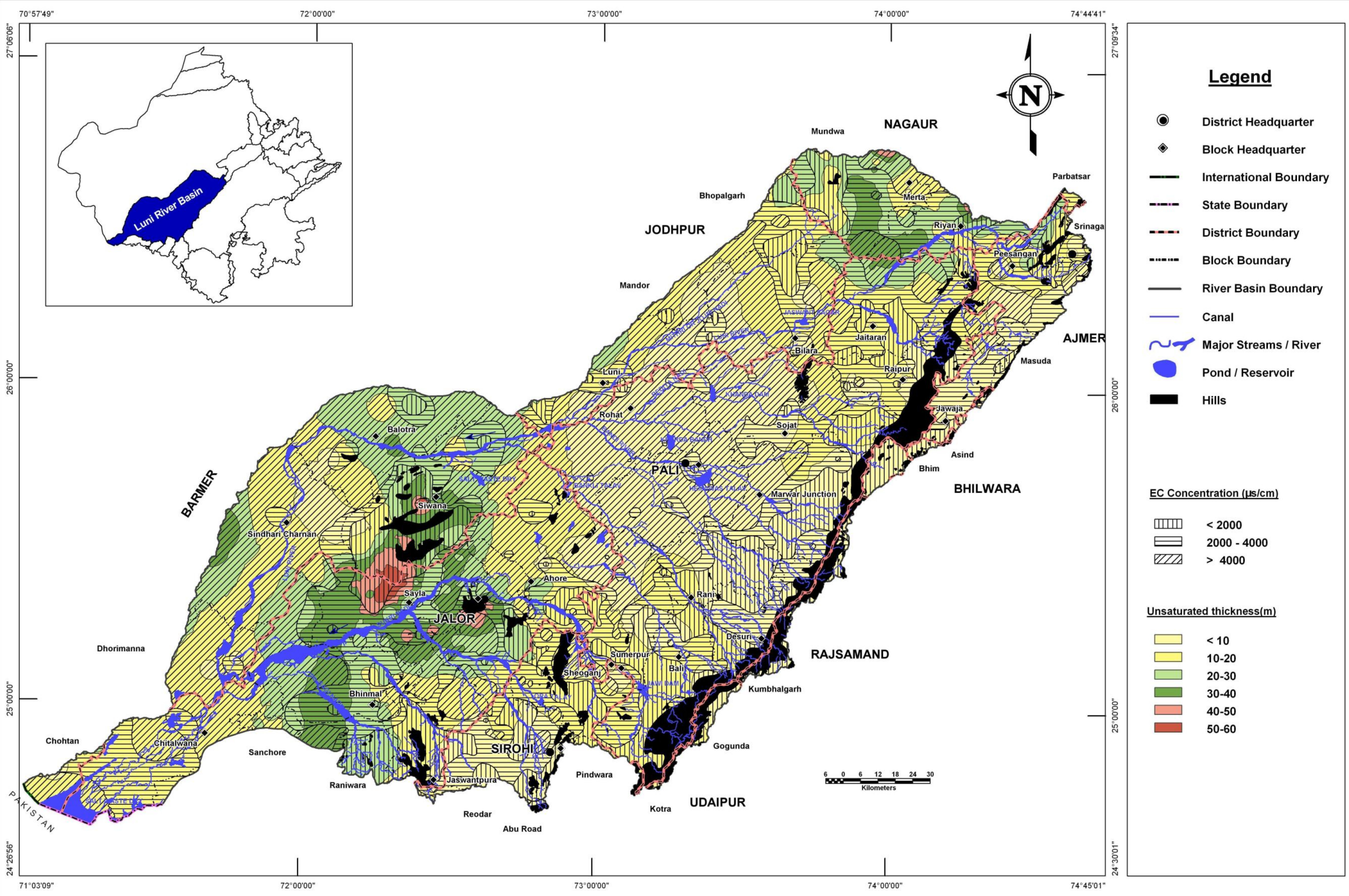


Fig. 26: Unsaturated thickness for Recharge Potential Assessment in Unconfined Aquifer of Luni River Basin

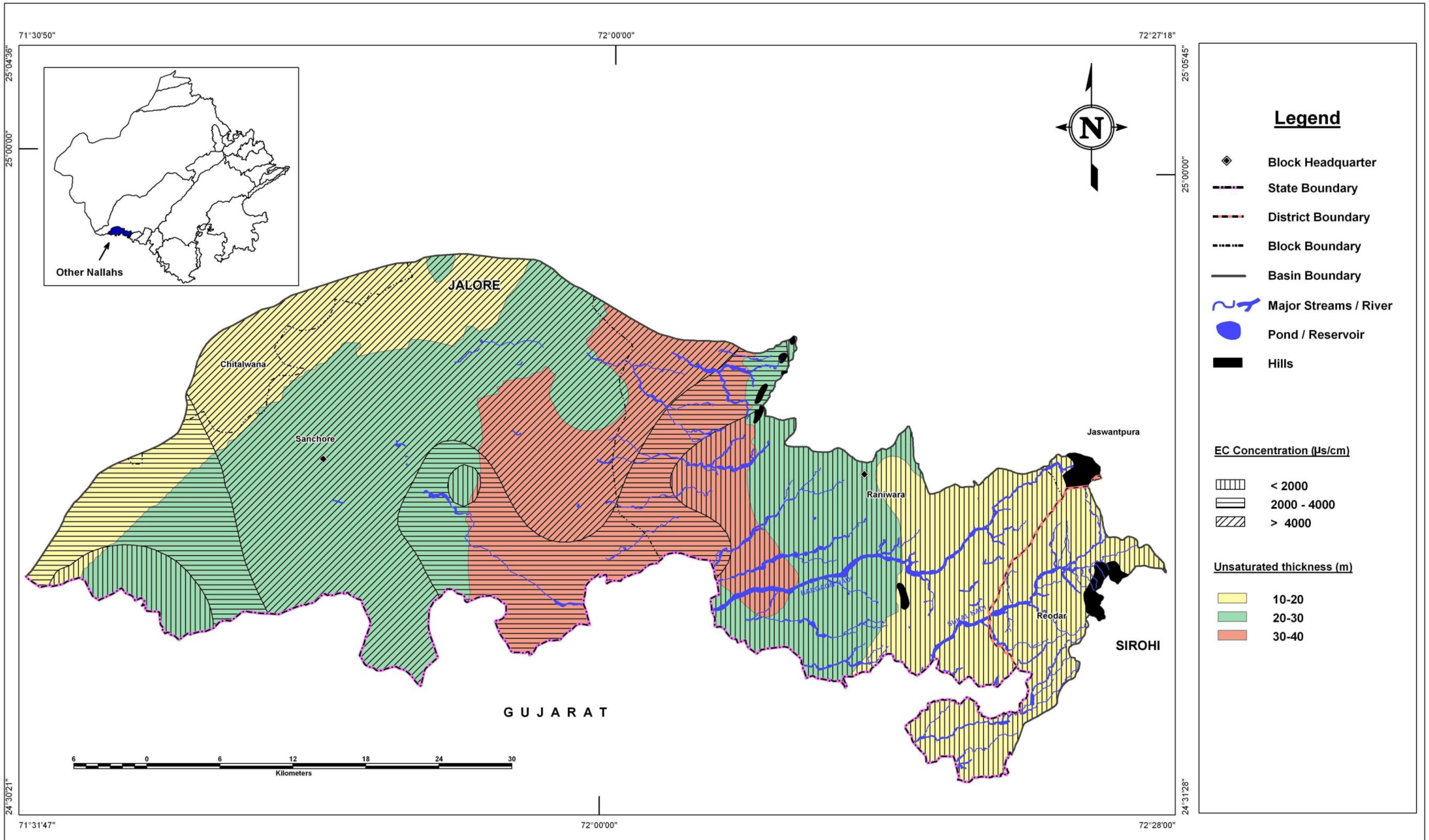


Fig. 27: Unsaturated thickness for Recharge Potential Assessment in Unconfined Aquifer of Other Nallahs Basin

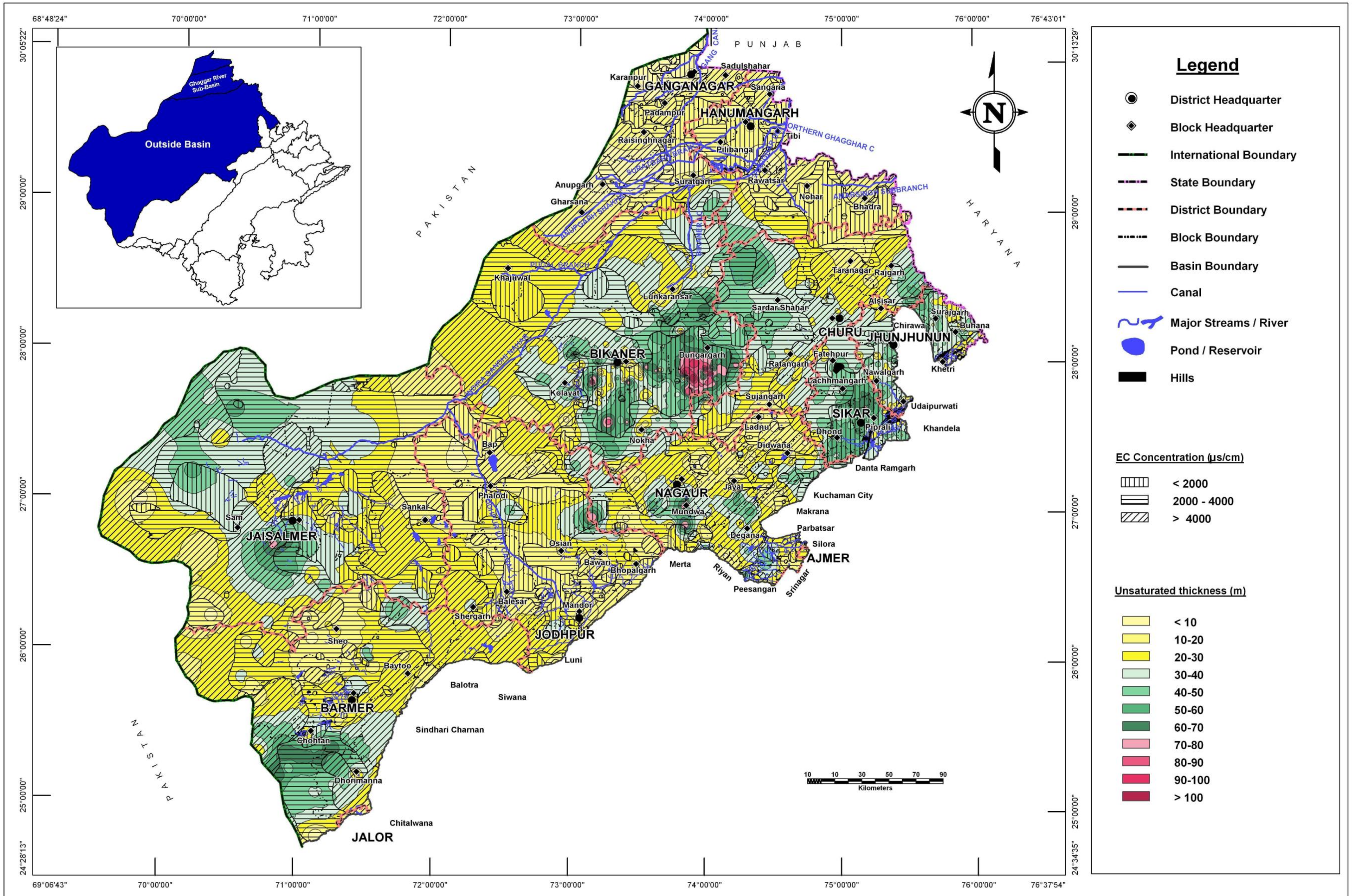


Fig. 28: Unsaturated thickness for Recharge Potential Assessment in Unconfined Aquifer of Outside Basin

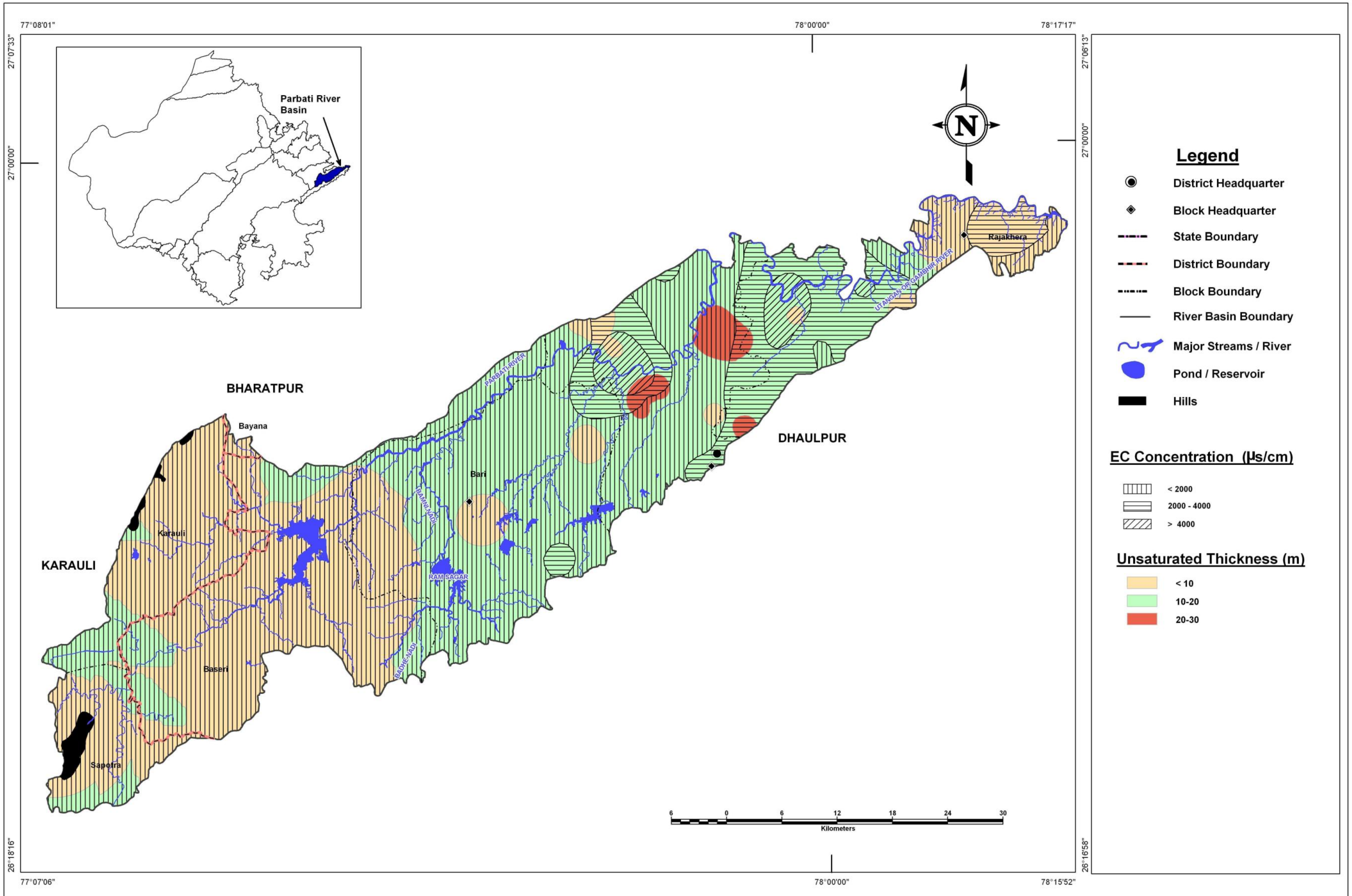


Fig. 29: Unsaturated thickness for Recharge Potential Assessment in Unconfined Aquifer of Parbati River Basin

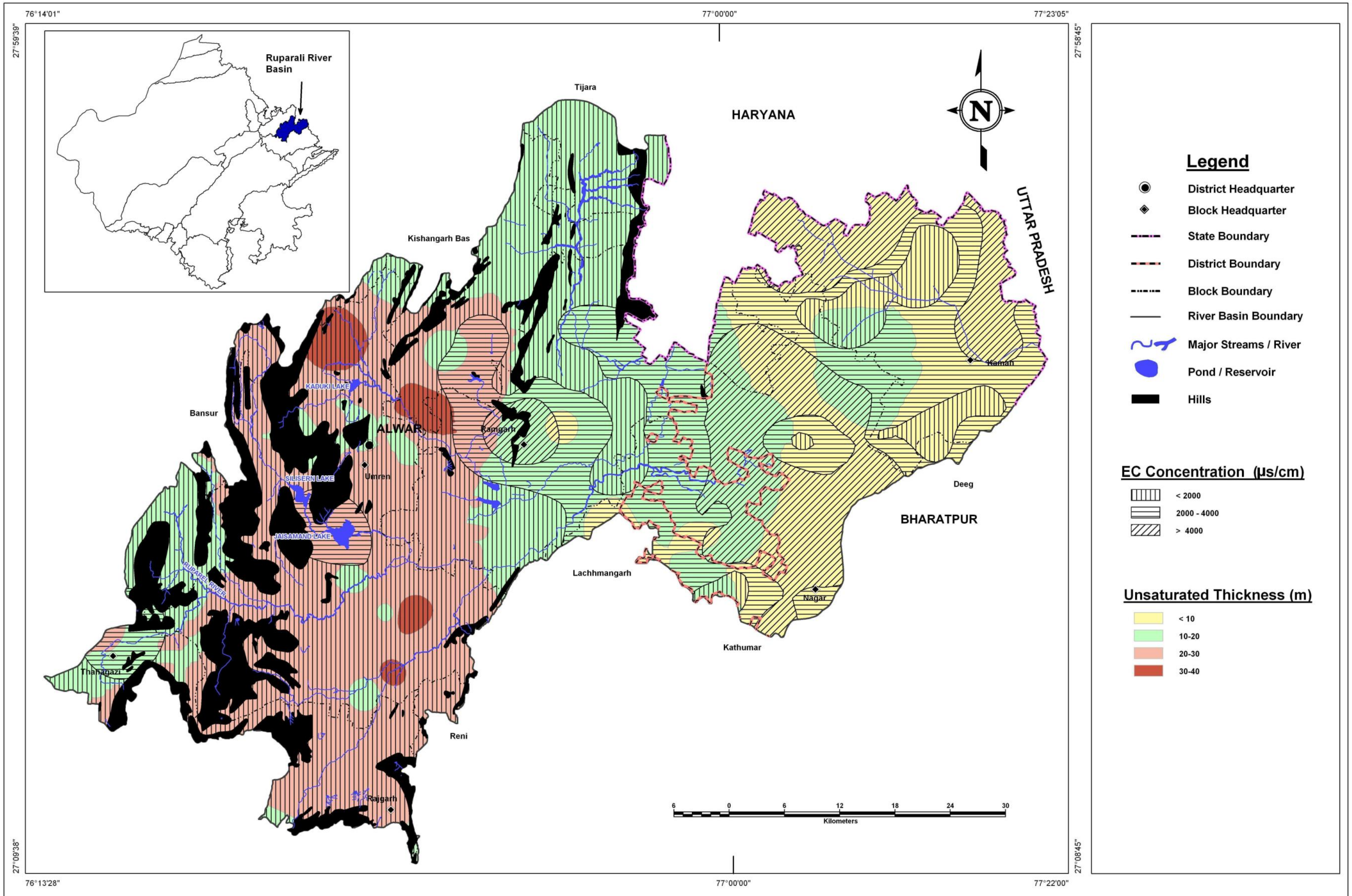


Fig. 30: Unsaturated thickness for Recharge Potential Assessment in Unconfined Aquifer of Ruparail River Basin

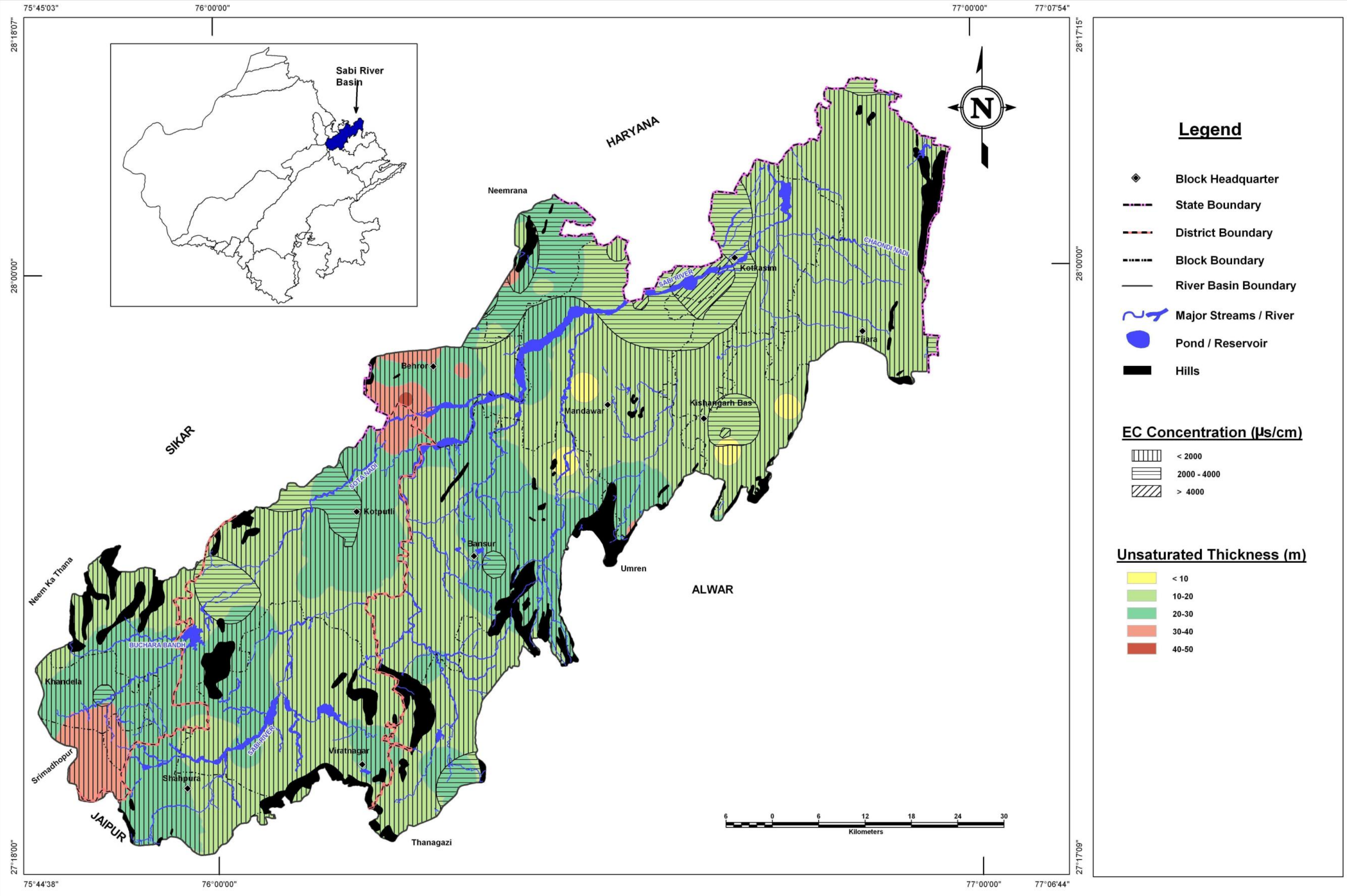


Fig. 31: Unsaturated thickness for Recharge Potential Assessment in Unconfined Aquifer of Sabi River Basin

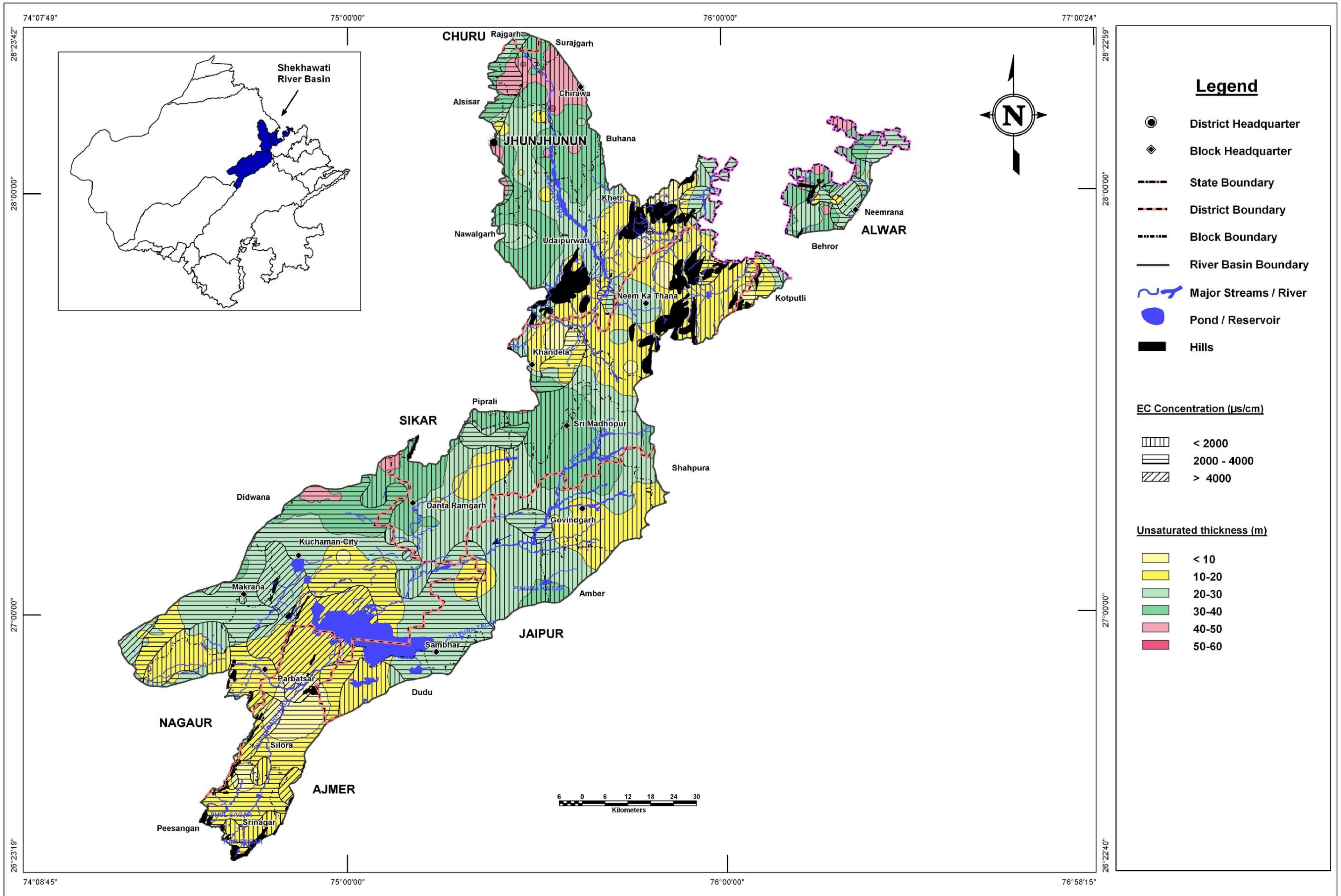


Fig. 32: Unsaturated thickness for Recharge Potential Assessment in Unconfined Aquifer of Shekhawati River Basin

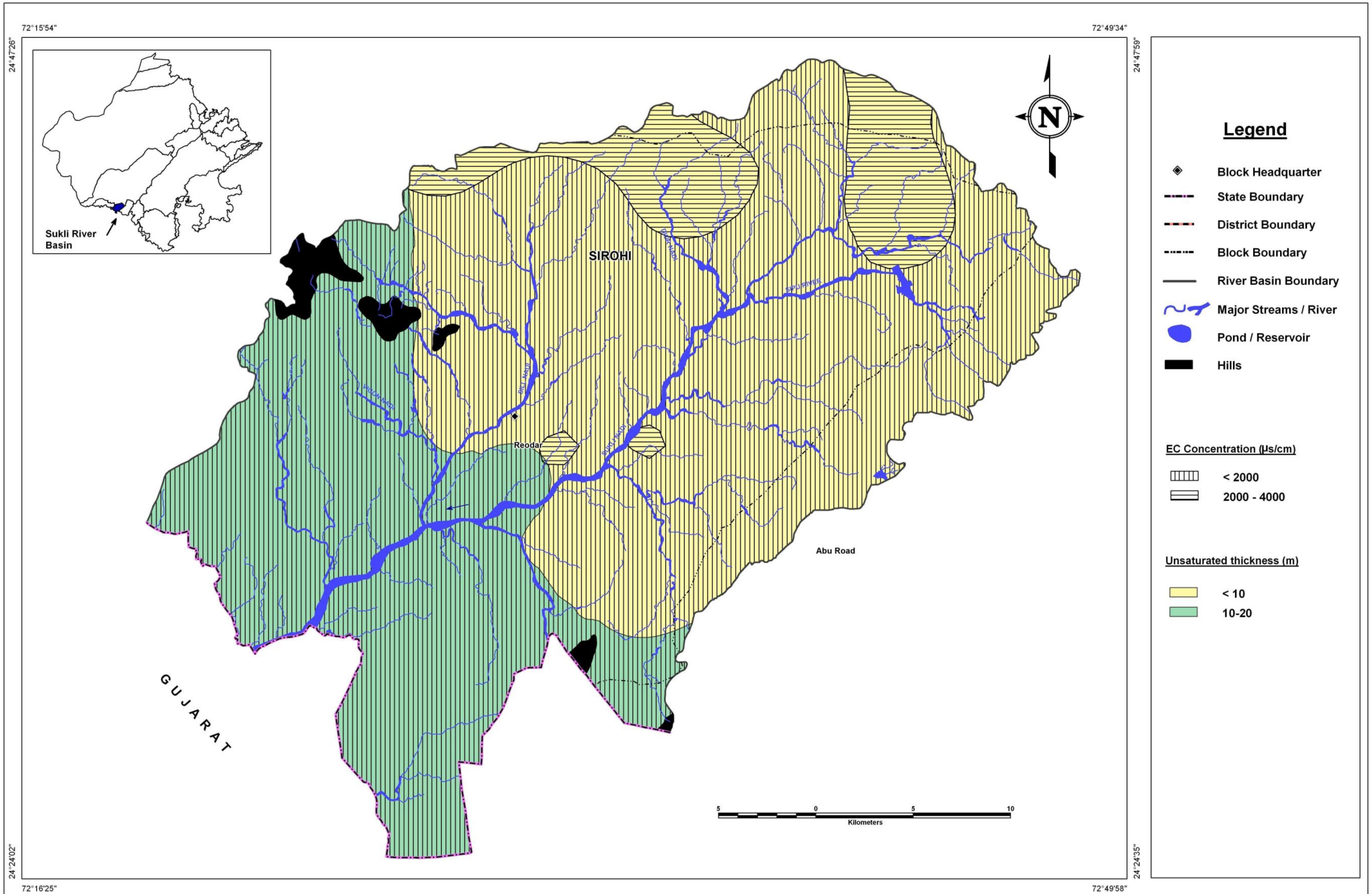


Fig. 33: Unsaturated thickness for Recharge Potential Assessment in Unconfined Aquifer of Sukli River Basin

5. Dynamic and Static Groundwater Resources

5.1. Ground Water Scenario in Rajasthan

Rajasthan state which has been categorized as the most water stressed state of the country as far as ground water exploitation is concerned. The Stage of Ground Water Development is defined by, Stage of Ground Water Development (%) = Existing Gross Ground Water Draft for All uses / Net Annual Ground Water Availability x 100

Categorization of Areas for Ground Water Development

The units of assessment are categorized for ground water development based on two criteria

(a) Stage of Ground Water Development,

(b) Long Term Trend of pre and post monsoon water levels.

Four categories are:

Safe areas which have ground water potential for development; **Semi-Critical** areas where cautious ground water development is recommended; **Critical** areas and **Over-Exploited** areas where there should be intensive monitoring and evaluation and future ground water development to be linked with water conservation measures. The criteria for categorization of assessment units as below:

Table 5.1: Categorization of areas based on stage of groundwater development:

S. No.	Stage of Ground Water Development	Categorization
1	<= 70%	SAFE
2	>70% and <= 90%	SEMI-CRITICAL
3	>90% and <=100%	CRITICAL
4	> 100%	OVER-EXPLOITED

As per year 2009 ground water resource estimates (carried out jointly by GWD and CGWB) based on guidelines of Ground Water Estimation Committee (GEC), 1997, Block has been considered as an assessment unit. The block has been further divided into potential zones. Out of a total 249 blocks in the state 138 blocks are categorized as Over-exploited, 26 blocks as Critical, 16 blocks as Semi Critical. Remaining 36 blocks which have been categorized Safe. 32 blocks have been treated as a notified area for ground water control and regulation. Tarnagar block of Churu district has not been assessed due to poor ground water quality in the entire block. The stage of ground water development in Rajasthan as on 2009 is 134.54%.

Categorization of assessment unit (Block) based on 2009 (after CGWB) Map is given below in (Fig.34)

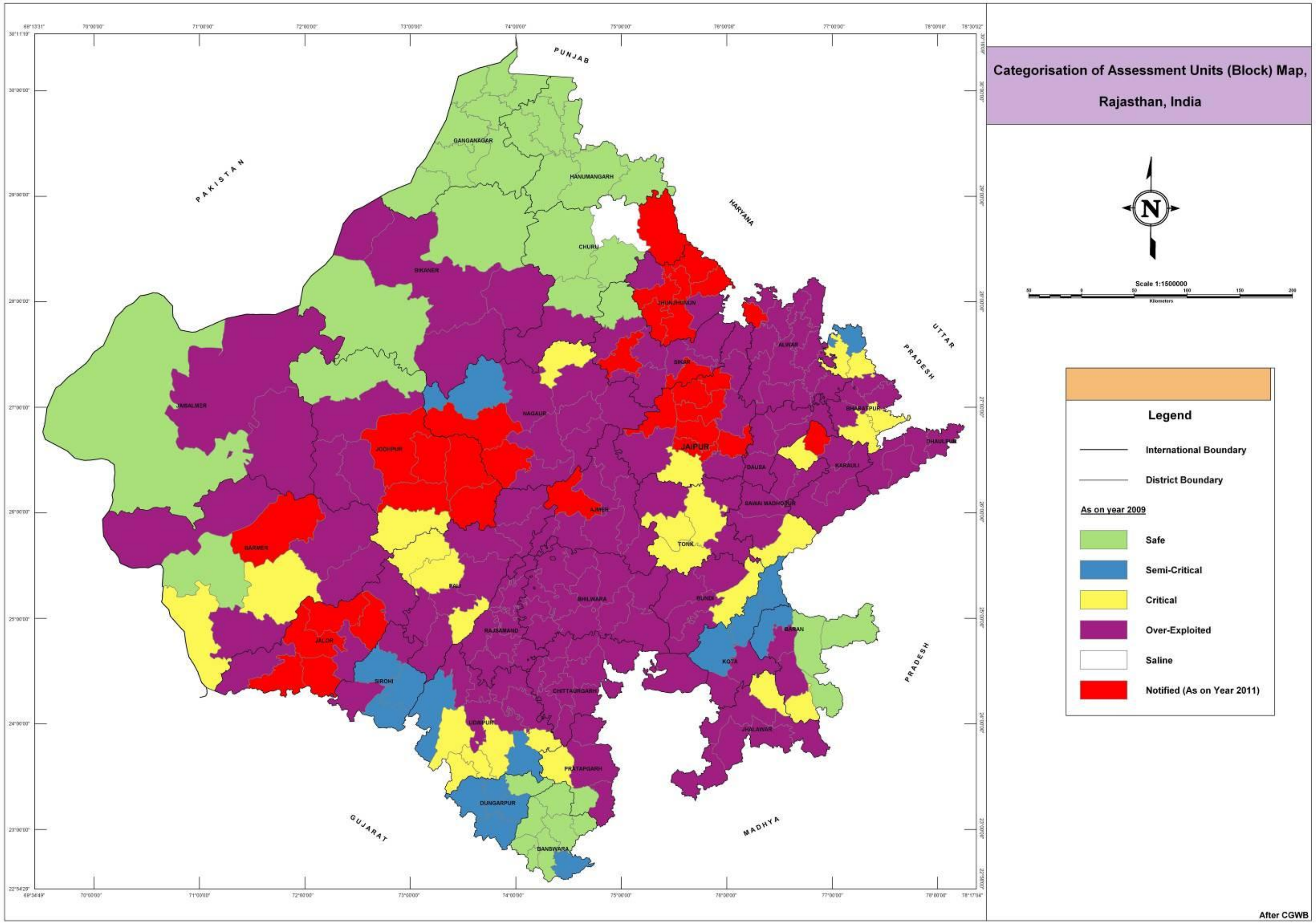


Fig.34: Categorization of Assessment Units (Block) Map

5.2. About dynamic resources

The dynamic ground water resources pertain to water level fluctuation zone of the unconfined/phreatic aquifer and as such the vertical extent of aquifer is not considered. In case of Rajasthan state, the rainfall is very low and hence the rainfall recharge is also comparatively less, however a significant quantity of water is exchanged as lateral flow from the adjoining areas. The ground water withdrawal is increasing day by day and in several part of the state the withdrawal is exceeding the annually replenishable dynamic ground water resources, in other words the ground water is pumped from below the zone of water level fluctuation. Hence, the need was felt for estimating the total ground water resources available up to the commonly exploitable depth or to a depth as decided by the Department based on the understanding of the aquifer systems.

In this project an attempt was made to establish the use of Geo Spatial Technologies to prepare various layers and to derive the parameters needed for Spatially Distributed Recharge Estimation following the GEC norms. Further, geo-spatial technique based water table fluctuation method was attempted for assessment of ground water resources. Different maps and their attributes were created in GIS database and estimation of spatially distributed resource parameters were carried out to estimate the ground water resource aquifer wise / basin wise.

After reviewing all the prevailing techniques vis a vis the data requirements as well as suitability in different hydrgeological environments, water table level fluctuation method is found to be most suitable for assessment of dynamic ground water resources, as water level fluctuation is the resultant of all inflows and out flows from the aquifer system.

Various thematic layers used in the present study for the all the river basin includes aquifer disposition, aquifer wise isopach maps, water level fluctuation maps and an exclusive layer of specific yield values attached with the aquifer polygons. Complete distributed approach was used for computing the ground water resources by overlaying a grid of size 250m X 250m for entire area available for assessment. After the grid wise computation, the same was integrated to arrive at basin wise and aquifer wise totals.

Further, since the GWD computes and reports groundwater draft on aquifer wise block wise, it is not possible to directly compare the draft to aquifer wise and basin wise resources. Therefore, an area weighted approach was used to re-compute the draft to GIS based aquifer polygons which were then used to deduct from total of resources to arrive at available ground water balance.

One of the major advantages of the present technique is creation of GIS database for the layers which are time invariant in nature such as aquifer boundaries or any other hydrological of administrative boundaries, aquifer parameters such as specific yield and rain fall infiltration factors. Since, the ground water recharge is dynamic in nature and highly dependent upon the spatial and temporal variations of rainfall, the manifestation of which is measured in terms of water level changes, the database created in GIS for all the time invariant layers would facilitate faster computations and the frequency of assessment may be increased, however that would require rigorous planning and protocol for spatial and temporal data collection.

5.2.1. Results of Dynamic Ground Water Resources

The assessment of dynamic ground water resources was carried out for all the 683 assessment units within the 249 Blocks and 33 Districts (as per GWD) which are parts of 19 Principal Aquifers identified in the state of Rajasthan. The assessment unit wise dynamic ground water resources is presented in the Annexure -D along with static ground water resources, total ground water draft and net balance.

Further the assessment unit wise resources was assimilated and integrated / summarized to represent the dynamic ground water resources aquifer wise and basin wise as given in table 5.2 and 5.3 respectively.

Table 5.2: Aquifer wise Dynamic Ground Water Resources (2010) of Rajasthan

Aquifer Name	Dynamic Ground Water Resources 2010 (mcm)
Basalt	773.33
BGC	425.82
Bilara Limestone	378.64
Gneiss	724.09
Granite	430.00
Granite Jalore	50.05
Limestone	590.76
Nagaur & Jodhpur Sandstone	863.43
Older Alluvium	7,385.99
Parewar Sandstone	6.76
Phyllite	847.47
Quartzite	366.60
Rhyolite	99.06
Sandstone	1,312.44
Schist	1,256.21
Shale	339.19
Tertiary Sandstone	468.20
Ultra Basic	4.12
Younger Alluvium	4,401.16
Total	**20,723.32**

From the following bar chart showing aquifer wise dynamic ground water resources , it may be observed that out of the total resources of 20.7 BCM, about 12 BCM (57%) is contained in the alluvial aquifers followed by aquifers made up of sedimentary rocks consisting of sandstone and limestone. The remaining aquifers represented by metamorphic / granitic suit of rocks has meager resources and development potential.

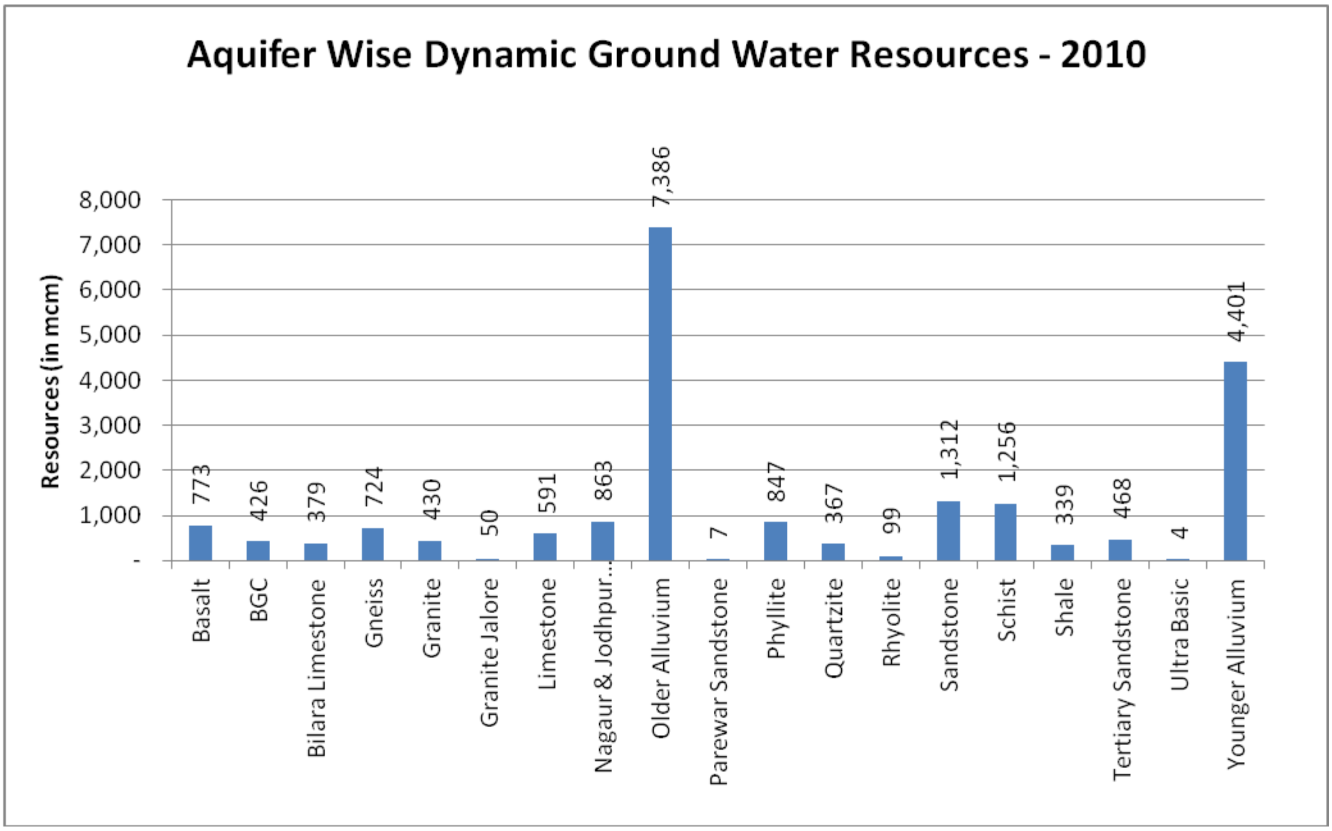
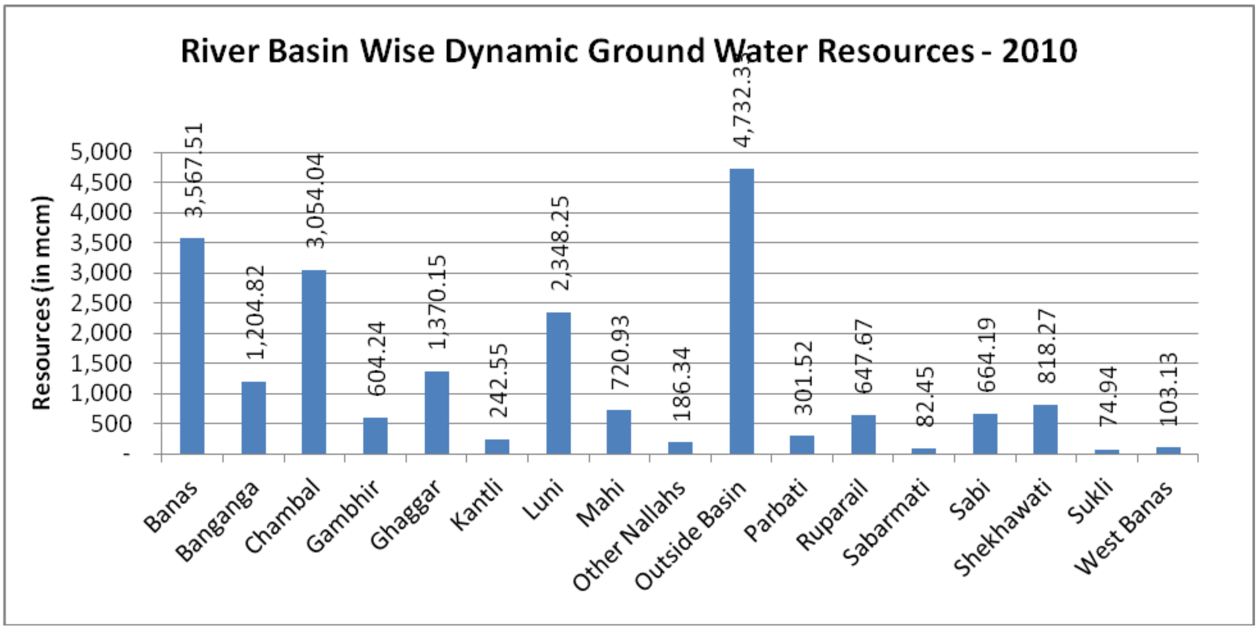


Table 5.3: Basin wise Dynamic Ground Water Resources (2010) of Rajasthan

Basin Name	Dynamic Ground Water Resources 2010 (mcm)
Banas	3,567.51
Banganga	1,204.82
Chambal	3,054.04
Gambhir	604.24
Ghaggar	1,370.15
Kantli	242.55
Luni	2,348.25
Mahi	720.93
Other Nallahs	186.34
Outside Basin	4,732.33
Parbati	301.52
Ruparail	647.67
Sabarmati	82.45
Sabi	664.19
Shekhawati	818.27
Sukli	74.94
West Banas	103.13
Total	**20,723.32**

From the following bar chart showing the basin wise distribution of dynamic ground water resources, it may be observed that about 67 % of the total dynamic resources is distributes in the Banas, Chambal, Luni and Outside basins because major part of these basins are underlain by alluvial aquifers.



The dynamic resources computed as above has further been assimilated basin wise and aquifer wise for representation purpose, this gives an overview of the resources available in different aquifers in a particular basin and vice versa. The same has presented in the table 5.4.

5.2.2. Saline Ground water Resources in the Dynamic Zone

The total saline ground water resource in the Dynamic zone was estimated as 1,024 MCM, the basin wise and aquifer wise breakup is given in Table 5.5. The saline ground water is limited to three basin namely Banas, Luni and Outside basin and Ghaghar sub basin. Nearly 50% of the total saline resources in the Dynamic zone are available in Outer basin underlain by Older Alluvial aquifer.

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Table 5.4: Aquifer and Basin wise Dynamic Ground Water Resources (2010) of Rajasthan

Basin/Sub Basin / Aquifer	Aquifer and Basin wise Dynamic Ground Water Resources- 2010 (mcm)																			
	Basalt	**BGC**	**Bilara Limestone**	**Gneiss**	**Granite**	**Jalore Granite**	**Limestone**	**Older Alluvium**	**Parewar Sandstone**	**Phyllite**	**Quartzite**	**Rhyolite**	**Sandstone**	**Sandstone Nagaur & Jodhpur**	**Schist**	**Shale**	**Tertiary Sandstone**	**Ultra Basic**	**Younger Alluvium**	**Grand Total Resource (mcm)**
BANAS	3.73	230.57		658.62			88.53	1121.78		118.66	19.66		53.01		816.85	122.78			333.33	3567.51
BANGANGA				5.31	2.50			929.57		4.53	107.76				7.41				147.74	1204.82
CHAMBAL	643.61			3.11			470.92	157.38		174.18	4.06		859.07		60.91	201.21			479.60	3054.04
GAMBHIR								505.17			6.13		92.94							604.24
GHAGGAR								58.37											1311.78	1370.15
KANTLI								163.57			38.43								40.55	242.55
LUNI		0.00	81.95	46.07	342.36	23.76	17.04	1106.80		115.59		8.94		19.94	104.16		24.21		457.44	2348.25
MAHI	125.99	195.25					14.27			328.98	0.02				37.09	15.21		4.12		720.93
OTHER NALLAHS					2.15			114.17				1.44							68.58	186.34
OUTSIDE BASIN			296.69	0.00	18.71	26.29		1528.62	6.76		35.58	88.69	173.84	843.49	88.58		443.99		1181.10	4732.33
PARBATI								167.94					133.58							301.52
RUPARAIL								591.67			56.00									647.67
SABARMATI					10.73					51.59	5.67				14.46					82.45
SABI								469.33			38.76								156.10	664.19
SHEKHAWATI				10.99				471.62			54.54				80.97				200.16	818.27
SUKLI					20.32					42.82									11.80	74.94
WEST BANAS					33.24					11.13					45.79				12.98	103.13
Grand Total Resource (mcm)	**773.33**	**425.82**	**378.64**	**724.09**	**430.00**	**50.05**	**590.76**	**7385.99**	**6.76**	**847.47**	**366.60**	**99.06**	**1312.44**	**863.43**	**1256.21**	**339.19**	**468.20**	**4.12**	**4401.16**	**20723.32**

Table 5.5: Aquifer and Basin wise Saline Ground Water Resources (2010) in Dynamic Zone of Rajasthan

Basin/Sub Basin / Aquifer	Aquifer and Basin wise Saline Ground Water Resources- 2010 in Dynamic Zone (mcm)																			
	Basalt	**BGC**	**Bilara Limestone**	**Gneiss**	**Granite**	**Jalore Granite**	**Limestone**	**Older Alluvium**	**Parewar Sandstone**	**Phyllite**	**Quartzite**	**Rhyolite**	**Sandstone**	**Sandstone Nagaur & Jodhpur**	**Schist**	**Shale**	**Tertiary Sandstone**	**Ultra Basic**	**Younger Alluvium**	**Grand Total Resource (mcm)**
BANAS				9.50				31.00							15.39					55.89
GHAGGAR								13.35												13.35
LUNI					55.20			220.84		12.82		5.74					0.66		66.12	361.36
OUTSIDE BASIN			4.37		12.46			277.25	1.82			44.65	37.96	23.30			110.65		81.42	593.88
Grand Total Resource (mcm)			**4.37**	**9.50**	**67.66**			**542.44**	**1.82**	**12.82**		**50.39**	**37.96**	**23.30**	**15.39**		**111.31**		**147.54**	**1024.48**

5.2.3. Observations

- ✓ Systematic primary and secondary data validation protocol was evolved applying various statistical / geo-statistical tools to check the data consistency in temporal as well as spatial domain. The water level and fluctuation data found erroneous, non-representative, inconsistent as well as the extremes in the form of outliers and inliers was removed from the data base
- ✓ After detailed analysis of water level fluctuation data in spatial domain and correlating with the rainfall it was observed that at several aquifers, there is significant rise in water level which is not in agreement with the rainfall, the possible reason could be significant lateral flow across the aquifer boundaries for which there is no specific measurement or parameter available. However, the ground water level fluctuation data meticulously observed and interpolated in spatial domain takes into account all the input and output from the system and is the resultant of all the stresses working on the aquifer during the period under consideration and hence, water level fluctuation methods was found more applicable in this case
- ✓ In the present exercise the distributed approach for spatial interpolation of water level was adopted through geo-statistical tools in GIS platform, the water level and fluctuation was computed on a regular grid of 250 m x 250 m which was then integrated to arrive at the fluctuation of individual aquifers units. The geo-statistical technique has advantage of incorporating spatial correlation through variogram models which overcomes the problem of in-homogeneities and outliers to larger extent. This value addition has brought the entire assessment close to the ground reality and systematically eliminated any spatial discontinuities
- ✓ Discrete values of the basic parameters such as specific yield and rainfall infiltration factor was used for individual aquifer assessment units
- ✓ Primary validation of water level and fluctuation data was made to eliminate any erroneous data, outlier / inliers or non-representative data. The pre and post water level fluctuation for the year 2010 was observed to vary between (-15m) and (+64 m)
- ✓ Further, the data was subjected to secondary validation using GIS based statistical tools in spatial domain using parametric methods to identified outliers or extremes in trends, after confirmation, the same was filtered from the data base to represent the true field conditions
- ✓ The negative fluctuation values exceeding (-2m) was observed at isolated points and hence all such values was filtered, similarly it was also observed that positive fluctuation values exceeding (15m) are very few in number and are at isolated points which are non-

representative or erroneous data and hence those data was also filtered and eliminated from the computation of dynamic ground water resources. The spatial distribution of wells showing fluctuation of water level in the range (-2m) and (+15m) considered for assessment of dynamic ground water resources is depicted in the map given at (Fig.35) From the map it may be clearly observed that the positive fluctuation is concentrated in the south-south east part of the state, however, the entire north and north western part the negative fluctuation is dominant irrespective of different type of underlying aquifer systems

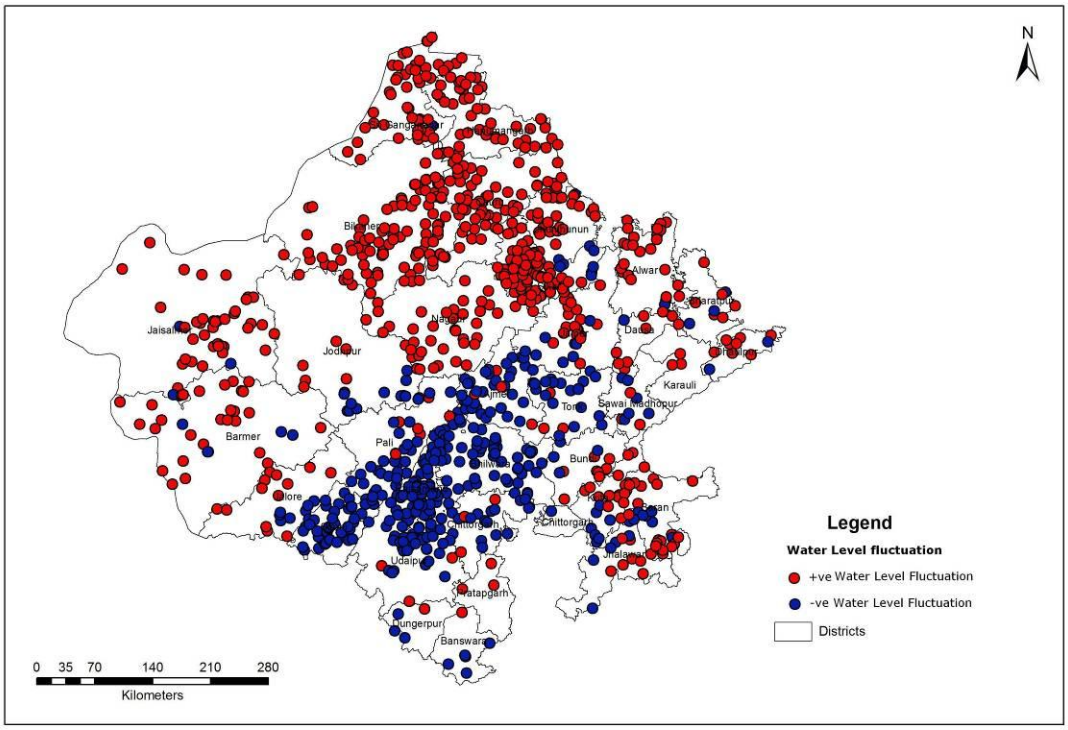


Fig.35: Wells showing water level fluctuation between -2m and 15m

- ✓ The isohyet of average rainfall for the state of Rajasthan is shown in (Fig.36), from the rainfall contours it may also be observed that the entire north and north western area with negative fluctuation fall in rainfall deficit zone where the average rainfall is less than 500mm. This in turn also indicates that the water level decline in the state is more correlated with stresses caused by external anthropogenic ground water withdrawal pattern rather than the natural recharge –discharge relationships.
- ✓ The data points identified as outliers / non representative or inconsistent excluded from the computation is shown in (Fig.37) From the map it may be observed that positive fluctuation of more than (15m) is concentrated in the southern part of the state around the districts of Pali, Rajsamand and northern part of Udaipur districts, which also coincides with the highest average rainfall area of the state. Similarly, the negative fluctuation exceeding (-2m) are concentrated in the extreme north, in the districts of Sri Ganganagar and Hanumangarh and

in the south eastern part of the state in the districts of Kota, Baran and Bundi. Surprisingly, majority of these districts fall under the category of overexploited and critical areas

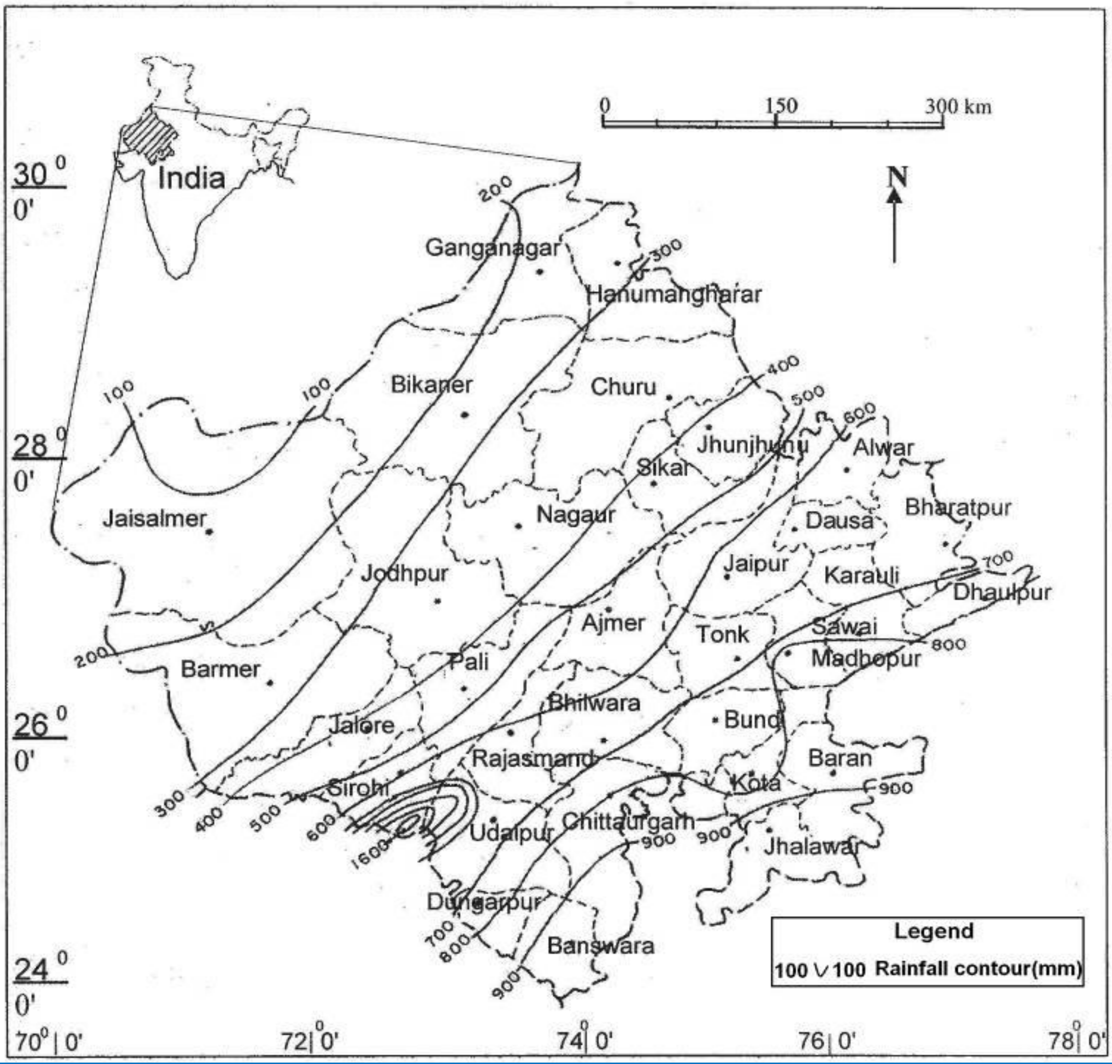


Fig.36: Isohyets of Average rainfall

- ✓ These extremes and outliers depicted in the map needs to be properly validated on the ground and attempt shall be made to correlate with the rainfall events and local ground water withdrawal rates. Otherwise, these extreme values in ground water level fluctuation may lead to in general over-estimation / under-estimation of dynamic ground water resources. At the same time it is essential to undertake limited field tests for determination of specific yield to authenticate the parameter values considered for estimation following GEC recommendations.

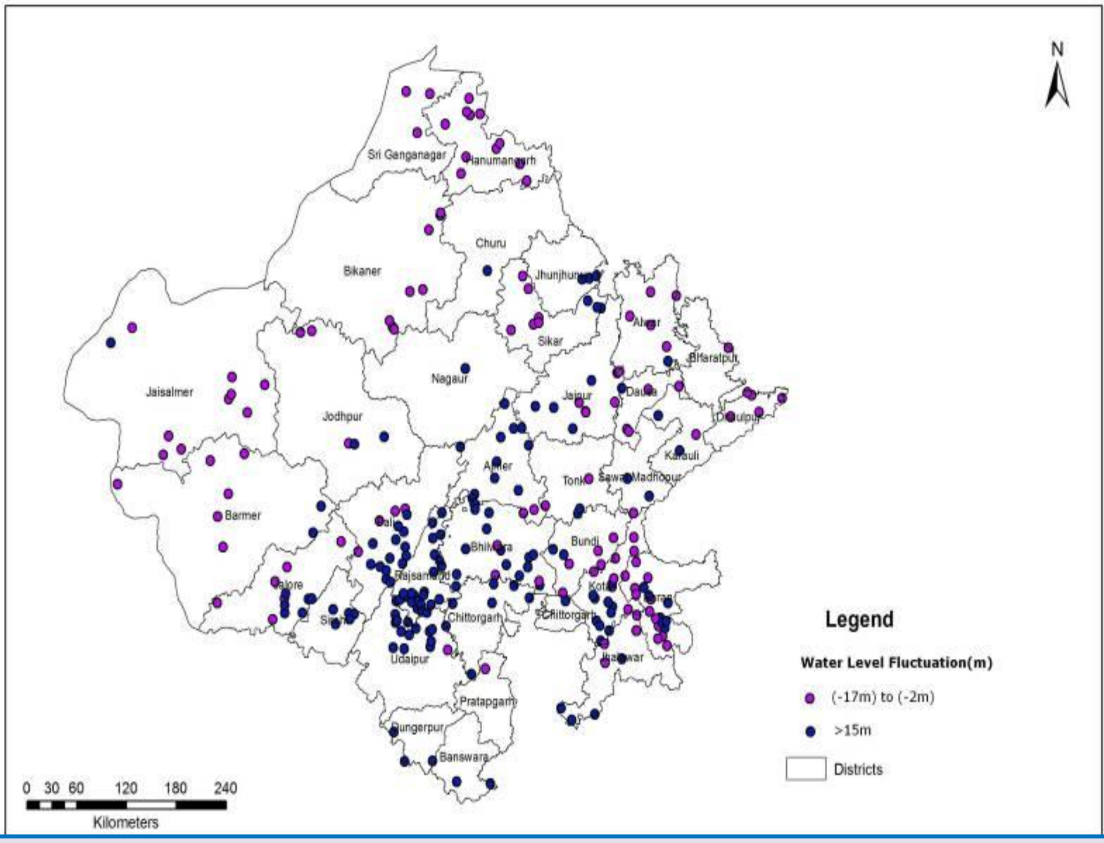


Fig.37: Well Showing Negative and Positive Water Level Fluctuation

5.3. About Static resources

As contemplated in the National Water Policy, the quantum of water available for development is restricted to long term average recharge or in other words to "Dynamic Resource". This indirectly indicates that the ground water resources available in the ground water fluctuation zone are generally available for utilization. However, the data of long term water level and their trends indicate that in areas with high degree of ground water development, water levels have not shown a significant declining trend. It is, therefore, considered that temporary depletion of water table taking place in drought years due to utilization of part of the static reserves available below the zone of fluctuation is made up in years of high rainfall or in other words the consequent depletion in water levels in drought years is made up during years of high rainfall. This may be studied by comparing the long term rainfall and the water table hydrograph to establish the periodical recharge. In such areas it would be desirable that the ground water reservoir be drawn to the optimum limit to provide adequate scope for its recharge during the following monsoon period.

This also necessitates the assessment of ground water reserve in the aquifers below the zone of fluctuation, at least to the prevailing exploitable depth or to the lower bound of the aquifer inferred from the ground water exploration programme. Hence, an estimate of static ground water reserve is desirable for overall planning the optimum utilization of the ground water resources of an area in future.

Keeping this in view an attempt was made to estimate the static ground water reserve below the zone of fluctuation. This is also a fact that as the ground water exploitation intensifies, there remains no sharp demarcation between the static and dynamic ground water resources as both the resources are linked with the water level changes and also the main source of recharge is same i.e. rainfall. The differentiation between the he two is influenced by topography, aquifer characteristics and external stresses on the aquifer system. It is also pertinent to mention that the source of recharge to both these components is common and it's only after the replenishment of the dynamic components, that the static reserve gets its share. The hydraulic relationships of static and dynamic components their potential as an individual entity are quite varied in the hard rock and alluvial aquifers and it is essential to understand and appreciate their responses in different hydrogeological environment before planning for development of static reserve.

5.3.1. Results of Static Ground Water Resources

The assessment of static ground water resources was carried out for all the 683 assessment units within the 249 Blocks and 33 Districts (as per GWD) which are parts of 19 Principal Aquifers identified in the state of Rajasthan. The assessment unit wise static ground water resources has presented in the annexure –D along with dynamic ground water resources, total ground water draft and net balance.

Further the assessment unit wise resources was assimilated and integrated / summarized to represent the static ground water resources aquifer wise and basin wise as given in table 5.6 and 5.7 respectively

Table 5.6: Aquifer wise Static Ground Water Resources (2010) of Rajasthan

Aquifer Name	Static Ground Water Resources 2010 (mcm)
Basalt	2,091.46
BGC	4,244.58
Bilara Limestone	18,394.79
Gneiss	4,400.46
Granite	4,359.44
Granite Jalore	858.4
Limestone	2,419.75
Nagaur & Jodhpur Sandstone	33,017.29
Older Alluvium	195,168.63
Parewar Sandstone	1,694.35
Phyllite	7,311.50
Quartzite	4,949.60
Rhyolite	2,691.54
Sandstone	30,650.48
Schist	8,885.31
Shale	1,148.48
Tertiary Sandstone	43,508.32
Ultra Basic	38.4
Younger Alluvium	1,00,419.47
Total	**4,66,252.26**

From the following bar graph shown above, it may be observed that out of the total static resources of 466 BCM about 63% is contained in the older and younger alluvial aquifer, the share of hard rock aquifers are meager.

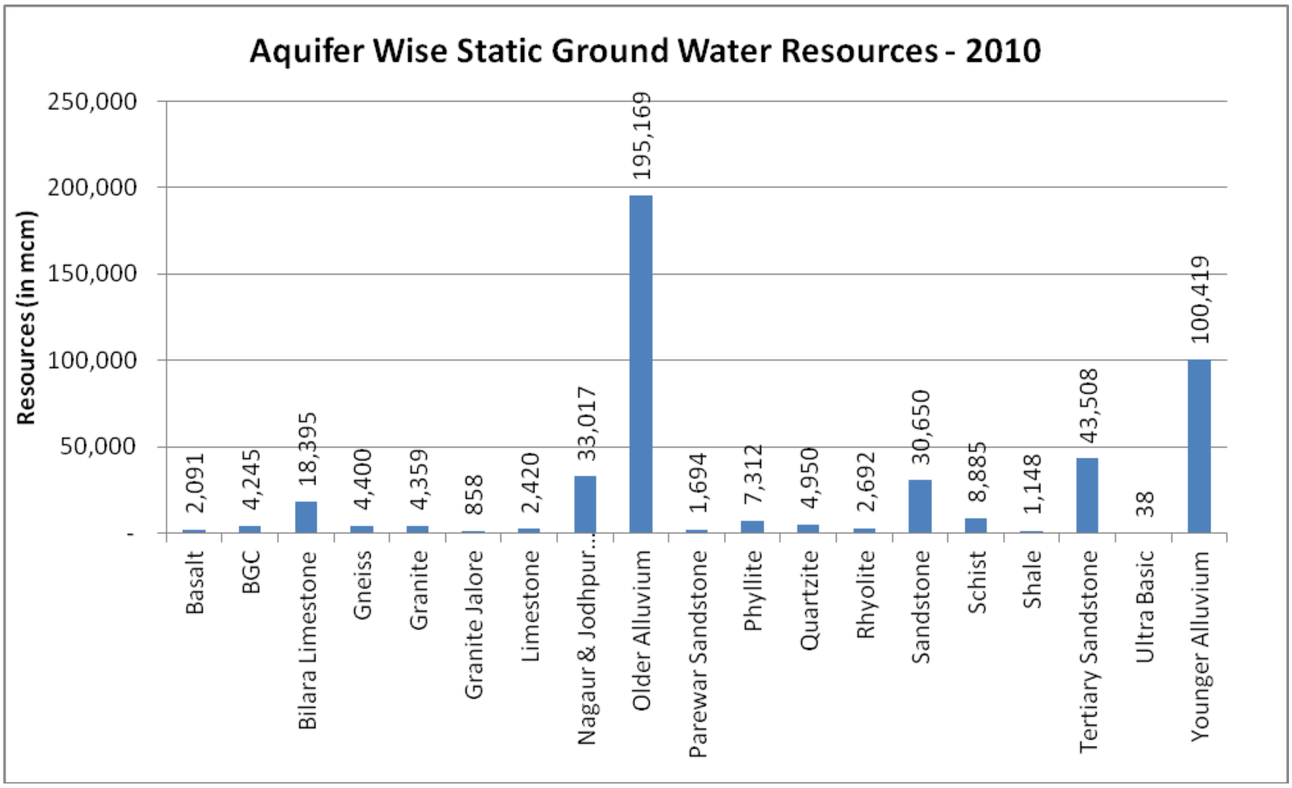
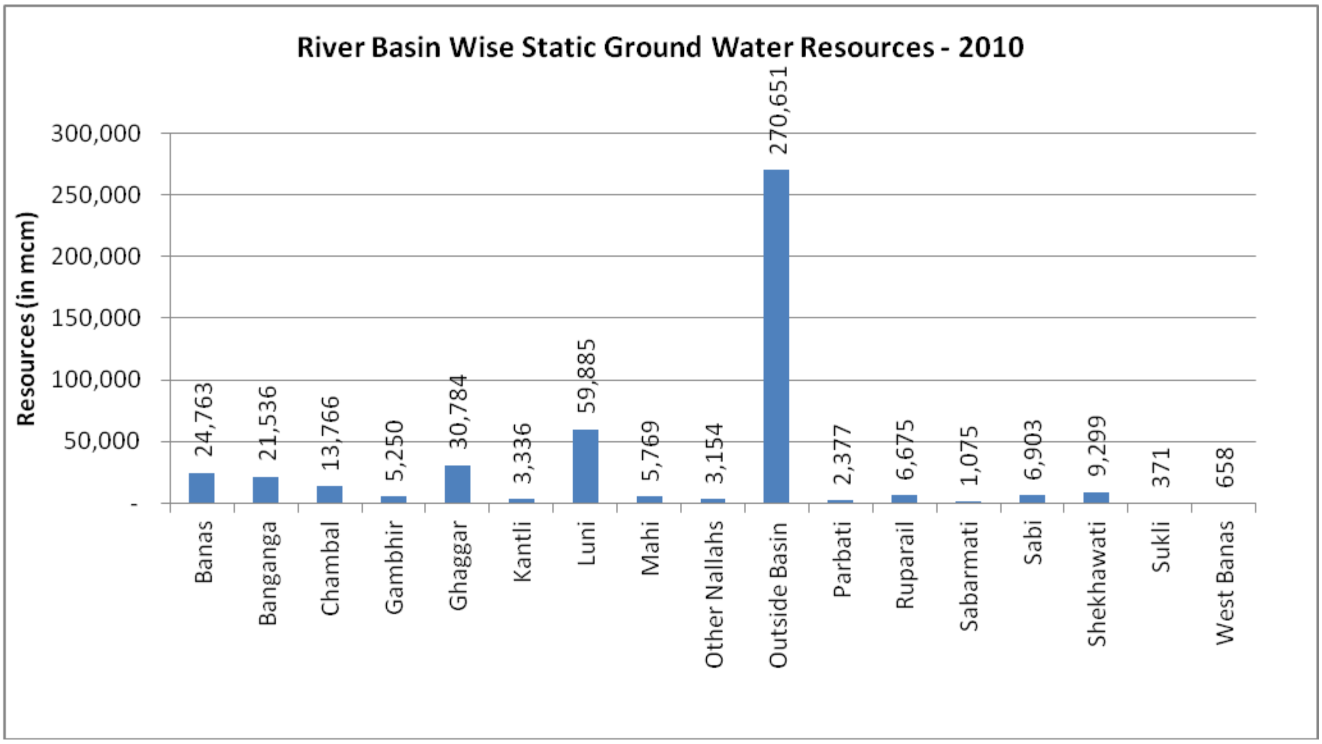


Table 5.7: Basin wise Static Ground Water Resources (2010) of Rajasthan

Basin Name	Static Ground Water Resources 2010 (mcm)
Banas	24762.85
Banganga	21535.95
Chambal	13765.94
Gambhir	5249.85
Ghaggar	30784.33
Kantli	3336.24
Luni	59885.02
Mahi	5768.63
Other Nallahs	3154.37
Outside Basin	270651.33
Parbati	2376.78
Ruparail	6675.34
Sabarmati	1075.40
Sabi	6902.81
Shekhawati	9299.33
Sukli	370.56
West Banas	657.52
Total	**466252.26**

From the following bar graph shown above, it may be observed that out of the total static resources of 466 BCM about 58 % is contained in the outside basin covering north and north western part of the state and mostly underlain by alluvial aquifer and semi consolidated formations.



The static resources computed as above has further been assimilated basin wise and aquifer wise for representation purpose, this gives an overview of the resources available in different aquifers in a particular basin and vice versa. The same has presented in the table 5.8.

5.3.2. Saline Ground water Resources in the Static Zone

The total saline ground water resource in the Static zone was estimated as 152 BCM, the basin wise and aquifer wise breakup is given in Table 5.9. The saline ground water is limited to three basin namely Banas, Luni and Outside basin and Ghaghar sub basin. Nearly 67% of the total saline resources in the Static zone are available in Outer basin underlain by Older Alluvial aquifer.

Table 5.8: Aquifer and Basin wise Static Ground Water Resources (2010) of Rajasthan

Basin/Sub Basin	Aquifer and Basin wise Static Ground Water Resources- 2010 (mcm)																			
Aquifer	Basalt	BGC	Bilara Limestone	Gneiss	Granite	Jalore Granite	Limestone	Older Alluvium	Parewar Sandstone	Phyllite	Quartzite	Rhyolite	Sandstone	Sandstone Nagaur & Jodhpur	Schist	Shale	Tertiary Sandstone	Ultra Basic	Younger Alluvium	Grand Total Resource (mcm)
BANAS	8.01	2676.53		3819.70			678.34	7541.54		889.03	199.82		259.18		5516.52	438.20			2735.97	24762.85
BANGANGA				174.79	95.18			15167.59		192.85	3025.07				264.78				2615.69	21535.95
CHAMBAL	1351.13			12.56			1270.33	1407.44		860.22	7.42		4886.45		384.08	667.60			2918.72	13765.94
GAMBHIR								4509.21			91.03		649.61							5249.85
GHAGGAR								5715.27											25069.06	30784.33
KANTLI								2597.90			272.99								465.35	3336.24
LUNI		0.02	1668.98	331.77	3118.95	338.40	388.53	37816.81		1265.74		138.44		475.99	876.41		597.19		12867.79	59885.02
MAHI	732.33	1568.04					82.55			3120.34	0.14				184.15	42.68		38.40		5768.63
OTHER NALLAHS					11.13			2386.59				16.70							739.96	3154.37
OUTSIDE BASIN			16725.81	0.00	666.44	520.00		99007.43	1694.35		186.97	2536.40	24048.65	32541.30	620.58		42911.13		49192.28	270651.33
PARBATI								1570.19					806.59							2376.78
RUPARAIL								6179.78			495.56									6675.34
SABARMATI					156.06					737.53	34.80				147.01					1075.40
SABI								4938.74			361.49								1602.59	6902.81
SHEKHAWATI				61.63				6330.15			274.32				599.89				2033.34	9299.33
SUKLI					101.65					186.93									81.98	370.56
WEST BANAS					210.02					58.86					291.89				96.75	657.52
Grand Total Resource (mcm)	**2091.46**	**4244.58**	**18394.79**	**4400.46**	**4359.44**	**858.40**	**2419.75**	**195168.63**	**1694.35**	**7311.50**	**4949.60**	**2691.54**	**30650.48**	**33017.29**	**8885.31**	**1148.48**	**43508.32**	**38.40**	**100419.47**	**466252.26**

Table 5.9: Aquifer and Basin wise Saline Ground Water Resources (2010) in Static Zone of Rajasthan

Basin/Sub Basin / Aquifer	Aquifer and Basin wise Saline Ground Water Resources- 2010 in Static Zone (mcm)																			
	Basalt	BGC	Bilara Limestone	Gneiss	Granite	Jalore Granite	Limestone	Older Alluvium	Parewar Sandstone	Phyllite	Quartzite	Rhyolite	Sandstone	Sandstone Nagaur & Jodhpur	Schist	Shale	Tertiary Sandstone	Ultra Basic	Younger Alluvium	Grand Total Resource (mcm)
BANAS				48.55				501.32							76.17				2735.97	3362.02
GHAGGAR								1250.152											25069.06	26319.21
LUNI					610.22			6342.316		243.33		98.27					63.017		12867.79	20224.97
OUTSIDE BASIN			199.10		412.22			21326.22	473.63			1323.70	5875.57	2304.15			21041.79		49192.27	102148.7
Grand Total Resource (mcm)	**0**	**0**	**199.10**	**48.55**	**1022.45**	**0**	**0**	**29420.02**	**473.63**	**243.33**	**0**	**1421.98**	**5875.57**	**2304.15**	**76.17**	**0**	**21104.81**	**0**	**89865.10**	**152054.9**

5.4. Results of Village wise Ground Water Resources Assessment

Onetime assessment of village wise dynamic and static ground water resources was carried out by area apportioning of the aquifer wise ground water resources at village levels using GIS and geo-statistical tools.

In total there are 41,597 villages, 249 blocks and 33 districts in Rajasthan. The district wise information is sorted alphabetically on administrative block, and then by Gram Pancayats and then by Village names. The Census of India village code is also retained for any future change tracking or for integrating this database with other statistical data of villages. Each village wise predominant aquifer was identified and presented in the table. Excluding this suitability of ground water quality for human and cattle consumption based on BIS standards and for use in agriculture purpose based on SAR values for each village also presented in tabular from. The final resources thus computed along with the ground water suitability for different purpose are then presented in as annexure-E.

6. Web GIS application

6.1. Purpose

Modern tools, techniques, technologies and applications have immense potential of bringing awareness among common people. Computer applications and Internet when adopted along with hydrogeology concepts working in the background are bound to bring the information and issues on groundwater in public domain. Any person whether a resident of Rajasthan or not will be able to know the ground water quality in each village of the state, ground water levels, rainfall and its distribution, trends over a period time on all these parameters.

To further make the information system more appealing, interactive and evolve a participatory approach to groundwater management in the state, unique tools have been developed that will help information updation and resource status on a day to day basis based on simple inputs from user end.

To meet one of the key objectives of the project that required stakeholder participation in groundwater management with emphasis on village level users, RGWD staff and others, Rolta had conceived and implemented a Web GIS application keeping all the requirements in mind. Series of meetings were held with stakeholders at different levels to gather information on their expectations. The same were documented, discussed and debated before finally implementing the same. The application is based on sound hydrogeologic concepts, innovative participatory solution and GIS technology which brings all the themes together for a unique solution.

Some of the challenges that can be met with on implementation of the web GIS application is listed below:

1. Information availability anytime, anywhere,
2. Basic information on geology, geomorphology, terrain, groundwater potential areas, drainage network etc,
3. Dissemination of information on distribution and location of key wells, tube wells, geophysical survey locations, exploratory well locations, rain gauge stations and information related to each of these in graphical and tabular form,
4. Deriving analytical insights, correlation among different factors affecting quality and quantity of resources based on historic data,
5. Participation of village level users in submitting and gathering basic information on groundwater, GPs to plan to manage the available resources better,

To address the above mentioned challenges, the proposed project aims at dissemination of hydro-geological, agricultural and rainfall related information among the stakeholders. The following project objectives are identified several User groups were identified and depending on expectations and requirements of each, specific modules were developed.

Further, to gather ground level inputs at village level, capability has been built into the system that will allow Authorized end users to feed water level and water quality information on frequent intervals that will be validated online and later by the RGWD staff and if found satisfactory can well be incorporated into RGWD database as authentic basic data input that can be used in future studies. This module also constitutes a firm base for expansion of data collection system and if operationalized successfully, then even a monthly water levels at village level is possible at no additional cost to the Department which will lead to significantly enhancing the database for the State.

6.2. User Management

User Groups

Currently there are seven levels of user groups as mentioned:

1. Guest user
2. Village Panchayat/WUG
3. Block level hydrogeologist
4. District level junior hydro geologist
5. Division level senior hydro geologist
6. Circle level: superintending hydro geologist
7. State level: chief engineer, government administrator, system/application administrator

Table 6.1: User groups and functionalities:

Tools	Guest User	Village: Village Panchayat/WUG	Block: Hydrogeologist	District Level: Junior Hydrogeologist	Division: Senior Hydrogeologist	Circle Level: Superintending Hydrogeologist	State Level: Chief Engineer	Government Administrator	System/ Application Administrator
Zoom in	√	√	√	√	√	√	√	√	√
Zoom out	√	√	√	√	√	√	√	√	√
Pan	√	√	√	√	√	√	√	√	√
Identify	√	√	√	√	√	√	√	√	√
Previous View	√	√	√	√	√	√	√	√	√
Next View	√	√	√	√	√	√	√	√	√
Overview Map	√	√	√	√	√	√	√	√	√
Display XY coordinates	√	√	√	√	√	√	√	√	√
Legend	√	√	√	√	√	√	√	√	√
Map snapshot	√	√	√	√	√	√	√	√	√
Print	√	√	√	√	√	√	√	√	√
Search	√	√	√	√	√	√	√	√	√
Map content	√	√	√	√	√	√	√	√	√
Bilingual Support	√	√	√	√	√	√	√	√	√
Selection	√	√	√	√	√	√	√	√	√
Redlining	√	√	√	√	√	√	√	√	√
Measure	√	√	√	√	√	√	√	√	√
Buffer Selection	√	√	√	√	√	√	√	√	√
Search by coordinates	√	√	√	√	√	√	√	√	√
Generate URL	√	√	√	√	√	√	√	√	√

Table 6.2: Mapping of tools with user groups

Tools	Guest User	Village: Village Panchayat /WUG	Block: Hydro geologist	District: Junior Hydro geologist	Division: Senior Hydro geologist	Circle: Superintending Hydro geologist	State: Chief Engineer	Government Administrator	System/ Application Administrator
Document Viewer		√	√	√	√	√	√	√	√
Pre-generated reports		√	√	√	√	√	√	√	√
Resource assessment tool at village level – data updation or view		√	√	√	√	√	√	√	√
Water level chart		√	√	√	√	√	√	√	√
Water Quality chart		√	√	√	√	√	√	√	√
Rainfall probability chart		√	√	√	√	√	√	√	√
Rainfall deprecation chart		√	√	√	√	√	√	√	√
Long term rainfall variation chart		√	√	√	√	√	√	√	√
Block wise water quality variation chart		√	√	√	√	√	√	√	√
Change password		√	√	√	√	√	√	√	√
Manage requests for user creation									√
Manage requests for village level resource data updation			√						√

Login Module

The application shall initially display a landing page. It shall display links as follows:

- Home
- Glossary
- Gallery
- FAQ
- Ground water facts
- MIS reports :
  - Well summary report
  - Block wise summary report
  - Basin detail report
  - Block wise water quality chart
- My village
- Public/Reports
  - River Basins Reports
  - Annual Report

- Brochures
- Ground water standards
- GEC guidelines

- Contact us
  - Departmental Offices
  - Departmental officers
- About Us
  - About RGWD
  - Organisation
  - Mission
  - Vision
  - Machine Power/Manpower Reports
- Tenders/Circulars
  - Tenders
  - Circulars
  - Orders
  - Notification forms
  - Guidelines
- Other departmental Links
- News feeds & departmental updates

The MIS reports shall enable the users to access the following:

- Well summary report: Quick display of district wise monitoring wells and shall consist of details of all type of wells like Piezometer, exploratory etc.
- Block wise summary report: Display of status in terms of categorization of blocks in various assessment years & display of district wise block category as per latest ground water assessment reports.
- Basin detail report: Display of aquifer basins & corresponding districts.
- Block wise water quality chart: Analyze the block wise quality charts for ions like Chloride, Fluoride, Nitrate and Total dissolved solids. The percentage range and the appropriate colors are indicated in the legend.

My village

My village shall display information for the selected village. User shall have an option to select the village from the list of available villages based on the district, block, grampanchayat etc. The output for "My village" shall consist of the following details:

- Population,
- Area (sq.kms),
- Predominant Aquifer Type,
- The suitability of available water for both human, cattle and agriculture purposes,
- Dynamic resource quantity,
- Static resource quantity

Reports link shall include reports like river basin, previous year assessment related reports etc. All these reports shall be available to users accessing the application. Contact us shall include information regarding departmental officers and offices. News feed shall be also displayed on the landing page for the user to be updated with latest highlights in the Rajasthan state regarding ground water facts. The news shall include both RSS feeds and internal departmental news.

Fig.38: Landing page of the web site

New User creation

The application allows for new user creation. Ideally the users at Village/ Panchayat level could be added through this. The village users need to send a request to the system administrator by updating the required information in the defined format with the set of optional and mandatory fields as given viz. Name*, Address, Phone No, Email Id*, Designation*, District *, Block*, Grampanchayat*, Village*, Remarks

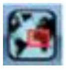
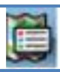
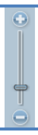
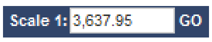
The requests will be displayed to the administrator along with the submitted details and the admin shall be provided an option to accept, reject or assign the status as on hold. Finally on approval, a new user will be added and will be informed about the acceptance of request through email.

6.3. GIS Mapping Interface

6.3.1. Tools

On logging into the system by any user, the user can view map containing information about ground water and related data, e.g. administrative boundaries, river basin, wells etc. User shall be able to view initially the complete Rajasthan state map on the map viewer. The list of layers that are made available for a user to browse, are mentioned in the above section 2.5.

The following tools are available for user the browse through the map data.

Tool icon	Name of the tool	Description
	Zoom In	Zooms in the map enter by clicking the map or by dragging the tool across the map to draw a shape. The map is then zoomed in to the area defined within that shape.
	Zoom Out	Zooms out the current map.
	Drag Pan	Pans the map as you drag the tool across the map.
	Identify	Displays information about a feature. Click the identity tool and then click an area on the map. Select the feature type that you want to view and all information associated with that feature is displayed.
	Previous View	Changes the view back to the previously displayed map view.
	Next View	Changes the view to the next map view in the sequence. This button is only available if user has clicked the previous map button at least once.
	Overview Map	Displays a miniature version of the full map and indicates the currently displayed map with a red rectangle to show where it is in relation to the full map.
	Display Coordinates	Turns on or off the set of coordinates in the lower right area of the map viewer.
	Legend	Displays the legend for the map.
	Navigation Tool	When viewing a map, several buttons display in the lower-left corner of the map that allows user to quickly pan or display the full extent of the map
	Map Slider	Map slider to quickly zoom in or out on the map. Move the slider up to zoom in or move the slider down to zoom out.
	Map Scale	The map scale represents the ratio of a distance on the map to the actual distance on the ground. Being able to change the map scale lets user can define how large or small user want to display the map. Depending on the map, user can either enter a number to define the map scale or select a map scale value from a list.

6.3.2. Functionalities

Identify

This helps in getting information related to the feature selected.

Selections

This functionality allows objects to be selected for query of reports.

Redlining

Redlined objects could be stored for discussion among user groups and shared with others. User can draw different types of shapes (point, line, polygon, circle, and rectangle), place custom images, or add text labels on the map. Any number of shapes, custom pages, or text labels can be marked on the map. In addition, user can delete a mark-up or edit it as well.

Document Uploader

Application has the functionality to select one or more graphic object (GMS points, Geophysical survey location etc.). User can select related documents with the help of guided steps from their local machine and upload them. These documents are uploaded to the database and automatically linked to the selected object.

Generate URL

The users can email a link/ of the map to other users so that when users click the link, the map will open to the same area and zoom level that you had selected when user has generated the link.

Printing

Printing facility is provided to the users and multiple types of printing are supported as described below:

- Map – includes legend; can be displayed in a new browser page or as a PDF file; both Landscape and Portrait modes are available.
- Map with selections - includes legend; includes a list of IDs of the selected features on the map; can be displayed in a new browser page or as a PDF file; both Landscape and Portrait modes are available.

Document viewer

User shall be able to view associated documents attached to any of the graphic river basin polygons for getting the info. The documents can be of three types: 3D model, fence and cross section.

Pre-generated reports

User can view the pre-generated reports saved in a particular folder linked to the web application. The web application shall display the folders and the static reports stored in the desired location.

6.3.3. Unique customized functionalities

6.3.3.1. Search

Creating systematically arranged data and porting the same on web is not an end in itself. The differentiator between a typical web based application and that based on GIS is its spatial query capability which is an added dimension. Rolta has conceptualized a set of queries that may be required to be answered by the system from time to time by different users. The following list summarizes the ones that can be readily run to fetch results.

1. **Locate ground water monitoring stations:** To locate ground water monitoring stations based on selection of district, block and agency.
2. **Well water quality:** To locate wells based on locational information like district, block, Grampanchayat and village along with well details like well type and depth information. Based on the combination of the above desired values the wells shall be selected and displayed on the map.
3. **Locate wells based on ownership and type:** To locate wells based on the on locational information like district, block, grampanchayat and village along with well details like agency and the well type like Piezo meter (PZ), PZ-DWLR etc.
4. **Locate wells based on well type and information:** To locate wells based on the on locational information like district, block, grampanchayat and village and well details like well type, Aquifer and basin name.
5. **Locate block Headquarters:** To locate block headquarters based on district name and headquarter name.
6. **Locate geomorphology based on patterns**: To locate geomorphology based on subtype like Alluvial fan, alluvial plain, Flood plain etc. The results displayed will be the selected geomorphologic unit in the whole state.
7. **Locate water bodies:** To locate water bodies based on the type and name of the water bodies.
8. **Locate Aquifers:** To locate aquifers based on the type of aquifer like Younger Alluvium, Schist etc.
9. **Locate area having specific concentration ranges for a parameter:** To locate areas based on the following criteria:
   - Fluoride concentrated area :Fluoride concentration greater than or less than 15 m
   - Saline area :Electrical conductivity (µs/cm) > 3000
   - Unsuitable for drinking: Electrical conductivity (µs/cm) < 3000, Cl (mg/l) < 1000, Fluoride (mg/l) < 1.5 ppm.

6.3.3.2. Village User interaction

Village level resource assessment

Groundwater being a hidden resource, it is generally perceived that water is perpetually available and can be extracted more if we dig deeper. By just looking at the water level in the well it is impossible to visualize how much of the resources would be available and how long it will last. To answer these basic queries, a simplified Village Resource Index has been conceptualized and computed for each village (the detailed methodology of arriving at the index is discussed elsewhere in this report).

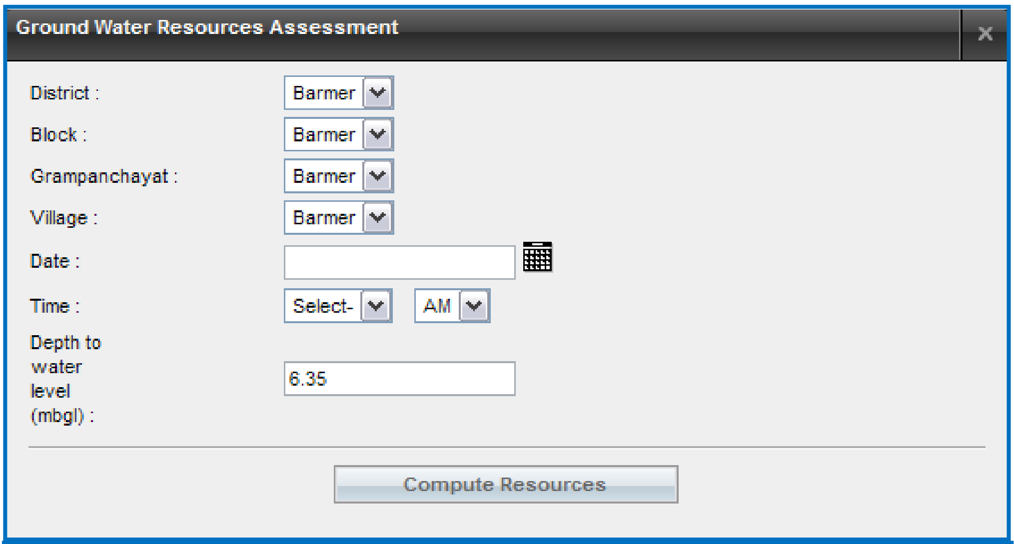


Fig.39: Village Level Resource Assessment for Non Authorized User

It just requires current date 'depth to water level' information from user in addition to date of WT data collection along with location of the well (Fig.39); and based on predefined parameters and formulae, it computes the water resource for the village on the date of measurement and reports the estimated resource to the user. Assuming a fixed (using standard) volume of water requirement for a domestic user, the net balance of water is arrived at. This readily gives user an idea whether Dynamic resource is available in the village or he is extracting water from Static resources which are not recommended for use by the State.

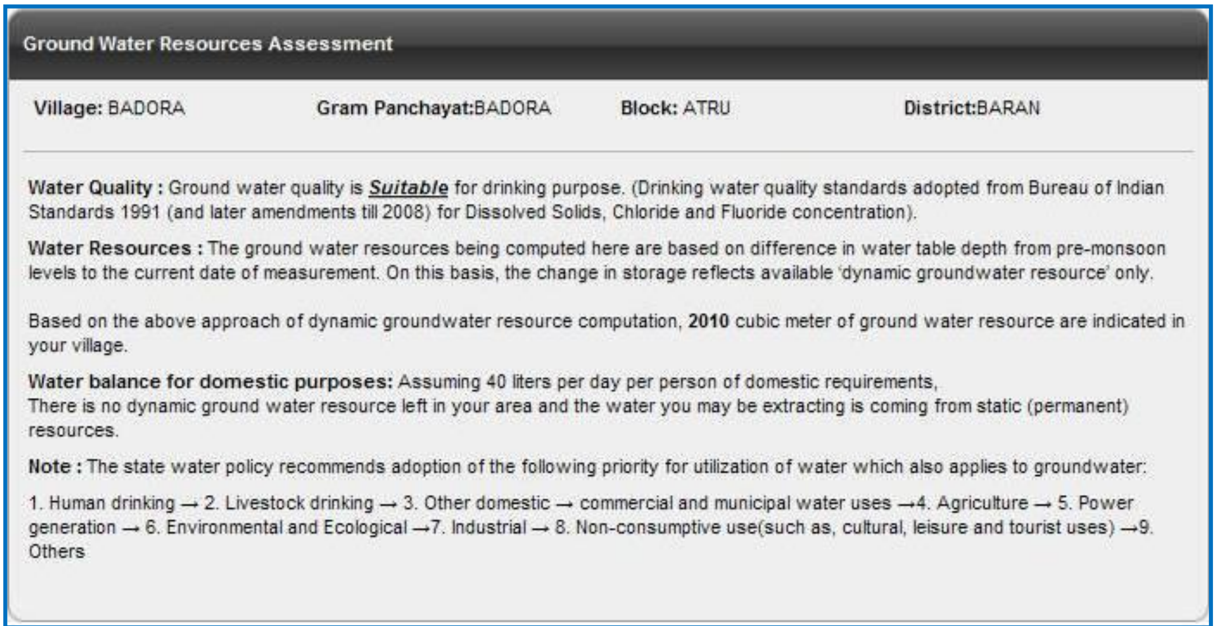


Fig.40: Resource summary when no resources are left as on date of measurement of WT

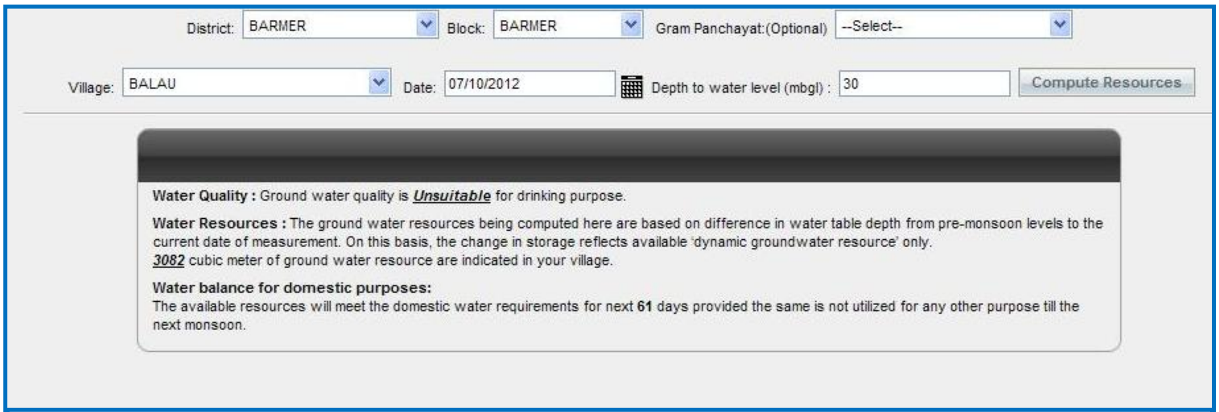


Fig.41: Resource summary when some resources are available as on date of measurement of WT

The above two screens appear based on the available resources with messages. Based on the computed output resource volume the villagers may take a cautious approach in its usage.

Groundwater related inputs from authorized users

Provision has been kept for authorized Water User Groups to provide inputs to GWD on basic parameters like water quality, water level and rainfall for a particular village (Figure No. 42). On providing minimal training to the WUG representatives, this may be made operational which has immense potential of data gathering and participatory groundwater management.

A dialog box as given in picture below would allow entering the following details:

- Depth to water level (mbgl)
- Electrical Conductivity,
- Chloride,
- Nitrate,
- Fluoride
- and pH (optional)
- Rainfall in mm (optional)
- Date (calendar)
- Time

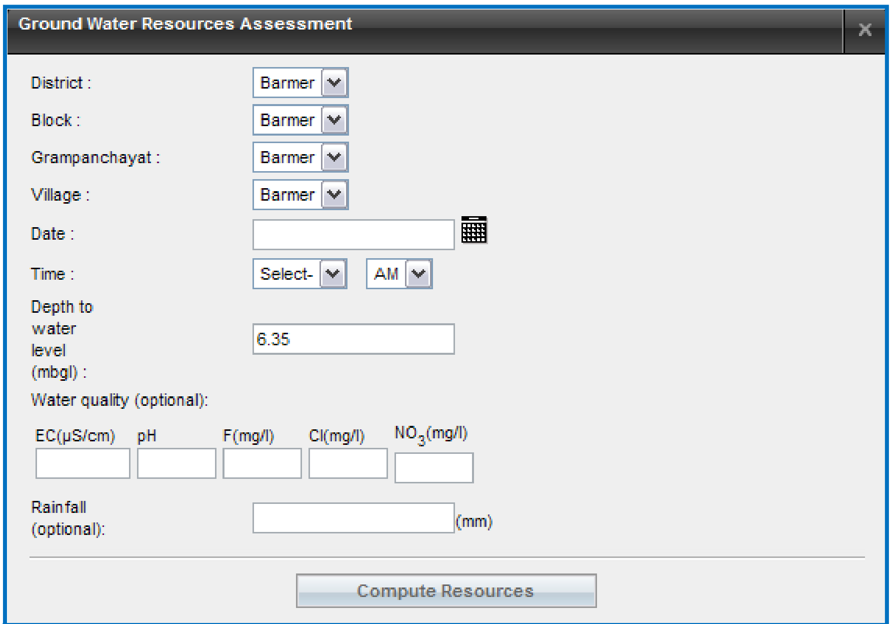


Fig.42: Input Form for Receiving Village Level Groundwater Information from Authorized User

Only authorized user will be able to enter the above information.

The values as entered by the authorized user shall be submitted for one level of verification to the hydro geologist at the block level.

Realizing the possibility of receiving incorrect information from the users, an additional step of verification is built into the system that takes the input value (from user entered screen) and validates it against predefined water levels for the village based on historic records. On verification if the data entered by the user is found to be varying in the historic range, the system allows the data to be submitted to the Department for another check and then acceptance.

The hydro geologist at the block level shall verify the updated values and shall have an option to accept or reject the request.

On accepting the updated values by the village users, the values shall be recorded and on rejection the status of the request will be updated to reject.

6.3.4. Analytical Graphics

For advanced users like the hydrogeologists and geophysists of RGWD, it is always helpful if they are able to get long term data of a location presented in one view in order to identify trends in water level, quality and rainfall. This section presents the different ways the data is being analyzed and presented graphically.

6.3.4.1. Water Level Charts

The water level chart shall enable the users to select the duration for which data is to be displayed and season. On selection of a particular well the data for the same is displayed. The key feature of the display is simultaneous presentation of trend and the depth to water for each year is split into saturated and unsaturated thickness presented in different colours in proportion to the total well depth.

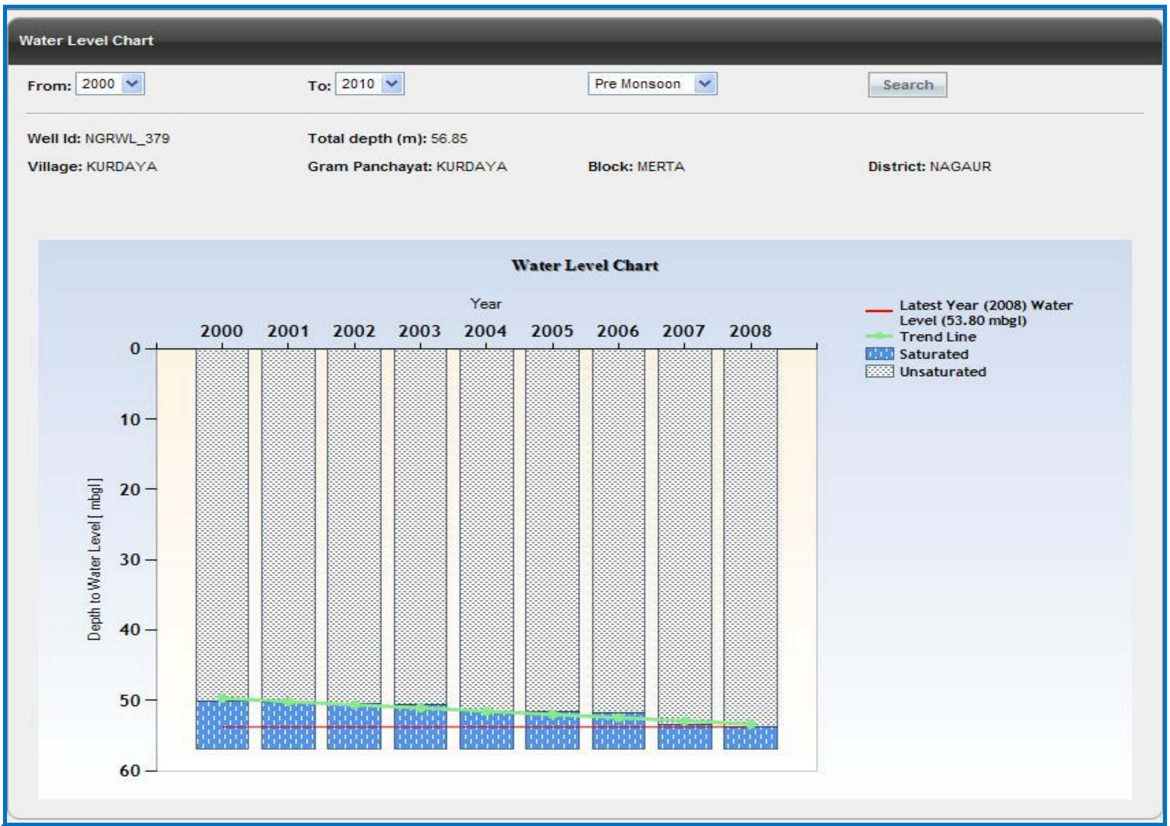


Fig.43: Water Level Chart

6.3.4.2. Long Term Rainfall Charts

This functionality allows user to prepare rainfall charts rainfall departure (Fig. 44) and rainfall probability chart (Fig. 45) for the desired rain gauge station & selected time period.

Fig.44: Rainfall Departure Chart

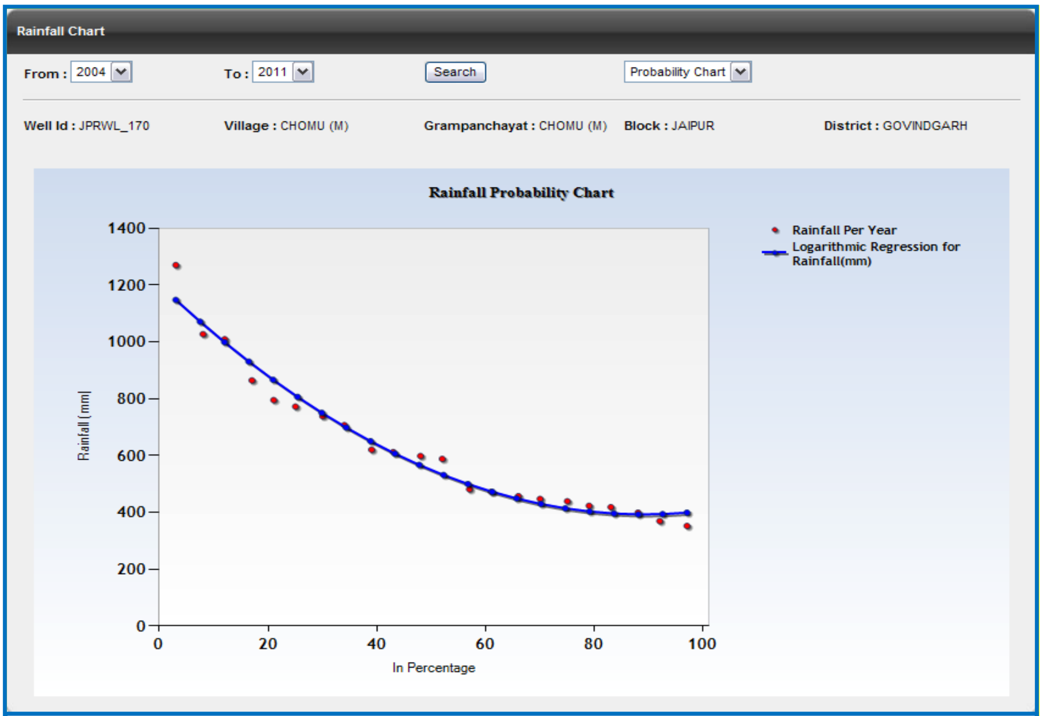


Fig.45: Rainfall Probability Chart

6.3.4.3. Well wise water quality chart

Location specific (village wise well data based) water quality chart can be quickly be prepared by only selecting the year for which data is to be viewed. A pie chart each for Anions (Cl, SO4, CO3-HCO3 and NO3) and Cations (Na, K, Ca and Mg) is displayed separately.

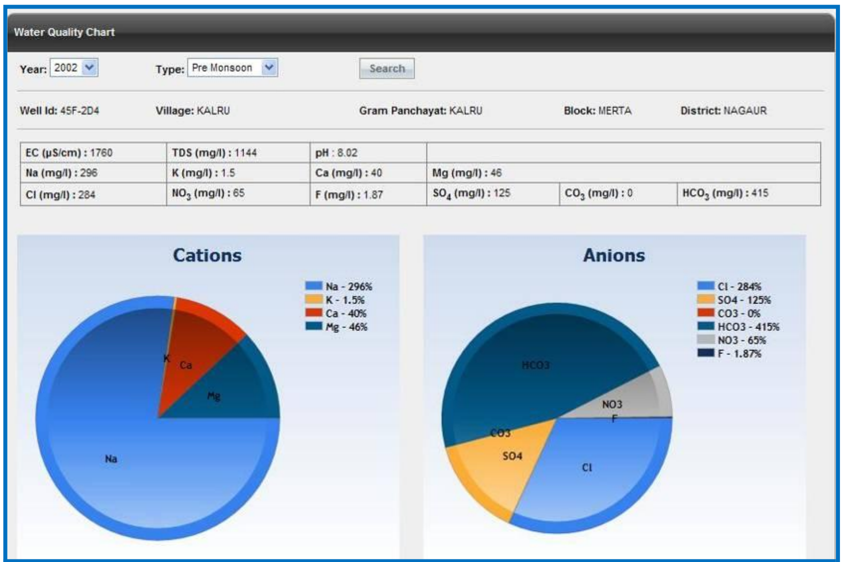


Fig.46: Water Quality Chart

6.3.4.4. Block wise water quality variation charts

As specifically requested by the Department, this customized pie chart has been designed. It allows long term water quality variation for selected key parameters be analyzed and trends be plotted graphically where the angle of pie is in proportion to the %age of samples in the block representing deterioration or improvement grouped in four classes. Currently it has displays variation in terms of EC, TDS, F, Cl and NO3 of the selected Block.

Fig.47: Block Wise Water Quality Chart

7. Training and Capacity Building

7.1. Introduction

The global scene is changing fast and with the advent of computers and softwares to handle complex data, it is now possible to interpret the data in very short time as compared to that in the past. Rajasthan GWD has a pool of Hydrogeologists, Chemists and Geophysists who are engaged in carrying out systematic data collection, interpretation and publication of results in the form of different reports from time to time. To internalize the new developments in the domain and to keep up with technology, the Department has been sending out its employees for short and long duration trainings to different organizations to learn and implement the same.

As part of ongoing projects from EU funding, the Department has procured several softwares that are relevant to the work of a hydrogeologist in simplifying their work and also the Department had some softwares in its possession already.

To achieve one of the goals of the current project, Rolta had undertaken capacity building in the Department for carrying GIS work through systematic training to its nominated officials. The intent of carrying out the user training was to specifically raise the awareness levels among all the concerned staff of RGWD on the GIS technology, the set of RASA tools softwares that the department had procured and to train them on GIS based groundwater resource assessment methods that Rolta had adopted for current project.

We had adopted a systematic approach wherein we initially interacted with key staff at RGWD and understood their current levels of skills and mapped them to the anticipated awareness levels. This was done through a need assessment study.

7.2. Training need assessment study

We had conducted meetings with RGWD Core Team, and developed a broad understanding of individual roles and responsibilities, and the current stage of computer exposure, software knowledge and availability of software at the disposal of the staff. We had also interacted with the district level concerned staff at the time of data collection stage and documented the information on the same points.

Secondly, having full understanding of the ongoing project, we prepared a matrix that defined the requirements of skill set for executing the project tasks.

Later a gap analysis was carried out between existing knowledge base and skillsets vs requirements, which clearly brought out the areas where the capacity in the department needs to be built through training.

7.3. Training Plan and execution

A training plan was thus worked out which had the details like, the contents of training, number of days that would be required to impart the training which was led to scheduling of sessions, locations wherein the same needs to be delivered, identification of staff for undergoing training, infrastructure requirement and timelines. Accordingly, training materials were prepared consisting of presentations, handouts for hands on sessions and tailor made exercises for practicing with their own data.

A comprehensive training preparation was completed and the sessions were organized in the form of training program for the GWD professionals from 17th September 2012 to 12th October 2012 at Jodhpur and Jaipur RGWD premises. For the sake of convenience of participants and keeping in view the infrastructure available, four separate batches were formed consisting of 71 shortlisted staff of RGWD and some invitees from other Departments.

While the above sessions were purely to impart knowledge and build capacity to enter the data, prepare maps, interpret them and analyze using softwares, separate training modules were given earlier in the month of February to selected staff of RGWD to handle the DGPS equipment and related issues. The DGPS (Differential Global positioning System) training had also been so structured that it led to complete knowledge of concepts of DGPS, equipment supplied, related softwares, calibration and carrying out differential correction with lab as well as field exercises.

It was mutually agreed that the capacity building will be two pronged wherein an extensive training on all related aspects be given to all shortlisted staff and a separate session of advanced training be given to further shortlisted staff who would be trained in further detail which would be called ‘training of trainers’ who would be specifically responsible for carrying out the analysis themselves once the project is over.

7.4. Designing of Training Modules

The following training modules were conceived in consultation with RGWD and implemented later in actual sessions:

- Basics of GIS and Remote Sensing,
- Geospatial data preparation and thematic mapping,
- Concept of RASA tools and their application,
- Working with Aquachem, Surfer and Rockworks,
- Overlay analysis, Querying on data and deriving conclusions,
- Overview of assessment methodology of GEC and integrated GIS approach,
- Village level resource apportion and
- Village resource Index computation for Web GIS Application

7.5. Training on Geo-Spatial Data Creation

7.5.1. On GIS and Remote Sensing through Rolta Geomatica

Rolta provided the training to the Key professionals on the Geographical Information System (GIS) and Remote Sensing using Rolta Geomatica with hand on exercises. Geographical Information System (GIS) is the backbone for planning, development, management and monitoring. Essentially it seeks to integrate a large range of spatial and non-spatial information with respect to topography and other spatial information. A geographic information system allows you to bring all types of data together based on the geographic and locational component of the data. But unlike a static paper map, GIS can display many layers of information. This allows integrating, visualizing, managing, solving, and presenting the information in a new way. Relationships between the data will become more apparent and the data will become more valuable.

During the training course the process of GIS creation was explained with hands on practice to the participants so that they can further utilize the GIS system in course of time. It will enable the key professionals to update their maps (Administrative, Hydrogeology, Ground Water Potential Zone, and Geomorphology Maps) on frequent basis.

Fig.48: GIS Overview

Training topics include history of GIS, Introduction to GIS, What is GIS, Data model in GIS, GIS data structures and Sources of data, Overlay analysis, querying the data, map layout preparation etc.; and on Remote Sensing, the topics related to the basics of Remote Sensing, image acquisition, processing, interpretation and integration of outputs with other GIS thematic maps.

Hands on exercises included execution of the knowledge gained above through Rolta Geomatica software.

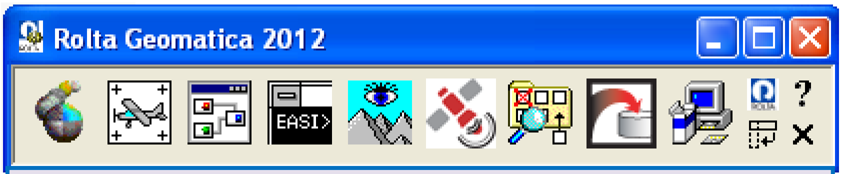


Fig.49: Rolta Geomatica

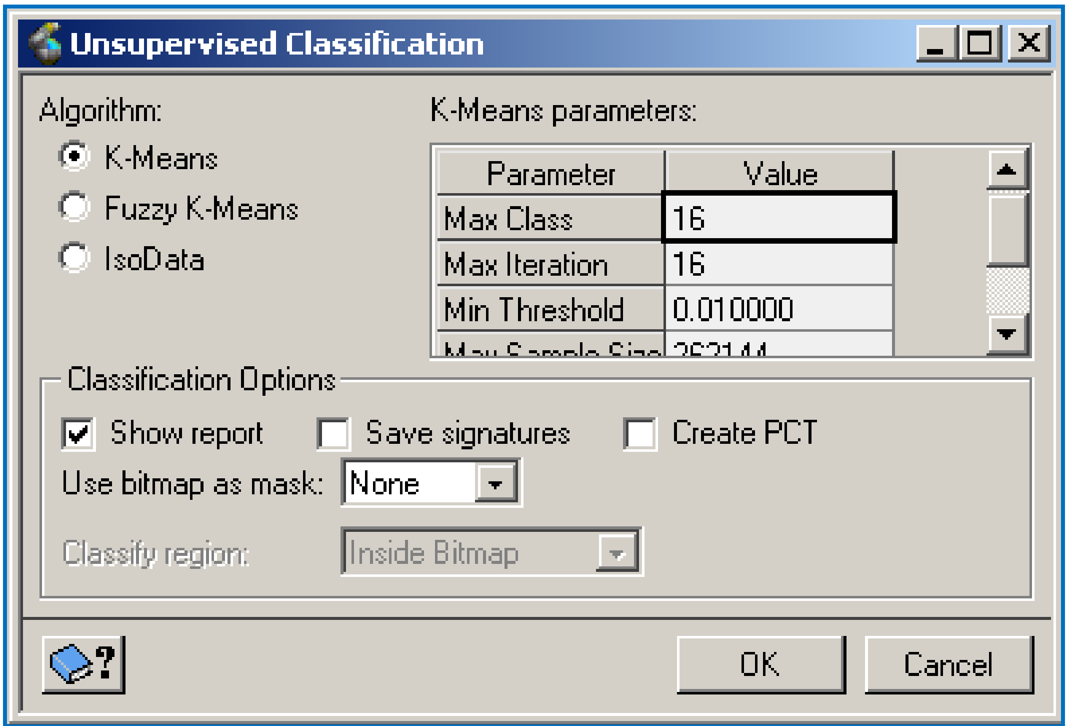


Fig.50: Unsupervised Classification

The detailed methodology of scanning, geo-referencing, mosaicing, data capture, geo-spatial data creation and spatial analysis was presented in the submitted technical report – 4.

7.5.2. Analyzing water quality data using Aquachem

Topics covered during the sessions included data requirements, entering water quality data and arranging, importing the data into the software, different types of diagrams that can be prepared for viewing and analysis of data (e.g., Piper's trilinear diagram, Stiff's polygon diagram, Durov and Extended Durov's diagrams, Wilcox diagrams etc.). Very importantly, the methods for integrating the graphics with maps were also explained for better correlation with ground scenario and spatial analysis of the data.

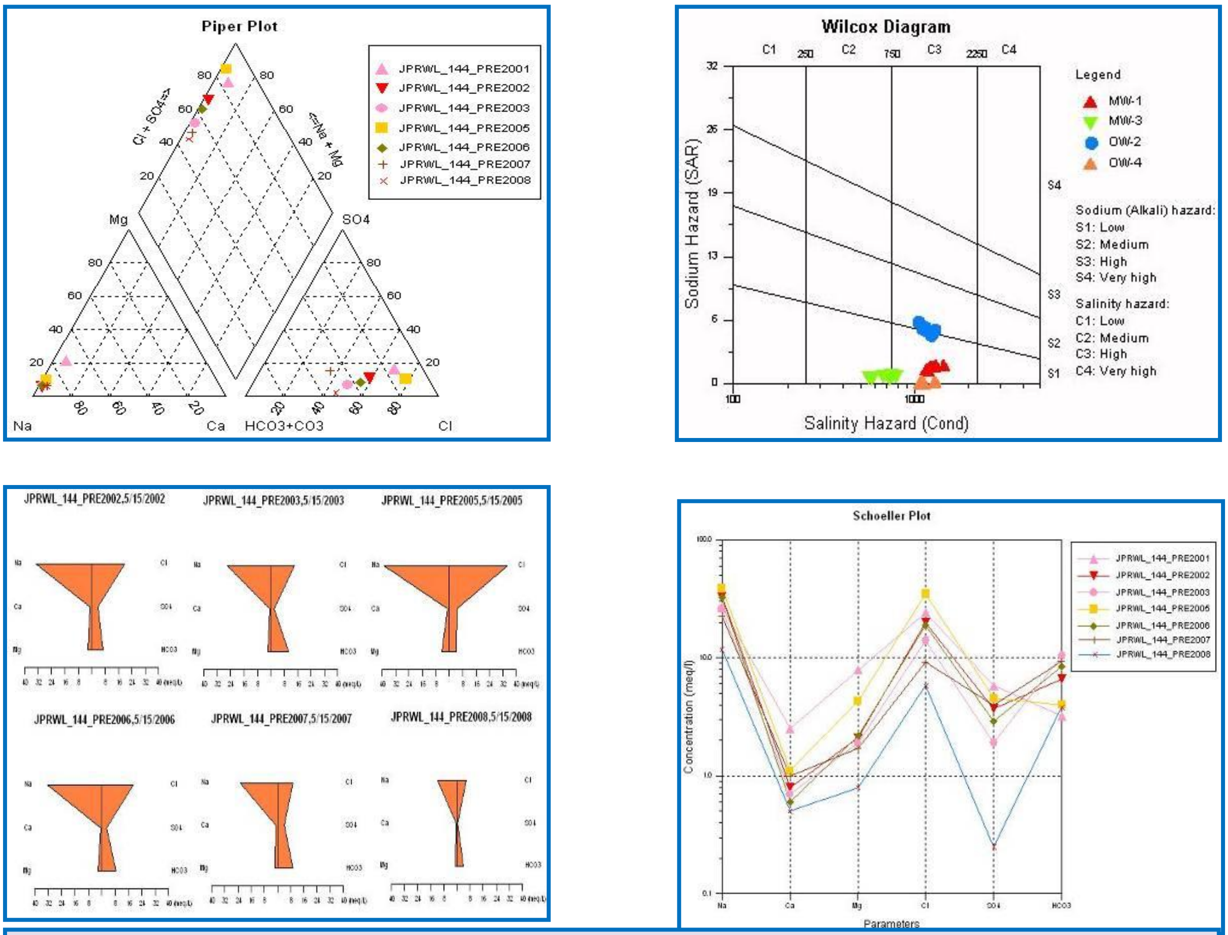


Fig.51: Water Quality Plots using Aquachem

7.5.3. Preparing contour maps using Surfer

Surfer software allows preparation of contours maps very quickly through very simple steps. The training sessions included input data preparation, types of maps that can be created by hydrogeologists to simplify their day to day work, Overlay with other data, clipping them and adjusting the contours with groundwater barriers, Layout preparation and making them more interpretable, along with hands on sessions covering all these aspects.

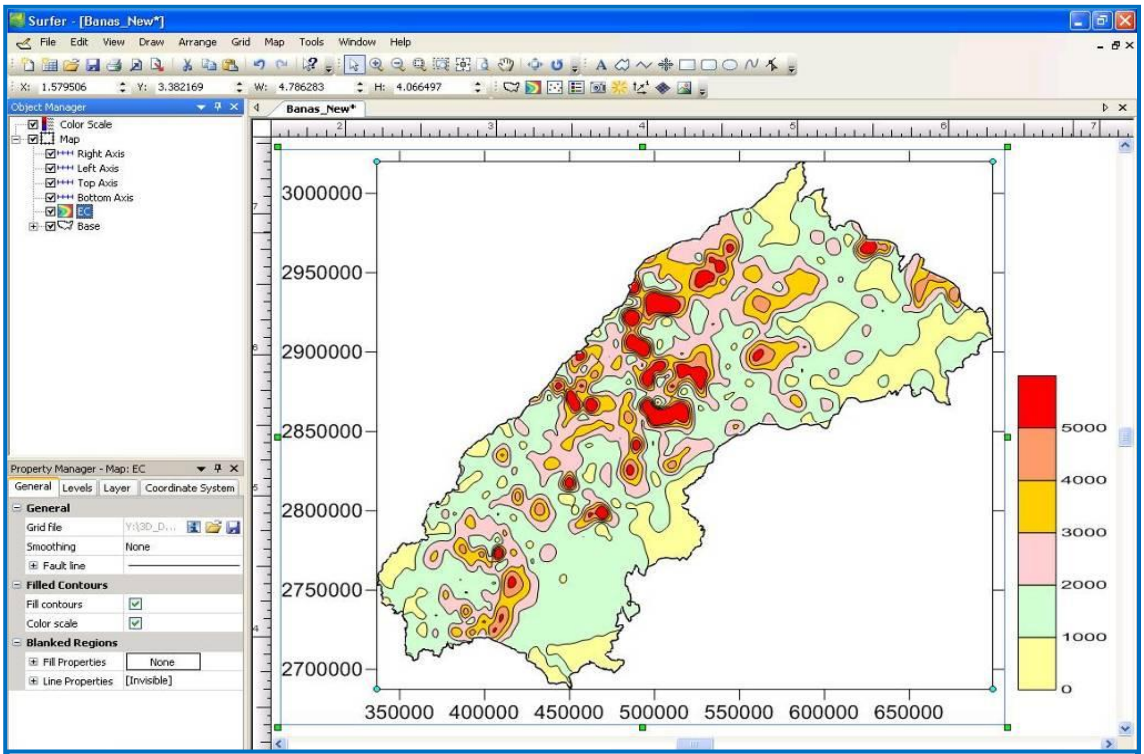


Fig.52: Contour map using Surfer

7.5.4. Presenting litholog data in 2D and 3D as cross sections, Panel diagrams etc. in Rockworks

Rockworks is one of the most useful softwares for a hydrogeologist. It helps in visualization of subsurface stratigraphy in three dimensions, the view can be rotated and tilted to gain more insight into a specific area, plots can be prepared and outputs integrated with other softwares.

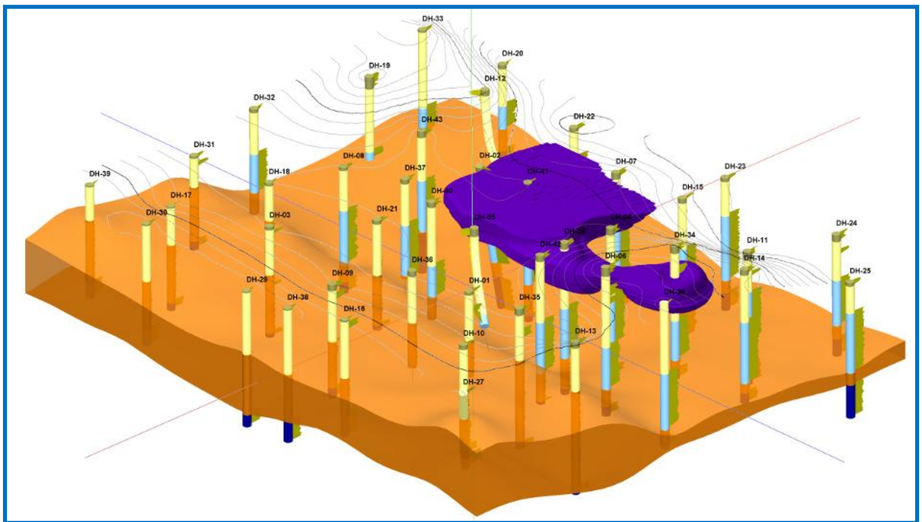


Fig.53: Litholog Data in 3D

The key themes covered in the sessions included the following topics:

- Input Data preparation for Rockworks
- Input data preparation for Location, Stratigraphy, Lithology and water table data
- Stratigraphy Model, Litho Model preparation steps
- Process for Generation of Cross Sections

- Generation of Strip Logs – Single and Multi logs
- Steps for generation of Isopach Maps
- Process for Generation of Fence Diagram
- Process for Generation of 3D Stratigraphy Model
- Working with RockPlot2D, RockPlot3D and Report Works

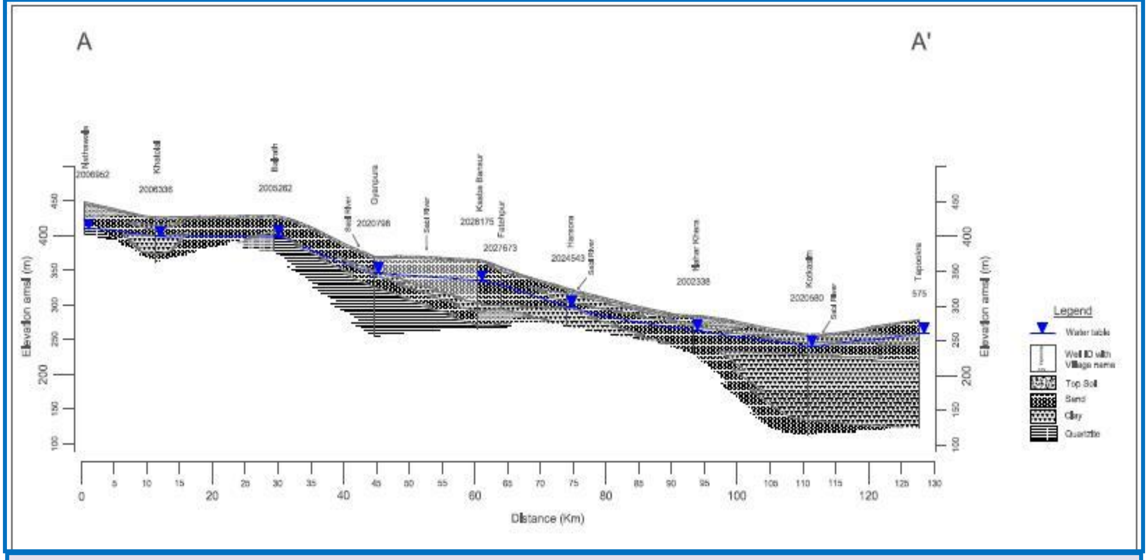


Fig.54: Cross Section

7.5.5. Groundwater Resource Assessment through GIS

A full day was dedicated to various aspects of resource assessment and Rolta explained the pros and cons of different methods, with special emphasis on why the current approach was adopted and limitation as well. The key issues discussed and explained on this topic included:

- GEC's 1997 approach of dynamic resource assessment,
- RGWD's current approach of resource assessment,
- Modifications that need to be done for adoption of GEC's approach in case of Rajasthan,
- The current GIS based approach,
- Scope for improvement in accuracy of parameters

The objective of the training program which was to build in-house capacity and capability to undertake basic GIS operations and help the core staff of GWD to use the application and manage / maintain GIS/MIS system with no or limited support from Rolta in future.

7.6. Feedback and Expectations of Trainees

At the end of the training session an open forum discussion was also facilitated to address any issues that had remained unaddressed in previous days and finally, feedback was collected from each and every participant. It was felt and observed that all the trainees felt better, more informed and could visualize the applicability of the new technology in their day to day work. Overall their impression was that the content and delivery was very much to their relevant activities and the hands on sessions during training gave them ample confidence in doing the work on their own. They realized the importance and also were of the opinion that if they have good infrastructure in place at their workplace, they will be keen to migrate to adoption of newer techniques in their activities otherwise the gains will be slowly lost. It was felt and observed by the trainees, that the duration of the training course is short keeping in view the complexity of subject, its applicability to different terrain/aquifer situations and the fact that most of them were new to GIS and the different softwares that they had undergone training on.

7.7. List of Participants

S.No.	Name	S.No.	Name
1	Sh. K.M. Mathur	34	Dr. Vimal Soni
2	Sh. N.D.Inakhiya	35	Sh. Mahendra Kumar
3	Sh. Khuswant Mistry	36	Sh. Rishendra Singh
4	Sh. Ashok Bhandari	37	Sh. P.C. Samar
5	Sh. V.S. Vyas	38	Sh. V.S. Paliwal
6	Sh. R.K. Dashora	39	Sh. U.S. Shaktawat
7	Sh. L.N. Khaldania	40	Sh. Arun Henry
8	Sh. Bal Kishan Borana	41	Sh. Laxman Singh Rathore
9	Sh. Mahendra Singh	42	Sh. Jitendra Kumar
10	Sh. M.C. Mehta	43	Sh. Naresh Bhatia
11	Sh. A.P. Singh	44	Sh. Yogesh Sharma
12	Sh. J.S. Bhakar	45	Sh. Brijesh Mishra
13	Sh. P.L. Gehlot	46	Dr. Vinay Bhardwaj
14	Sh. S.L. Soni	47	Sh. M.M. Kant
15	Sh. R.K. Godara	48	Sh. Sunil Sharma
16	Sh. R.M. Kudal	49	Sh. B.K. Maheshwari
17	Sh. M.K. Dhabai	50	Sh. Vivek Sukhija
18	Sh. Shailendra Dhargave	51	Sh. R.P. Sharma
19	Dr. V.N. Bhave	52	Sh. S.K. Bhatnagar
20	Sh. Anuj Agarwal	53	Sh. M.K.Mathur
21	Sh. Ashok Badala	54	Sh. S.C. Sharma
22	Sh. K.C. Mishra	55	Sh. Ashutosh Srivastava
23	Sh. K.S. Pathak	56	Sh. Gurudutt Bohra
24	Sh. M.S. Batar	57	Sh. Kailash Chand Sharma
25	Sh. Rajesh Pareek	58	Sh. Sumer Lal Meena
26	Sh. R.D.S. Jyani	59	Sh. Vijay Kumar Singh
27	Sh. N.K. Vaishnav	60	Sh. R.K. Bhola
28	Dr. R.K. Bansiwal	61	Dr. P. Athaiya
29	Sh. Niranjan Mathur	62	Sh. A.K. Pandey
30	Dr. Prahlad Singh	63	Sh. A.K. Jain
31	Sh. Subodh Mehta	64	Sh. Sanjeev Lochan (PHED)
32	Sh. R.S. Vyas	65	Sh. V.K. Balana (PHED)
33	Sh. Hanif Khan Gauran		

8. Recommendation Suggested Action Plan

Having worked very closely with the Rajasthan Groundwater Department for the past nearly two years, interacting with its officials, field visits, historic data analysis, focused studies on aquifers, groundwater resource assessment methodology etc. on one hand and also based on its visualization of future growth path for the department along with EU's vision for the state, Rolta summarizes its recommendation organized in the form of sections on each segment that needs to be addressed. It is believed that if a systematic action plan is worked out based on recommendations; the Department can maintain its leadership position in using modern tools and techniques in groundwater management.

8.1. Departmental skill enhancement related

Seminar and conference participation, outside visits

In order to adopt community driven approach of ground water management right from village level, it is essential that the members of the Water Committee from village level may be provided proper technical exposure visits and trainings.

It is proposed that the present Technical Training Center should be supplemented with more functionaries to liaison with the national and international level organizations in order to impart training to the staffs/officers/professionals involved in the process of ground water exploration, assessment and management

Research

The GWD should adopt multidisciplinary approach to reclaim deteriorating ground water condition caused due to over exploitation of ground water and release of effluent discharges from industrial and urban areas and also ingress of saline ground water from surrounding saline areas.

Training of trainers

A staff orientation and training are regarded the most important step in getting PHM started. It will be part of the overall capacity building strategy. The team composition should be multi-disciplinary. Ground water user group representatives, like farmers, industrial user, domestic user, who show interest in the activity should be invited to be part of the team.

The themes to be covered should include

- Hydrological cycle
- Occurrence and distribution of GW
- History of ground water development in the area
- Delineation of a hydrological unit

- Data collection frequency
- Data collection and recording procedures
- Participatory tools for effective farmer
- Water resources issues and primary health care.
- Promoting and creation of local committee.
- Local community conflict resolutions
- Monitoring of water points and its importance for demand management.
- Groundwater protection and policing of water legislation.
- Operation and maintenance of rural water supply installations, such as hand pumps.
- The capacity building of the GWD needs to focus mainly towards migration from the traditional approach of ground water assessment to the more scientific and GIS approach, enhancing capability towards ground water modeling, 3D demarcations of aquifers and Web GIS application

8.2. Team restructuring

The RGWD is a multidisciplinary organization, comprising of Engineers, Hydrogeologists, Chemists, Geophysicists, and Hydrometeorologists. While the overall skillset as well as the duties they are supposed to discharge are diverse, there is also a clear need to bring focus in the team's activities and align them to meet the challenges of future. The new tasks need to be accommodated into their roles and additional responsibilities be given. As it is also recommended later in this chapter that some of the routine activities that the department performs may be outsourced without impacting the quality, it is expected that the time the department's staff spends on those activities be now spent on delivering a much different and high end work in line with department's growing needs.

It is recommended that focused teams be constituted:

- That will hold meetings to deliberate groundwater management related issues on a frequent basis. Such team should be multidisciplinary in nature with adequate representation given to all groups.
- To interact with other departments like: State Meteorological Department, PHED, Agriculture Department, Revenue Department and so on, and will be responsible for communicating the data requirements of GWD and also verify the received inputs from others that they are in line with expectations. This will enhance timely and good quality receipt of data for carrying out timely and more frequent assessment of groundwater resources in the State.
- To explore the possibility of utilizing the facilities of Common Service Centers (CSC) or e-Kiosks that are likely to be in place under national e-Governance program being

implemented by Department of Information Technology, Ministry of Communications & Information Technology (Government of India). Under this program it is proposed to establish one CSC for a cluster of six villages with the facility of a desk top computer, Internet connection and other peripheral facilities for the common man. These CSCs are to be maintained by one of the agencies identified by the concerned state. Once such arrangements are successfully synergized, the data collected at the village level may be entered in the suitable format manually and subsequently in to the software / application to be developed. This would facilitate bringing the entire data set in to a central repository. The identified RGWD team should establish contacts with the Central team of the Ministry and explore the possibility of taking the initiative forward.

- An expert group be identified that will have expertise in handling computer (both software and hardware), work with GIS who will be able to prepare responses to Assembly or Parliament questions and prepare presentable outputs using recent data, updation and management of content of Web GIS software, upkeep and flow of data both internally and externally, carry out groundwater resource assessment at more frequent intervals using new method. These are some of the activities for the group, whereas the potential is unlimited.

8.3. Infrastructure related

On Groundwater quality monitoring kits be packaged and used by either GPs of other representatives engaged in collection of field data so that a number of measurements are done at well head itself. Secondly, infrastructure should be upgraded or revamped in order to reduce time between sample collection and actual analysis of the sample. The delay between collection and analysis significantly affects the samples leading to deterioration and results will be more accurate if this is done immediately after collection. One solution can be setting up small capacity labs at more locations specializing in analyzing key parameters only.

Enhancing the capacity of existing labes to analyze some heavy metals and pollutants discharged as effluents by industries and sewage water.

Geophysical labs should be equipped with more equipment and software to undertake studies on specific farmer requests. This may be taken up at a nominal fee also which will help the department not only in raising funds for sustained growth but will also help in raising capacity to deliver and generate employment to specially qualified people.

Computerization of more offices and more computers at existing locations is very important. All key staff at RGWD must be able to carry out most of their day to day work using computers which will help them conduct their work faster and that of consistent quality. Electronic data also can be shared over internet with teams sitting far apart that would ultimately enable the Department in improving overall efficiency.

8.4. Community involvement in water resource management

Keeping in line with State Government's water policy wherein it is set as one of the goals to involve the stakeholders in groundwater management, it is recommended that the actively engages with local community / end user for effective and sustainable uses of the ground water resources locally. The specific activities can be chalked out jointly by RGWD and identified community representatives which can be taken up in all 33 districts of the state beginning with the districts falling under over-exploited category; that should be adequately staffed to achieve the objective. This helps local communities to form a community opinion to support appropriate measures for managing the available resources equitably. Following are some of the preparatory activities the department needs to undertake:

Establishment of groundwater management committees (GMCs) at GP level

A set of people be identified at Gram Panchayat level (ideally at village level) who should be made aware of issues involved, water resources in hand, collection of basic data, usage of basic tools and take decision on water allocation for different uses based on local requirements while conserving for future, interact with adjacent GMCs and develop/resolve regional plans etc. Steps to begin with can be:

Identification of volunteers

Strategically, both the male and female members of the society be given adequate representation, having basic qualification to write and understand forms/formats for updation, general awareness of groundwater related issues and requirements of the area he would represent, willing and desire to be part of initiative should be kept in mind while identification of volunteers.

Training to volunteers

Once volunteers are identified, they should be systematically and sufficiently trained for community capacity building. A one day training session is required before the start of data collection. The training first orients the farmers towards the concept and set the expectations of both sides and introduces the monitoring tools. Later sessions essentially includes practice by the farmers in handling the equipment and in the data collection protocol.

Awareness rising

While everyone in the state realizes that water resources are scarce in the state, it still needs to be conveyed to all whether in rural or in urban areas on different aspects of the issue. The traditional methods like Posters and pamphlets, street plays, folk songs etc. remain the media for conveying the message. The Department should also consider new methods such as:

- Using Mobile network messages can be sent as SMS texts on conservation measures each one can adopt along with one liner slogans,
- Websites
- Emails
- Panchayat Notice boards etc.

These should be sustained campaigns to pass on the message till it reaches masses and people start talking about it.

8.5. Assessment Methodology and parameter related

The Department carries out systematic ground water resource assessment from time to time. As part of the project, Rolta had carried out a thorough review of the methodology currently adopted by RGWD and evaluated that with recommendations of GEC published recently and also with international best practices. While the details of the same were covered in the previously submitted Technical Report 3A – Part1, the key recommendations are reiterated here. These have been grouped into two sub-heads, first being the overall approach and the second on specific parameters involved in assessment.

8.5.1. Assessment Methodology

GIS approach be adopted

It is strongly recommended to switch over to GIS based approach of resource assessment than the current non-GIS approach. The grid based computation of resources is the way forward which is independent of any boundaries. The results can be summarized to any boundary very quickly.

Revision of all maps

The water bearing formation boundaries, saline area boundaries, shallow water table areas, Canal command areas etc. have changed over a period of time. The last updation of maps by the department is not consistent and some have been recently updated whereas others were updated more than five years back. Due to faster depletion of water in the sub-surface reservoirs, the formation that used to yield water might have changed to on that is lower in stratigraphic column and this warrants attention. Since this is the single most important factor determining availability of water in any area, latest and correct information on this is of prime importance. Rolta has updated all the maps related to water level and water quality distribution whereas the updation of maps that are exclusively dependent on field survey inputs need to be undertaken by RGWD on priority and published at the earliest for adoption across the state.

Frequency of assessment

Assessment should be carried out on more frequent basis, preferably every year, so as to keep track of the fast changing scenario.

Percentage Difference (PD) Factor

In the existing methodology of ground water assessment, there is a provision for computation of PD Factor. This PD factor is used to find out variation in groundwater estimated by linear regression method and rain fall infiltration method. In case of PD factor more than 20%, ground water resource estimated by rainfall infiltration approach is adopted and database approach of linear regression method is discarded. It is observed that the PD factor in most of the cases more than 20%, as such ground water resource estimated by ad hoc method is adopted while more realistic values computed by linear regression method are not accepted.

It is suggested that the computation of PD factor should be limited to the extent to scrutinize water level fluctuation data. Once these water level data are cross checked and rationalized by ignored some abnormal values, then ground water resources estimated by linear regression method should be adopted straight away.

8.5.2. Refinement of Parameters

Optimization of monitoring network

A separate project is being executed by m/s Rolta India Limited, which has the objective of optimizing use of existing monitoring network in the state of Rajasthan. It requires density of network of stations would be scrutinized in light of local ground water conditions and reliable long term depth to water level and ground water chemical quality data. Keeping these observations in view, recommendations regarding strengthening of data network or replacement of key wells to prepare reliable database had been given. For future assessment studies if the data from an optimized network is used as input, the accuracy of outputs can be improved.

Frequency of water level monitoring

The frequency of water level monitoring is required to be decided in light of its objective. The present practice of GWD to monitor entire network during pre-monsoon, post-monsoon and post-irrigation periods is suggested to be continued as this provides database for assessment of ground water resources. The frequency of some selected stations, where local ground water condition is significantly different from surrounding area may be monitored as per requirement of the local ground water conditions, i.e., daily/monthly basis.

Also keeping in mind one of the goals of RGWD to integrate the data with CGWB, it is advisable to carry out groundwater level monitoring four times every year in consistency with CGWB approach. CGWB carries out water level data collection during May/June, Sept/Oct, Jan/Feb and March. The exact dates for measurements may be decided in consultation with the State Agencies and stakeholders.

8.5.3. Refinement of data

RGWD monitoring network of stations consists of dug wells/ dug cum bore wells/ tube wells or piezometers. The depth to water level data collected from these wells, other than piezometers, are often in operational or recuperation condition, as such measurement of static depth to water level is not possible. It is recommended that monitoring stations, where reliable data of static water level or chemical quality of ground water are not available may be replaced by piezometers. These piezometers are required to be properly developed before put in use for monitor purposes of depth to water level and collection of water samples. The periodical development of piezometers is also suggested to remove clogging and siltation developed with passage of time.

The GWD is using measurement tape to monitor depth to water levels. This is not only time consuming but affects the accuracy wherever water levels are very deep. It is also expedient entire network within shortest time period. In view of this, it is suggested to use automatic water level recorders (AWLR) such as electric water level sensors (visual or sonic sensors), digital water level recorders (DWLR) which will not only improve quality of database but also synchronize time period of monitoring of entire network.

Frequency of quality monitoring

The GWD is regularly collecting water samples during pre-monsoon and post monsoon period since 1984. It is suggested to review the entire database to see the necessity of collection of water samples from the entire network during post monsoon period. After scrutiny of the database, the frequency of collecting water samples in some localized areas, where deterioration in quality of ground water is noticed, may be increased looking to local conditions.

Specific yield values

RGWD had conducted a number of pump tests under different hydrogeologic investigation programs in the past, however there is still need of additional pumping tests and hydrograph analysis of DWLR and piezometer data. It has been observed that because of heterogeneity of aquifer parameters; specific yield and transimissivity varies considerably in any single aquifer. The specific yield value being site specific, it is suggested that in place of specific value, average specific yield value of an aquifer must be taken into account while computing ground water resources. The average specific yield may be determined by using the basin wise water balance technique. The ground water draft data and corresponding water level fluctuation data may also be used for validation of average specific yield of an aquifer.

It is recommended that a thorough review of specific yield values be carried out for the whole state. Also now that GIS approach of assessment allows interpolation be carried out for point values, it could be a significant advancement in adopting proper specific yield values if the well locations where the yield tests were carried out are plotted and their influence area is demarcated within the aquifer it is measured. In the presence of multiple specific yield values over the same aquifer, instead of computing and adopting average value of specific yield, it will be better if an interpolation is carried out using all the point specific yield values and a grid layer be created in line with water level or fluctuation values discussed earlier in GIS approach.

Draft data

The GWD is estimating agriculture ground water draft on the basis of information/data provided by Tehsil headquarters. These datasets require validation by adopting remote sensing techniques and details on consumption of electricity for irrigation purpose. The satellite imagery of particular period may be used to find out crop area and type of crop. It is recommended to use latest techniques to refine groundwater draft.

The domestic, industrial and other commercial ground water draft requires to be monitored precisely by the concerned departments to improve database for estimation of ground water draft.

Till the time the remote sensing outputs are in pilot stage, an immediate step the Department may consider taking, is adoption of village wise well census data usage in computation of draft. Especially, if village wise draft is available, the same can be used to create a spatial data and a grid data of draft that will be more accurate as compared to summing up all the draft at block/tehsil level and then distributing them to aquifer boundaries.

Rainfall Data

The GWD is estimating ground water recharge due to rainfall by using rainfall data collected from Tehsil and District headquarters. The current density of rain gauge stations is highly inadequate, particularly given the wide range of lateral variation in rainfall pattern and that a village level ground water management plan is to be evolved. The interpolation of low density rain gauge station’s data leads to approximation, as such it is suggested that density of rain gauge stations in the state should be adequately increased keeping in view the objective of preparation of village level ground water management plan. It is recommended that establishment of at least one rain-gauge station at GP level be done. While it is understood that it is practically not possible to have this system in place in one go and also given the fact that rainfall is scanty in many areas of Rajasthan (especially in the

Western part), priority be given to the GPs which receive good rainfall and progressively extending the network to all the areas.

8.6. Maintenance of IT Infrastructure and Data updation

Now that the Web GIS has been implemented the information collection and dissemination is possible electronically and on a real time basis. While this is a great opportunity to enhance transparency of the system, it has its own challenges as well in terms of maintenance and upkeep. It is very important hence, to display most current data, maps and other relevant information up to date that requires dedicated team and effort. It is therefore recommended that an internal team be identified that understand all the issues related to data flow, preparation of maps, uploading the same on website etc. who will ensure that most accurate and recent data is available to the public for reference and decision making. It is advisable to list out the data content to be updated, updation frequency for each item, source, advance notification issue mechanism to sources (in case the information is coming from outside sources) so that timely availability for updation and responsible empowered persons for each item.

For internal department usage also, frequent data inflow is required especially on water table and water quality data that is collected frequently that needs to be quickly integrated into GEMS. This is the only way in which the Department will be able to exchange information with CGWB and synchronize the data.

8.7. Additional focused studies on local themes/requirement

The current project of aquifer mapping and village level assessment has laid the foundation for spatial studies because now the Department has in possession, a strong GIS database, softwares and computers to analyze the data. While the study has been on state level, it is imperative to find some generalization and overlooking of local issues. Focused local studies on specific issues will help in analyzing the situation in a better way in a scientific manner, using modern tools and techniques.

It will also be very helpful in engaging the RGWD staff abreast with the world at the same time solving local problems. Some of the studies can be:

1. Aquifer potential analysis for long term sustainability.
2. Urban/industrial area water requirement analysis,
3. Possibility of mapping out fresh water pockets among saline water tracts in deeper aquifers,
4. Causes behind high fluoride concentration in any area, its distribution pattern, area impacted etc.
5. Application of Remote sensing inputs for refining groundwater draft estimation in any area, corroborated with pilot studies

6. Salinity affected area demarcation and causative factors,
7. Trend analysis of water levels of wells to project their life and need for deepening,
8. GIS based approach for well siting,
9. Groundwater flow modeling from environmental perspective.

8.8. Suggested action plan

In order to carry forward the gains made by implementing the project and to maintain the leadership position in GIS based approach to groundwater problem solving, the Department must work out a detailed micro level action plan and manage the necessary manpower and finances. To meet the recommendations of the project, we have also worked out a broad action plan. This will help the Department in chalking out detailed activities and attach timelines to them based on its prioritization by them and feasibility on ground. It is appreciated that the concerned staff at GWD have a fair understanding of the recommendations and are by and large in a position to implement them, there are certain areas where they will require external support. The support would be both in terms of supplementing skill sets and manpower in order to increase their efficiency levels at work.

Further to elaborate on this topic here is given the nature of work that GWD needs to handle (purely from the current project point of view) and the possible better way to handle the same more effectively:

Field based data collection

The Department currently carries out massive exercise of field based data collection on different aspects like:

1. **Water Table measurement:** This is a routine exercise that department currently conducts thrice every year (pre-monsoon, post-monsoon and post-irrigation). As part of this project and the other project on benchmarking of monitoring network, it is apparent that in order to improve the database of the state an increase in measurement frequency (four times every year) and also density of network is very much required. Keeping this aspect in mind and also the fact that this is a routine work that does not require a lot of scientific background to collect water level data, it is strongly recommended that the Department considers outsourcing this work to any competent private company. This will not only reduce effort of scientific staff of the department in carrying out the routine work but will also help in utilizing their time for better internal purposes like interpretation and analysis of data. Secondly, the survey also demands a lot of travel to remote areas which requires a fleet of vehicles to be either maintained internally by the Department or hired in field which can be avoided completely, if the task is outsourced to competent private companies. It is suggested that the Department carries out a cost benefit analysis for outsourcing the work to external

agencies vs. pursuing current model of doing it in-house with more hiring to meet projected additional data collection; and then based on the outcome, take appropriate decision.

2. **Water sample collection for chemical analysis:** In this case also, if the recommendations of the ongoing projects are implemented, more data in terms of frequency and density of points would be required. The sample collection and analysis requires some data to be collected on the well head itself whereas a detailed chemical analysis in lab. Given the current practice and infrastructure at GWD, there is significant gap between data collection and the actual time when analysis is carried out. Scaling up infrastructure at GWD is definitely an option that the Department has but this will require lot of expense in purchasing field kits, their maintenance, opening up new labs at district levels along with their staff and upkeep. Therefore, in this case also it is suggested that the Department carries out an internal exercise to evaluate the internal scaling up model vs. outsourcing model and adopt the one that suits it best. Going by recent trends in the country, it is observed that outsourcing the work to a competent vendor and monitoring them internally yields better results.
3. **Geophysical surveys:** This is scientific and technical work in which the Department has gained a lot of expertise and local knowledge that cannot be replicated by any outside agency. Another aspect of this is that there is a lot of demand from non-governmental agencies (individuals and industries) to undertake these surveys for well siting. In this situation the Department is uniquely placed to render service to the market on payment basis and there is immense potential to earn revenue for the Department. Therefore, it seems more appropriate that the Department strengthens its Geophysical survey team (wing) both in terms of manpower and equipment so that they are in a position to take up more work and provide consultancy services to cater the huge requirement for such services in the State.
4. **Data Entry and internal transmission and communication with CGWB:** Since all of the historic data has been entered into a centralized system in digital format, it will be very easy for the Department to enter the incremental data on event driven basis and add to existing repository. The data if computerized at district level itself and shared with data centre, the chances of error also get reduced significantly so it is suggested that the Department undertakes this work using its own resources and just define a protocol for data entry through usage of recommended formats and sharing among themselves and with CGWB through GEMS (that is installed in its premises in Jaipur).
5. **Map updation, publication on website:** A large number of thematic maps are going to be

published by the Department through its GIS based portal. It is very important to keep the site update with recent set of maps and data. For this activity since the Department does not have sufficient number of spare GIS experts to generate the maps on frequent basis and post them on website, it is suggested that this activity be outsourced to a competent external agency with clear cut list of maps to be updated and their frequency of updation. This may be continued till the Department develops in-house capability to manage the maps on their own. 2-3 manmonths of a GIS expert will be required for one set of map updation each time.

6. **Resource assessment:** Carrying out statewide groundwater resource assessment is one exercise that the Department has been successfully carrying out for over a decade through non-GIS methodology. As part of this project a GIS based approach has been introduced that has advantage over the traditional methods. It is strongly advised that future studies are carried out using GIS based approach and improving input parameters both in terms of accuracy and detail (like more widespread specific yield values for aquifers collected through pumping tests; Agriculture draft assessed through indirect means of Remote sensing where Crop type is identified and Draft is computed by assigning standardized water requirement of each crop type and its spatial coverage; More widespread data on rainfall than current ones with one value per block, etc.) step by step. The GIS based assessment requires handling multiple layers of data and complex overlay queries that would be challenging for the Department to carry out immediately. Therefore, this also is one area that Department can consider outsourcing to a competent agency and also raise its frequency of assessment to annual basis to monitor the changes in position closely.
7. **Local problem solving and focused studies:** A team of Department's scientists should be constituted to list out unique local groundwater problems through their local contacts and knowledge. They should then be prioritized for taking up and then they must be projectized for undertaking and solving through modern tools and techniques for benefit of users.
8. **Updation of Groundwater Potential Maps:** These maps that constitute basis for any groundwater related study, needs to be updated on a frequent basis. This is because the water level is showing a continuous declining trend as a result of which shallow aquifers are drying up leading to extraction from deeper and (maybe) different aquifer from the one that used to yield water earlier. With new water level, well lithologs data being added to the database, the corresponding maps also must be revised on annual basis and published across Department for reference and usage. Also the scale of mapping be further increased from current (equivalent of) 1:250,000 to 1:50,000 and up to 1:10,000 in future.
9. **Awareness raising campaigns and village level participation in groundwater management:**

New channels and innovative methods of information propagation have been recommended in this report which must be adopted to pass on the message to village level users. It may be taken up as an action item to energize existing means of distribution of pamphlets etc. while also considering hiring of private ad agencies for designing thematic campaigns and conducting them as well.

The following table briefly summarizes the suggested actions to fulfill the recommendations of the report.

Table 8.1: Activity list with suggested action plan

Activity	Skill set/equipment required	Availability with RGWD	Suggested action
Water Table measurement	Basic understanding of water table and taking measurements using tape	Available	Can be outsourced to increase effectiveness of Department
Water sample collection for chemical analysis	Knowledge of water sample collection, labeling and handling of basic WQ analysis field kit	Skill set is available but only limited equipment present	Can be outsourced to increase effectiveness of Department
Geophysical surveys	Handling Geophysical equipment and interpretation	Available	Internal scaling up to undertake professional consultancy services
Data Entry and internal transmission and communication with CGWB	Basic computer knowledge and understanding of xls and database	Available	Can be done internally by Department
Map updation, publication on website	RASA tools, cartography and GIS	Very limited skill set available	Preferably outsourced till the time Department becomes fully capable of handling
Resource assessment	Hydrogeology and advanced GIS techniques	GIS part of skill set is very limited	To be undertaken jointly by Department and private agencies
Local problem solving and focused studies	Hydrogeology, GIS, RASA tools and field survey	partly available	To be undertaken jointly by Department and private agencies
Updation of Groundwater Potential Maps	Field survey, analysis of lithologs and cartography	Available	Can be done internally by Department
Awareness raising campaigns and village level participation in groundwater management	Communication skills, community mobilization skills, ad campaign planning and execution	Limited availability	Preferably outsourced

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Plates

Annexure

A. Ground Water Monitoring Stations – Water Level Data
B. Total Annual Rainfall Data (2000 – 2010)
C. Assessment Unit Wise Specific Yield and RIF Values
D. Assessment Unit Wise Ground Water Resources, Draft and Net Balance of Rajasthan
E. Village wise Ground Water Resources