केन्द्रीय भूमि जल बोर्ड

जल संसाधन, नदी विकास और गंगा संरक्षण

विभाग, जल शक्ति मंत्रालय

भारत सरकार

Central Ground Water Board

Department of Water Resources, River Development and Ganga Rejuvenation,

Ministry of Jal Shakti

Government of India

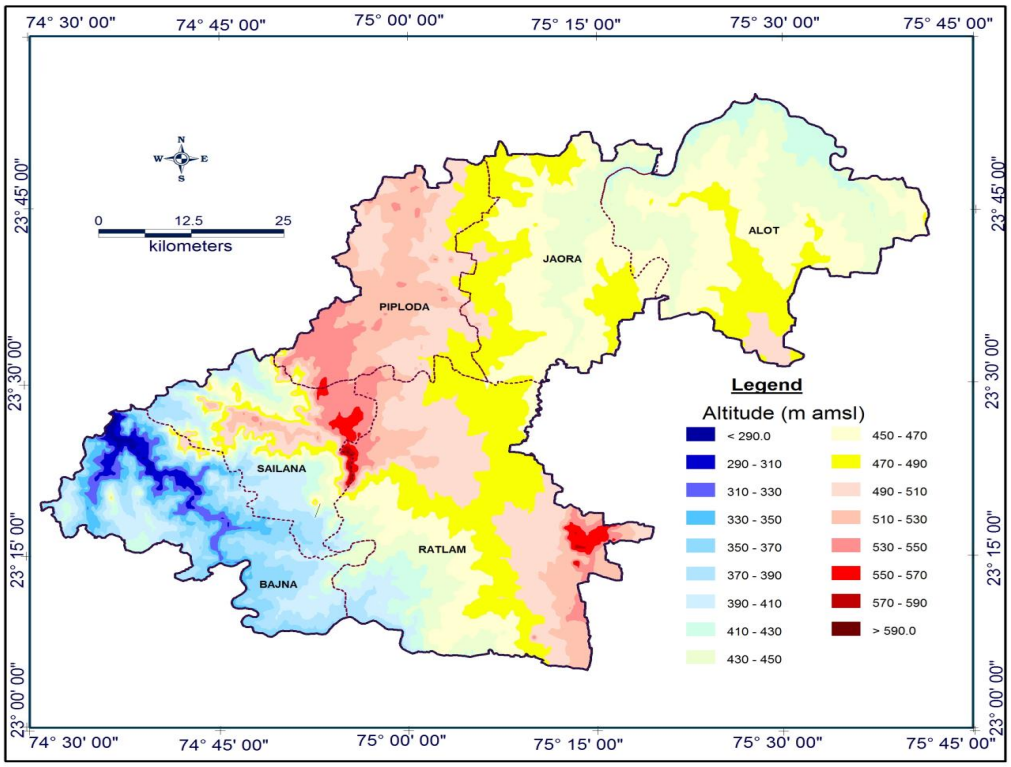
AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES

RATLAM DISTRICT
MADHYA PRADESH

उत्तर मध्य क्षेत्र, भोपाल

North Central Region, Bhopal

AQUIFER MAPPING AND GROUND WATER MANAGEMENT PLAN OF RATLAM DISTRICT, MADHYA PRADESH



By

DEVENDRA JOSHI
Scientist – D
(AAP: 2018-19)

Central Ground Water Board
North Central Region, Bhopal

Aquifer mapping & Groundwater Management plan of Ratlam District, Madhya Pradesh

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LIST OF FIGURES

LIST OF TABLES

Preface

Aquifer mapping can be defined as a scientific process, wherein a combination of geologic, geophysical, hydrologic, and chemical field and laboratory analyses are applied to characterize the quantity, quality, and sustainability of groundwater in aquifers. Systematic aquifer mapping is expected to improve our understanding of the geologic framework of aquifers, their hydrologic characteristics, water levels in the aquifers and how they change over time, and the occurrence of natural and anthropogenic contaminants that affect the portability of groundwater. Results of these studies will contribute significantly to resource management tools such as long-term aquifer monitoring networks and conceptual and quantitative regional ground-water-flow models used by planners, policymakers, and other stakeholders.

Under the project on National Aquifer Mapping (NAQUIM), Central Ground Water Board (CGWB) North Central Region, Bhopal has taken up Ratlam district to prepare the Aquifer Maps for the entire district and formulate Aquifer Management Plan. Ratlam district occupies an area of 4861 sq. km, out of which the groundwater recharge worthy area is 4616 sq. km. and hilly area is 245 sq. km. Ratlam district falls under Ganga and Mahi river basins. The tributaries of Chambal River drain about 70 % geographical area of the district. Most part of the district is mainly occupied by Deccan trap; rest by Alluvium and Vindhyan. As per the Dynamic Ground Water Resource Assessment Report, the annual extractable ground water resource 80882.77 ham and groundwater extraction for all uses is 102423.17 ham which results in the stage of groundwater extraction being 126.63% as a whole for the district. After successful implementation of the supply-side and demand-side management plan the stage of extraction in Ratlam district is expected to improve condition of the district in terms of ground water. The interventions suggested in the report will not only have a positive impact on the groundwater regime but would also play a key role in augmenting the net cropping area and would ultimately enhance the agricultural productivity and economy of the district.

I would like to place on record my appreciation of the untiring efforts **Sh. Devendra Joshi, Scientist-D** for preparing the Aquifer maps and Management plan and compiling this informative report. I fondly hope that this report will serve as a valuable guide for the sustainable development of Ground Water in the Ratlam District, Madhya Pradesh.

Rana Chatterjee
(Regional Director)

CHAPTER-1

INTRODUCTION

1.1 Objectives

The main objectives are to define aquifer geometry at 1: 50,000 scale, type of aquifers, ground water regime behavior, hydraulic characteristics, geochemistry of aquifer systems and also to develop a dynamic system for sustainable management of ground water resources for an aquifer as a unit.

1.2 Scope of the Study

Under NAQUIM, Ratlam blocks have been studied and utilized existing data of exploration, water level and water quality of NHS wells. Data collection, compilation, bringing entire data to GIS platform, data gap analysis and data creation can be done through this study. It will establish the most appropriate technique or combination of techniques for identifying the aquifers in different hydrogeological terrains which will help in management of ground water resources in an efficient and equitable manner, for sustainable development of groundwater and for its recharge.

1.3 Approach and Methodology

Entire blocks of Ratlam district has been covered under Basaltic lava flow areas with isolated pockets of alluvium formation. Under NAQUIM, area is divided grid wise and aquifer wise for establishing aquifer geometry and characteristics upto 200 m where data generation is required, then a Base Maps of geology and geomorphology are prepared. Compilation of existing data is highly required for mapping. Exploratory Data or Geophysical Information could be used for this purpose. Pre- processing of Exploratory Data, Ground Water Level and Ground Water Quality data are needed for proper study of particular area.

Methodology for arriving at data gap

Exploratory Data : (Desirable spatial scale – in 5’ x 5’ grids) Exploratory well of 200 m depth, 5- EW’s and 5- OW’s should be constructed at suitable locations, preferably one in central quadrant and one each in the four corner quadrants for establishing aquifer geometry and determining aquifer parameters.

- Aquifer performance test shall be conducted at all the five EW’s tapping the fracture aquifer to estimate the aquifer hydraulic parameters and water quality.
- Existing exploratory Data and Data gap analysis.

Geophysical Data: 2 or 3 Profiling/VES/TEM having 200 meter interpretation depth should be carried out in each of the nine quadrants of the toposheet totalling 18 to 27 nos. in each sheet to decipher aquifer geometry

- Existing Geophysical Data and Data gap analysis.

Ground Water Monitoring Data: Data Required**:** 5' x 5' grids.

- For 1st aquifer (un-confined/Phreatic) two open/dug wells are recommended for each quadrant of a toposheet.
- For 2nd and 3rd aquifer the well-constructed in the Well field and Special Purpose wells may be used as piezometers for GW monitoring. Minimum four times monitoring annually.

Ground Water Quality Data: Data Required: 5' x 5' grids.

- For 1st aquifer (un-confined/Phreatic) one sample from open/dug wells are recommended for each quadrant of a toposheet
- For 2nd aquifer the sample is to be collected from well-constructed in the Well field explained above and Special Purpose wells for GW Quality monitoring. Minimum two times monitoring initially is recommended.

Data Generation:

- Value addition of Geological map. Preparation of subsurface geology of the area ,
- Value addition of Geomorphological map ,
- Analysis of Land use pattern,
- Conduct additional required VES/TEM ,
- Analysis of Water bodies of the area ,Impact of Water bodies on surrounding Ground Water Regime, Surface water –Groundwater interaction studies,
- Water level monitoring of key wells - 4 Times in a year for 3 Consecutive year ,
- Exploratory drilling –Construction of EW, OW, PZ, SH, Pump test of EW for Determination of Aquifer Parameters, Piezometer construction for AWLR,
- Groundwater quality Data Generation: Collection of required water samples and analysis for Ground water Quality Assessment.

AQUIFER MAP PREPARATION: 1:50,000 SCALE MAP SHOWING DIFFERENT LAYERS

Aquifer Wise Management Plan

Aquifer wise ground water management through integration of various data / information in the form of thematic layers,

- Feasible areas for ground water development along with yield potential / Depth of drilling / safe yields etc.
- Feasible areas for rainwater harvesting and ground water recharge vis a vis aquifer storage available for recharge and surplus non committed surface water available for recharge.
- Aquifer wise vulnerability map in terms of ground water availability (potential areas / ground water stress areas), water logged areas and quality problem areas.
- Demarcation of Ground Water Regulatory Zones (GRZ).
- Demarcation of Ground Water Sanctuaries to be reserved for drought proofing.
- Ultimate goal is to construct a ground water flow simulation models at appropriate scale to arrive at technically and economically feasible aquifer management options.

1.4 Location Details :

Ratlam district is located on northwest part of Madhya Pradesh. Area extends between the parallels of latitude 23^0 05' and 23^0 52' North and between the meridians of longitude 74^0 31' and 74^0 41' East. The district is bounded by Mandsaur district in the north, Jhabua and Dhar district in the south, Ujjain and Shajapur districts in the east, Banswara district of Rajasthan state in the west and Jhalawar district of Rajasthan state in the northeast. Ratlam district is well connected by roads and rail. Ratlam is also divisional head quarter of western railway.

Location of Ratlam district and administrative units has been depicted in Fig.1.1 and 1.2 respectively.

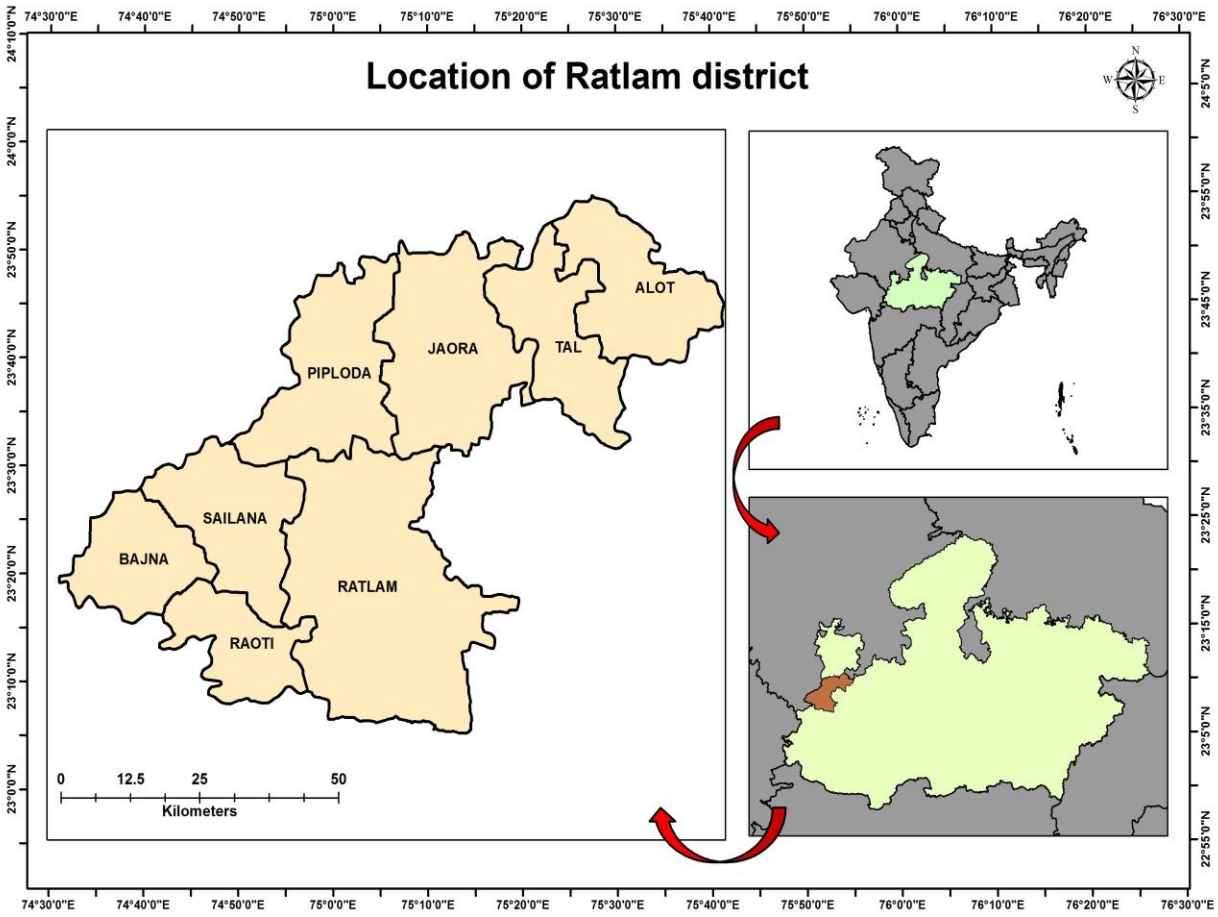

Fig.1.1 Location of Ratlam district

Ratlam district area is falling in the Survey of India degree Topo Sheet No. 46I and 46M. Block wise area with toposheet number (1:50,000) is given in table 1.1 and administrative detail is given in table 1.2.

Table 1.1: Toposheet number

S. No.	Block	Area (Sq Km)	Toposheet number
1	Alot	945	part of 46 M/5,46 M/6 46 M/9 46 M/10
2	Bajna	682	part of 46 I/11,46 I/15 46 I/1246 I/16
3	Jaora	763	part of 46 M/1,46 M/2
4	Piploda	604	part of 46 M/1,46 M/2 46 I/13 46 M/14
5	Ratlam	1331	part of 46 I/15, 46 M/3,46 M/4
6	Sailana	536	part of 46 I/10 46 M/14 46 I/15

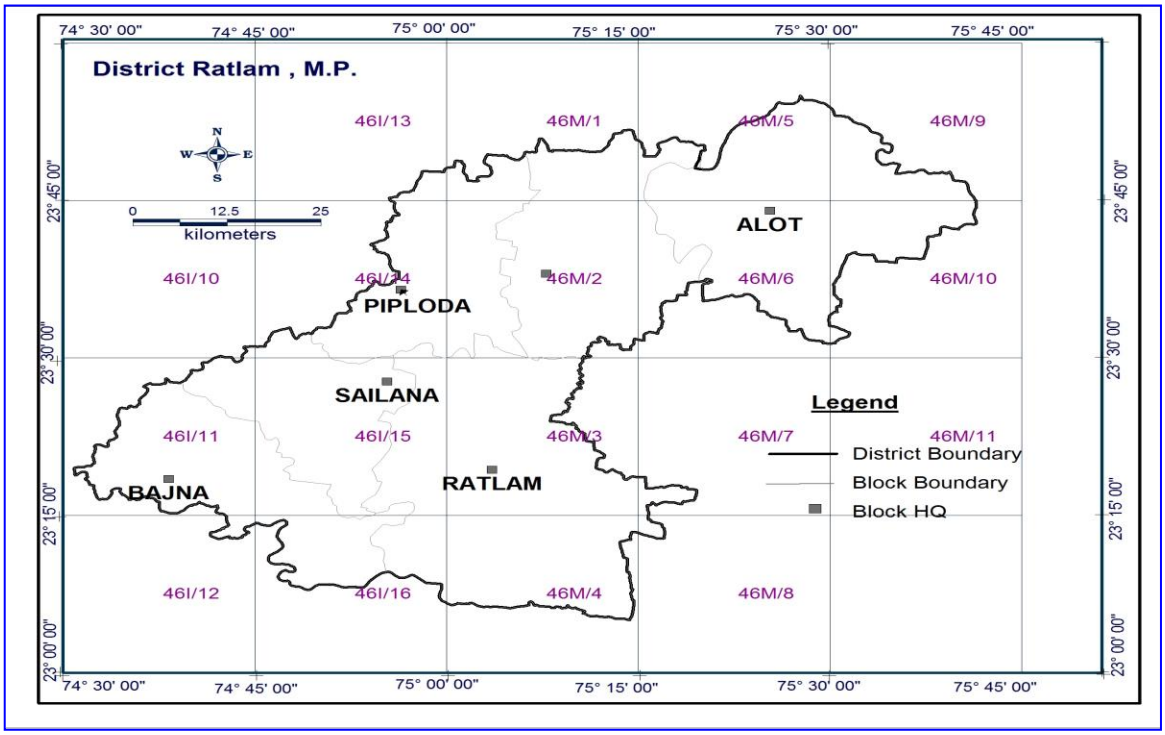

Fig. 1.2 Administrative units of Ratlam District

Table 1.2: Administrative units of Ratlam district with area (Sq Km)

S. No	Tehsil	Block	Area (Sq Km)	Villages No.	Villages Panchayats No.
1	Alot	Alot	945	191	90
2	Bajna	Bajna	682	220	65
3	Jaora	Jaora	763	145	68
4	Piploda	Piploda	604	90	52
5	Ratlam	Ratlam	1331	169	97
6	Sailana	Sailana	536	238	47
Total			**4,861**	**1053**	**419**

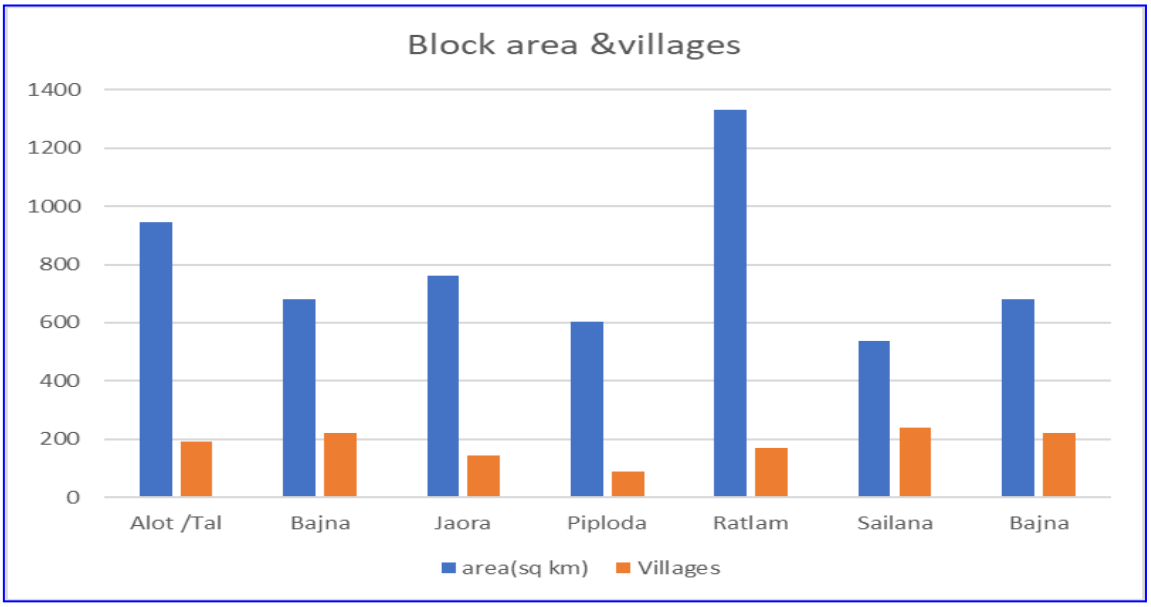

Fig.1.3 Graph showing the block area and villages of Ratlam District

- **Recharge worthy Area of Ratlam**

The total geographical area of the district is 4,861 Sq. Km. The hilly & forest area in it is about 245 Sq. km. The mappable area or recharge worthy area is 4616 Sq. km (95%) (table 1.3).

Table 1.3: Total Area of Ratlam

District	**Area**					
Ratlam	**Unit**	**Total Geographical**	**Recharge worthy**	**Hilly**	**Command**	**Non command**
	Ha	486100	461600	24500	8614	452986
	Sq km	4861	4616	245	86.14	4529.86
	%	100	94.95	5.05	1.866	98.133

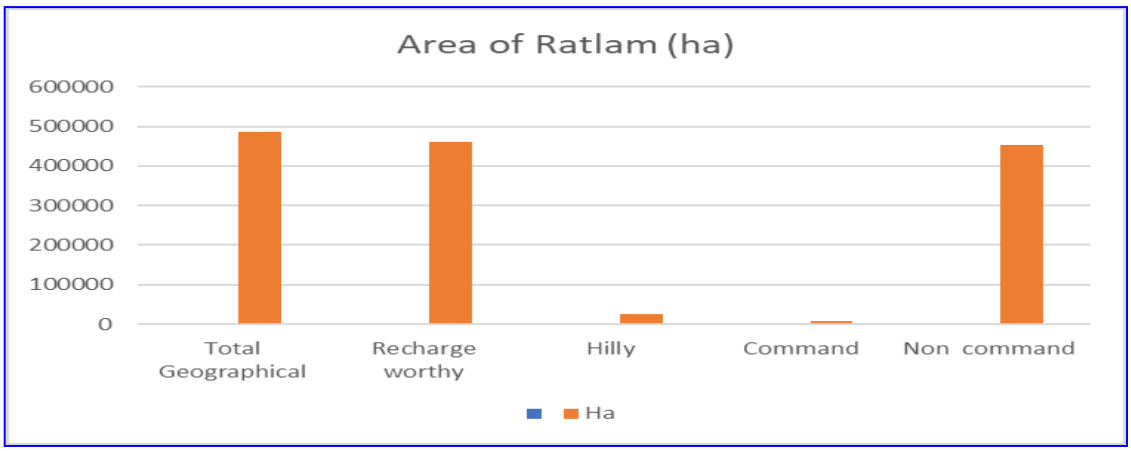

Fig.1.4 Total area of Ratlam District

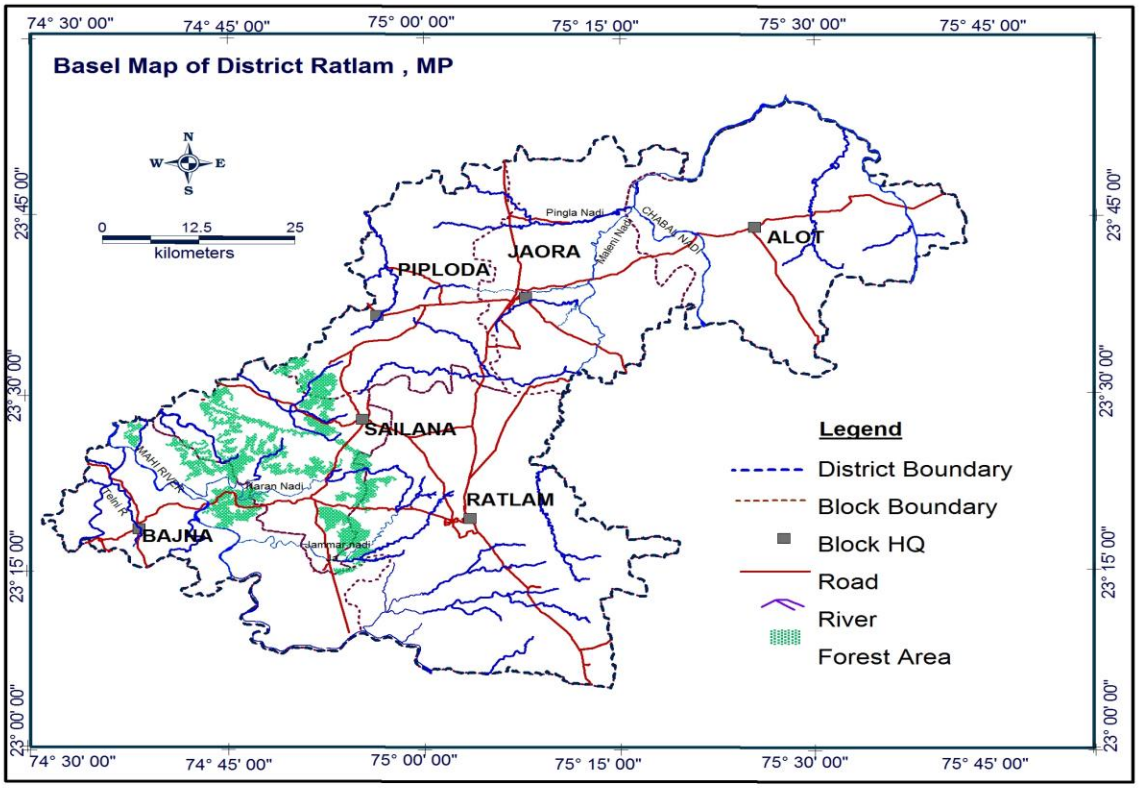

Fig.1.5 Basal map of Ratlam District, MP

- **Stage of GW Extraction**

There are 4 block which are having over exploited condition and Stage of GW Extraction (%) varies from 110.07 to 167.58 %. The semi critical blocks are Bajana & Sailana having Stage of GW Extraction(%) 78.41 & 77.71 respectively (Table 1.4).

Table 1.4: Stage of Groundwater Extraction

District	Block/Mandal/Taluk						
	Over-exploited	**Stage of GW Extraction (%)**	**Critical**	**Semi-critical**	**Stage of GW Extraction (%)**	**Safe**	**Poor Quality**
Ratlam	1.Alot 2.Jaora 3.Piploda 4.Ratlam	113.18 167.50 163.58 110.07	Nil	1.Bajna 2.Sailan	78.41 77.71	Nil	Nil

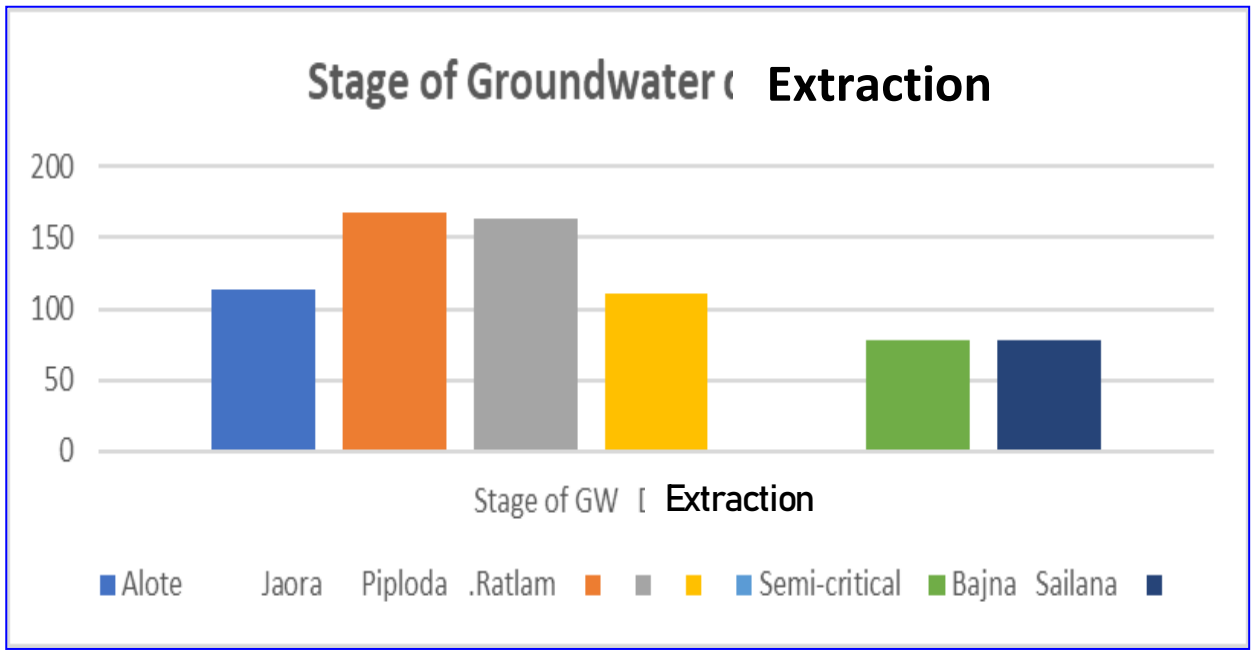

Fig. 1.6 Graph showing stage of GW extraction of Ratlam District

- **Population :** Ratlam has a population of 12,15,393 according to census 2001 and There are 1095 villages and 3,91,438 houses in the district Population Ratlam has a population of 19,86,864 peoples.(2011).(table1.5), Population density in sq km (2011) is 326. There is marked increase in the population density per sq km in last two decade is from 227 (1991) to 326 (2011). In the last ten year (2001 to 2011) the percentage increase in population is 16.12%.

Table 1.5: Population of Ratlam District

Population Type	Male Population	Female Population	Total Population
Rural	6,16,353	5,91,298	12,07,651
Urban	3,99,939	3,79,277	7,79,213
Total	10,16,289	9,70,575	**19,86,864**

Tribal Blocks: Sailana and Bajna blocks are major tribal blocks where the tribal population is 79.36 % and 92.79 % respectively. The tribal population of the Ratlam district is 25.89 %. Rural and urban area are 5,896.79 km² and 194.21 km² respectively.

1.5 Rainfall and Climate

Ratlam has a humid subtropical climate, with mild, dry winters, a hot summer and a humid monsoon season. Summers start in late April and go on till mid-June, the average temperature being around 30 °C (86 °F), with the peak of summer in May, when the highs regularly exceed 40 °C (104 °F). The monsoon starts in late June and ends in late September. These months see about 40 inches (1020 mm) of precipitation, frequent thunderstorms and flooding. IMD normal annual rainfall of Ratlam city is 715 mm. The normal annual rainfall of Ratlam district is 914.5 mm. Ratlam district receive maximum rainfall during southwest monsoon period i.e. June to November. About 92.1% of annual rainfall is received during monsoon season. The surplus water for groundwater recharge is available only during the southwest monsoon period. The average temperature is around 25 °C (77 °F) and the humidity is quite high. Temperatures rise again up to late October when winter starts, which lasts up to early March. Winters in Bhopal are mild, sunny and dry, with average temperatures around 18 °C (64 °F) and little or no rain. The winter peaks in

January when temperatures may drop close to freezing on some nights. Daily mean normal temperature of Ratlam in May is 40.7^0 C and minimum is 26.4^0 C.

The annual normal rainfall in the area is 914.5 mm /yr

Table 1.6: Monthly/yearly rainfall of Ratlam

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total
2004	28.2	0	0	2.2	6.2	72.5	199.6	524	20.6	45.5	0	0	898.8
2005	0	0	6	12.5	0	54.9	279.3	188	128.7	0	0	0	669.4
2006	0	0	19.9	0	27.2	151.6	245	883.9	432.5	7	1.3	0	1768.4
2007	0	3.4	0	2.2	22.5	119.7	426.1	382.9	168.4	0	0	0	1125.2
2008	0	0	0	13.5	0.3	109.7	218.1	129.6	125.4	41.5	1.5	0	639.6
2009	1.2	0	0	0.2	19.6	69.8	313.6	146.1	101.8	85.1	56	24.5	817.9
2010	0.6	8.8	0	0	0.7	11.9	217.9	328.2	80.7	16.7	45.8	2.2	713.5
2011	00	00	5.0	0.0	0.0	174.4	452.5	458.9	147.0	0.0	0.0	0.0	1237.8
2012	00	0	0.0	0.0	3.0	12.0	455.0	214.0	0.0	0.0	0.0	0.0	684.0
2013	00	4.0	33.0	7.0	0.0	271.0	456.0	352.0	90.0	25.0	0.0	0.0	1238..0
2014	17.0	43	4.0	0.0	17	36	264.0	165.0	55.0	6.0	0.0	33.0	640.0

District	Normal monsoon rainfall (mm)		
	monsoon rainfall	Non monsoon rainfall	Total rainfall
Ratlam	**922.5**	70.4	992.9

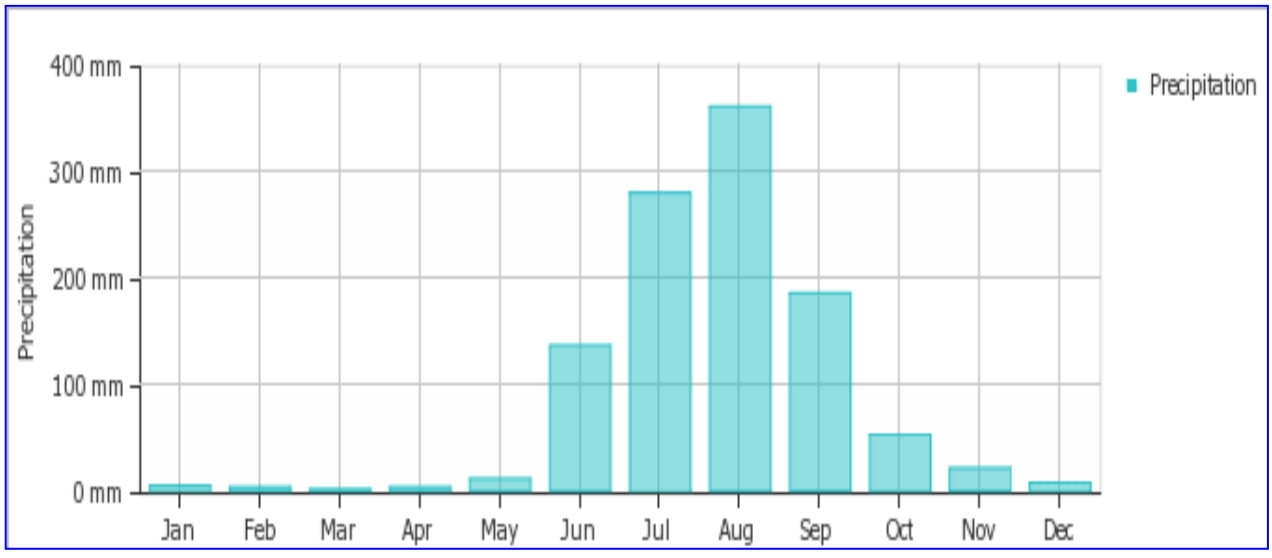

Fig: 1.7 Average monthly precipitation over the year

1.6 Physiography

Physiographycally the Ratlam district lies on the western margin of Malwa Plateau and can be divided into

(i) Region of low level occupying the north-eastern and southern parts
(ii) The northern plains.

The low level plateau region has a general elevation ranging from 418m to 600m above msl. The northern plain include the plain covered by black cotton soil and older flood plain covered by alluvium

Topography of the Ratlam district is highly rugged and undulating comprising hills, dissected plateau, valley and flats. The maximum elevation of about 603m amsl is observed in the area Ratlam block and lowest elevation is <266.8m amsl in the Bajana block area in the south west of Ratlam district.

Table 1.7: Blockwise elevation of Ratlam District

Block	Elevation (m) amsl		
	Maximum	Minimum	Difference
Alot	504.5	405.8	98.7
Bajna	514	266.8	247.2
Jaora	522.4	416	106.4
Piploda	445.1	561.9	116.8
Sailana	600.4	277.3	323.1
Ratlam	603	366.1	236.9

The low level plateau region has a general elevation ranging from 418 to 600 m above msl. The highest elevation is 612 m above msl near Sakroda in the south western part.

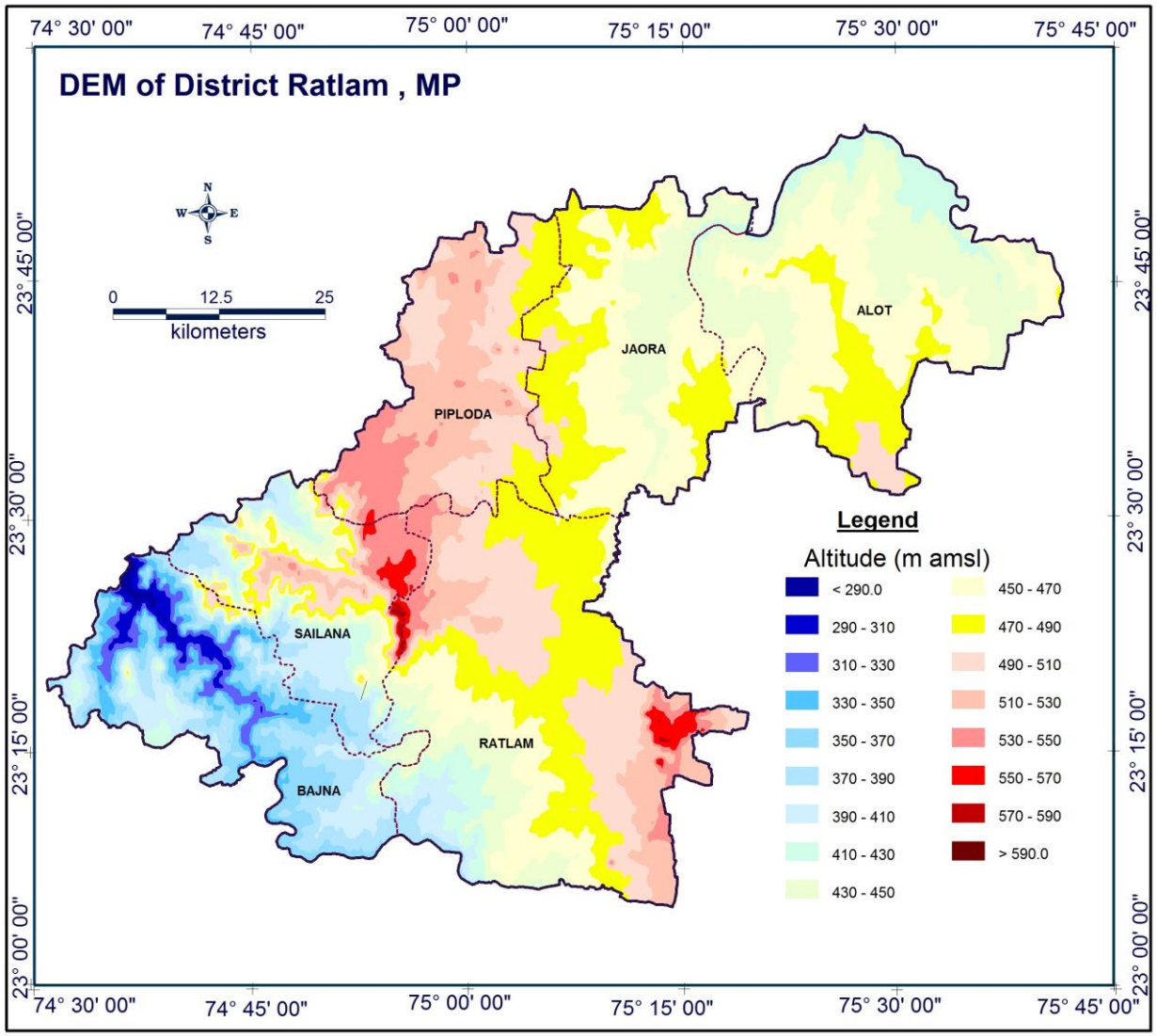

Fig. 1.8 Digital Elevation Model (DEM) of Ratlam District

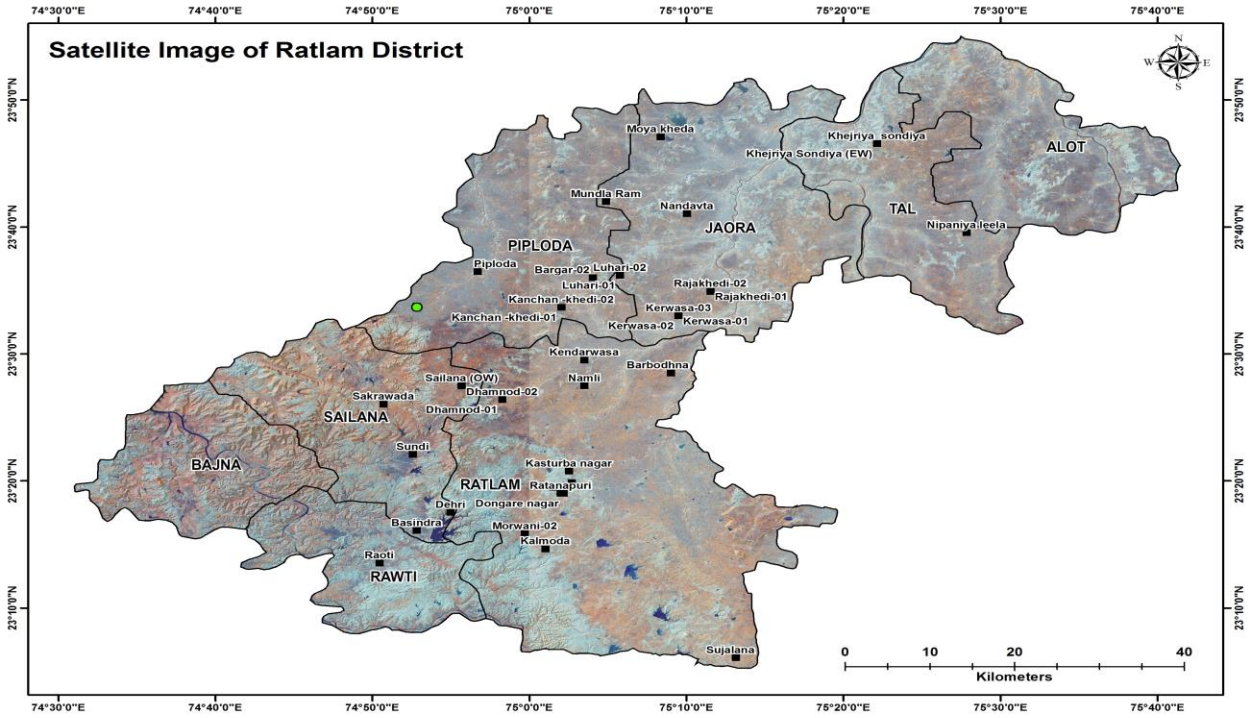

Fig.1.9 Satellite image of Ratlam District

1.7 Geomorphology

The geomorphic surface area is such that the area becomes steep to moderately sloping to nearly flat in the middle reaches of the river. The distribution and structure of valleys landforms reflect the geomorphic processes that created them. The general scene is of undulating country sloping towards north and marked by series of high hills and valleys. There are isolated hills and attain prominence in the southeast of the district and near the western margins of the plateau. In the west hills are dissected and slopes into the narrow valleys of seasonal steams of Mahi. Geomorphology of Ratlam district can be divided into five divisions.

1. The Malwa plateau in the east
2. The western hills of Sailana
3. The Mahi valley
4. The plateau of Sailana
5. The Chambal valley

In general, Ratlam district is characterized by hilly to undulating terrain with altitude ranging between 434 m and 549 m above mean sea level. The low-level plateau region has a general elevation ranging from 418 to 600 m above msl. The highest elevation is 612 m above msl near Sakroda in the south western part. Lowest elevation of the district is 305 m above mean sea level

at village Chandragarh in Sailana block. The Chamala Khipra / and Mahi river sub basin in Ratlam area are consist of flood deposit along the river banks and denudation hill, highly dissected Plateau. Pediment, vally fill and pediplain.

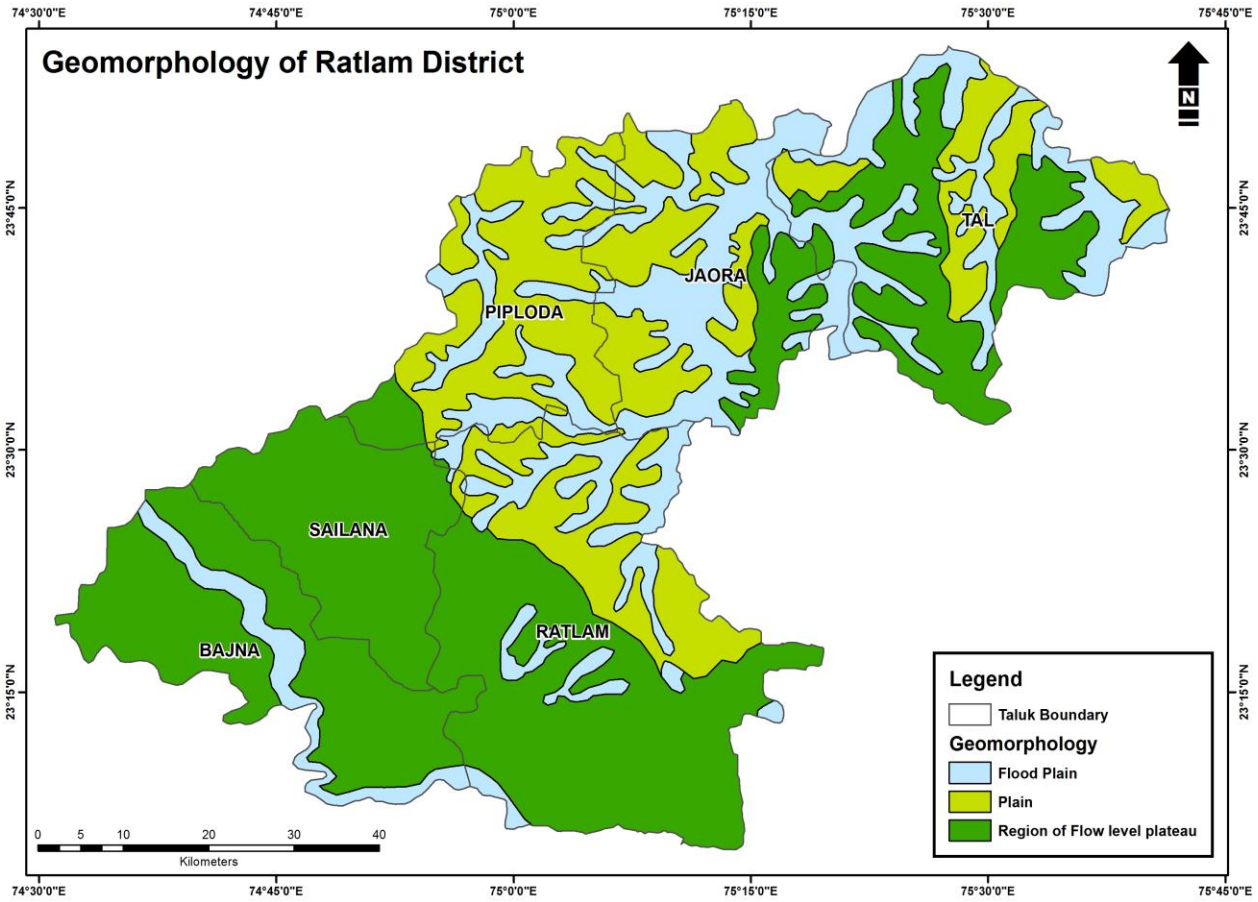

Fig.1.10 Geomorphological map of Ratlam District

1.8 Soil

Two types of rocks, sedimentary and basaltic rocks, mainly cover the district. The nature and characterizations of the soil is dependent on type of lithology in the area. Hence the soil of the district has been classified into two groups.(1) Soils of sedimentary & (2) Soils of basaltic rocks.

Soils of sedimentary rocks are found in western parts of the district mainly in Sailana tehsil where the land is occupied by numerous hills of Vindhyans rocks and the soil are sandy in nature and having reddish and brown colour.

Soils of basalt are occurring in major parts of the district covering Ratlam, Jaora, Alot and Piploda blocks. It is generally known as black cotton soil, fertile in nature and suitable for cotton crops. Black cotton soils with heavy to light texture are found in the whole area. Light textured

silty ‘Kankar’ and admixtures of clay in the form of alluvium occur along the bank of major streams.

The district faces considerable problem of soil erosion, which is aided and abetted by faulty forming practices and also by natural agents like wind and water

1.9 Drainage

Ratlam district falls under Ganga and Mahi river basins. The tributaries of Chambal River drain about 70 % geographical area of the district.

The northern part of the district is drained by Chambal river and its tributaries viz Kshipra, malani and Rajhar(sau).The Mahi river flows in the south western part and its tributaries’ The Mahi River is a consequent river, which originate from Dhar district. The main tributaries of the Mahi River are **Bageri, Jammer, Karan, Pundia, Bunad Pampavati and Telni.**

The type of drainage in general is dendritic developed on Deccan Trap basaltic rocks.

1.10 Land use pattern

Cultivated area is about 336367 Ha which is 69.21 % of total area. The forest area is 34339 ha The less than 0.5 to 3% of total forest area are Jawara, Piploda and Tal blocks. The highest forest area is in the Bajana block i.e.10718 ha (31.21%).

Table 1.8: Land use pattern (Ha) 2016-17

Block	Geo graphical area	Forest area	Area not available for Agriculture	Non-agriculture land	Agriculture land	Fallow land	Cultivable land	Area of double crop
	1	2	3	4	5	6	7	8
Alot	49143	990	6518	4533	1359	40	35703	25587
Jaora	75704	319	7881	4281	3467	151	59606	47437
Piploda	60252	17	5103	3859	1812	169	49292	38792
Ratlam	133084	9970	16465	7219	5002	549	93879	67036
Sailana	54537	8975	11743	1786	1384	279	30370	8191
Bajana	34744	10718	6505	1177	397	31	15916	3102
Rawati	33155	3219	11957	1149	1057	38	15735	4311
Tal	45388	131	4238	3606	1479	68	35866	26416
Total	486007	34339	70410	27610	15957	1325	336367	220872

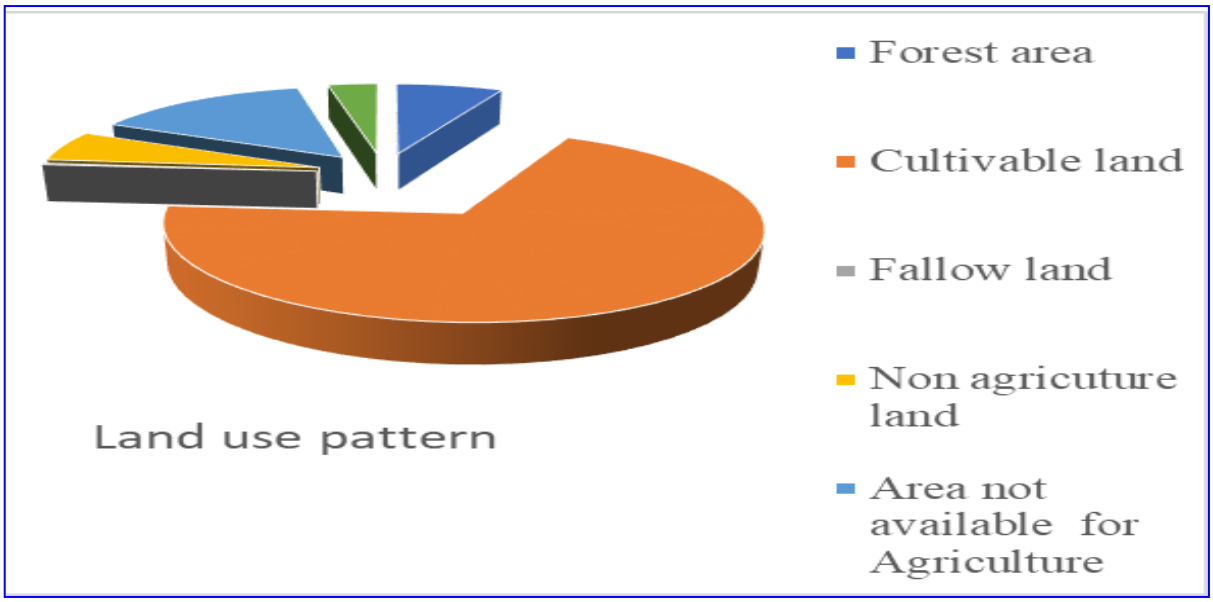

Fig.1.11 Landuse pattern of Ratlam District

- **Change in Land use pattern :** Net sown area have been decreed to 591ha and double crop area become reduced in last 3 year i.e from 240093 to 220871 ha i.e.19222 ha.

Table 1.9: Change in Land use pattern (Ha) in 03 year from 2014-2017

Year	Agriculture land	Fallow land	Net sown area	Doubled crop
2014-15	13415	1483	336958	240093
2015-16	15682	1475	336224	214650
2016-17	15957	1325	336367	220871
Variation in Ha in last 03 year	**2542**	**158**	**591**	**19222**

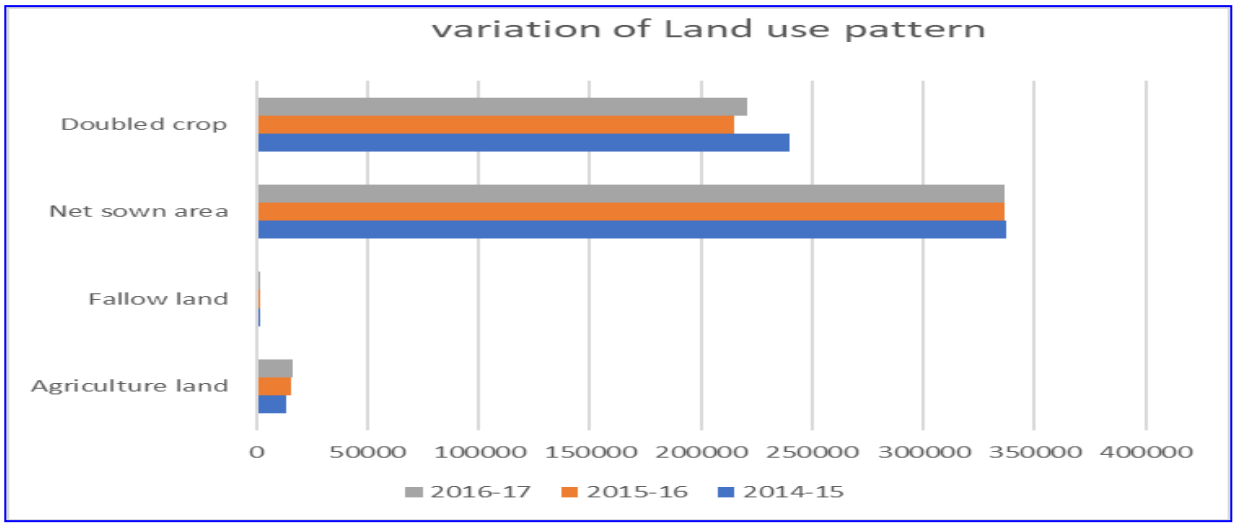

Fig. 1.12 Variation in Landuse pattern of Ratlam District

1.11 Agriculture and cropping patterns

Ratlam district is mainly agriculture-based district and its cropping pattern is diversified. The total crop area is 4987.87Sq km while double crop area is 220872 Ha. The main crops in kharif season are rice, maize, Bajara and groundnut while in the Rabi, crops are wheat, gram etc

- Area of Kharif crop : 336334 Ha
- Area of Rabi : 308329 Ha

Table 1.10: Change in area of Kharif and Rabi crop (Ha) in 03 year from 2014-2017

Year	Kharif			Rabi			Total Kharif+Rabi
	Food crop	Non food crop	Total Kharif	Food crop	Non food crop	Total Rabi	
	1	2		3	4		5
2014-15	43984	295805	339789	222840	14855	237695	577484
2015-16	48719	281220	329939	200815	13868	214683	544622
2016-17	43869	292465	336334	292465	15854	308319	557238

- **Cereal Crop area**

The total cereal area is about 154237 ha during 2016-17. This area had been increased in the previous year to 169250 h.e.15013 ha (9.86%) during 2015-16. Wheat area has been reduced since 2014 from 123113 to 119238 ha.

Table 1.11: Year wise Cereal Crop area in the Ratlam district (2014- 17)

Year	Wheat	Rice	Jawar	Maize	Other cereal	Total cereal
	1	2	3	4	5	6
2014-15	**123113**	**1278**	**23**	**42730**	**210**	**152172**
2015-16	**113974**	**1248**		**35970**	**250**	**169250**
2016-17	**119238**	**1228**		**33696**	**75**	**154237**

Table 1.12: Block wise cereal Crop area (Ha), Ratlam district (2016-17)

Block	Wheat	Rice	Miaze	Other cereal	Total cereal
	1	2	3	4	5
Alot	13473		1851	13	15337
Jaora	23045	5	3506		26556
Piploda	20698	9	1305	3	22015
Ratlam	36020	13	5572	5	41610
Sailana	6276	254	8007	10	14547
Bajana	2895	719	6259		9873
Rawati	4039	228	4846	35	9148
Tal	12792		2350	9	15151
Total	**119238**	**1228**	**33696**	**75**	**154237**

- **Pulse Crop area**

Table 1.13: Block wise Pulse Crop area (Ha), Ratlam district (2016-17)

Block	Channa	Tur	Urd	Other Pulse	Total Pulse
	7	8	9	10	11
Alot	3713	179	228	263	4383
Jaora	11901	164	230	698	12993
Piploda	7440	68	162	675	8345
Ratlam	17681	291	352	2865	21189
Sailana	830	88	605	42	1565
Bajana	140	3	269	194	606
Rawati	150	38	474	28	690
Tal	5423	173	203	221	6020
Total	47278	1004	2523	4986	55791

Table 1.14: Main Crop area (Ha), Ratlam district

Block	Sugar cane	Fruits	Vegetable	Masala	Total food	Cotton	Others	Total
	12	13	14	15		16	17	18
Alot		163	310	4520	4993	24713	14	24727
Jaora	3	61	1001	7043	8108	47657	204	47861
Piploda	1	65	870	5675	6611	36971	627	37598

Block	Sugar cane	Fruits	Vegetable	Masala	Total food	Cotton	Others	Total
Ratlam		531	4143	8162	12836	75615	2726	78341
Sailana		3	382	594	979	19091	5958	25049
Bajana			26	17	43	10522	3313	13835
Rawati		6	98	94	198	10036	3898	13934
Tal	1	274	218	4650	5143	26314	26	26340
Total	5	1103	7048	30755	38911	250919	16766	267685

Table 1.15: Oil seed area (Ha), Ratlam district

Block	Tel	Alsi	Groundnut	Rai/Custer	Cotton	Soyabean	other oil seed	Total
	19	20	21	22	23	24		25
Alot	14	115	159	109	2208	29977	686	33254
Jaora	204	17	469	89	2637	51651	585	55448
Piploda	627	15	1312	34	1897	44083	171	47512
Ratlam	2726	7	32	54	296	76856	35	77280
Sailana	5958			6	9	11881		11896
Bajana	3313	3		111		4179		4293
Rawati	3898	4		42		4618		4664
Tal	26	48	134	94	2123	30808	654	33861
Total	16766	209	2106	539	9170	254053	2131	268208

- **Average crop production**

Table 1.16: Average crop production (Ha)

Year	Rice	Soyabean	cotton	Wheat	Jawar	Miaze	Chana
	1	2	3	4	5	6	7
2014-15	1610	1550	1550	3550	1200	3300	1383
2015-16	2138	780	789	3643	2101	4200	1182
2016-17	1879	810	830	3598		3800	1285

Year	Mung & Moth	Urd	Alsi	Tel	Rai/Mustered	Tur	Ground nut	Sugar cane
	8	9	10	11	12	13	14	15
2014-15	1075	850	0.99	1020	16.35	1075	1760	0
2015-16	1300	795	0.92	780		1300	1700	0
2016-17	1288	820	0.93	760		1288	1720	

1.12 Irrigation

Ground water irrigation in the area is about 89.0 % (178848 ha) of total irrigation area of various sources i.e. 201118 ha.

Table 1.17: Irrigation sources of Ratlam district (2017)

Source	Irrigated area (ha)
Surface water	13400
Groundwater	178848
Area of other Source of irrigation (Ha.)	8870
Total	201118

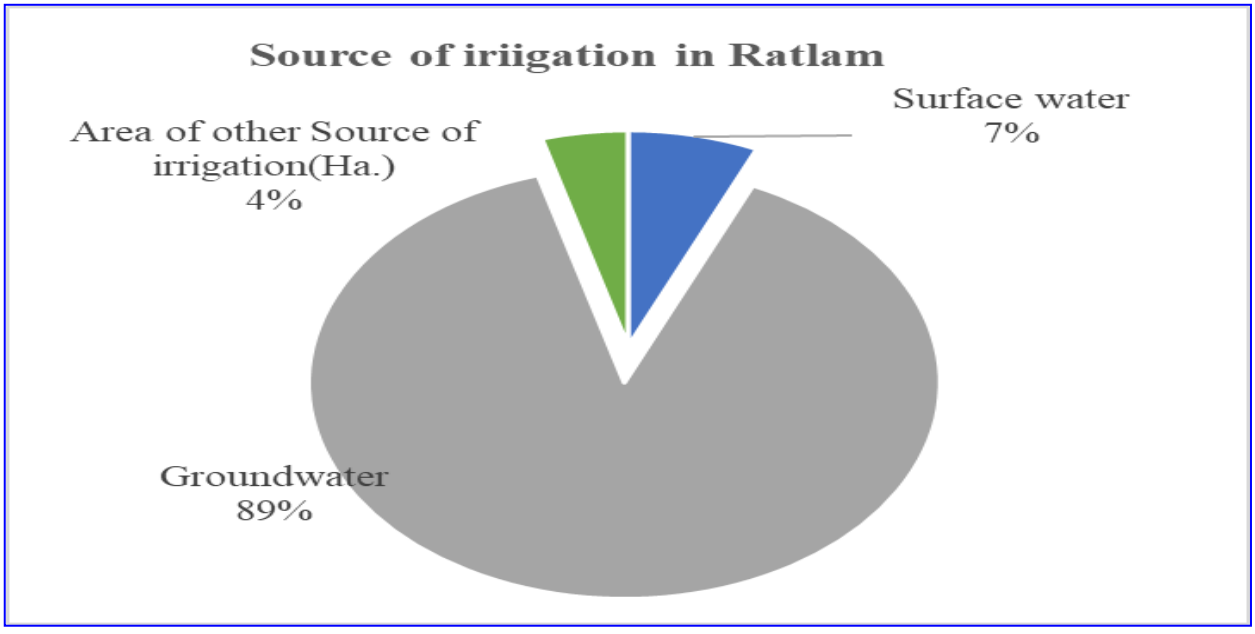

Fig. 1.13 Sources of irrigation in Ratlam

Table 1.18: Total Irrigated areas from various sources

	Source	Structures	Number	Area(ha)	Total	%
Irrigated area (Ha)	Surface water	Canal	52	5860	13400	6.97%
		Ponds	179	7540		
	Groundwater	Tube wells	49958	93201	178848	93.03%
		Dug wells	533330	85647		
		Total	583519	**192248**		**100%**

- **Groundwater Irrigated areas and structures**

The total groundwater irrigation is 78848 Ha in the Ratlam district area out of which Dug wells irrigation is about 85647 Ha while tube wells irrigation is about 93201 Ha.

Table 1.19: Block wise Groundwater structures and Irrigated area

Block	Dug well		Tube well		Total	
	Number	Irrigated area (ha)	Number	Irrigated area (ha)	Number	Irrigated area (ha)
Ratlam	12152	13876	37935	39847	50087	53723
Alot	6646	12145	1095	12637	7741	24782
Tal	6242	8439	2203	11272	8445	19711
Jaora	10699	25621	2632	13222	13331	38843
Piploda	10295	20820	4242	12130	14537	32950
Sailana	3798	2486	1499	2832	5297	5318
Bajana	2224	1042	204	279	2428	1321
Rawati	1274	1218	148	982	1422	2200
district	53330	85647	49958	93201	103288	178848

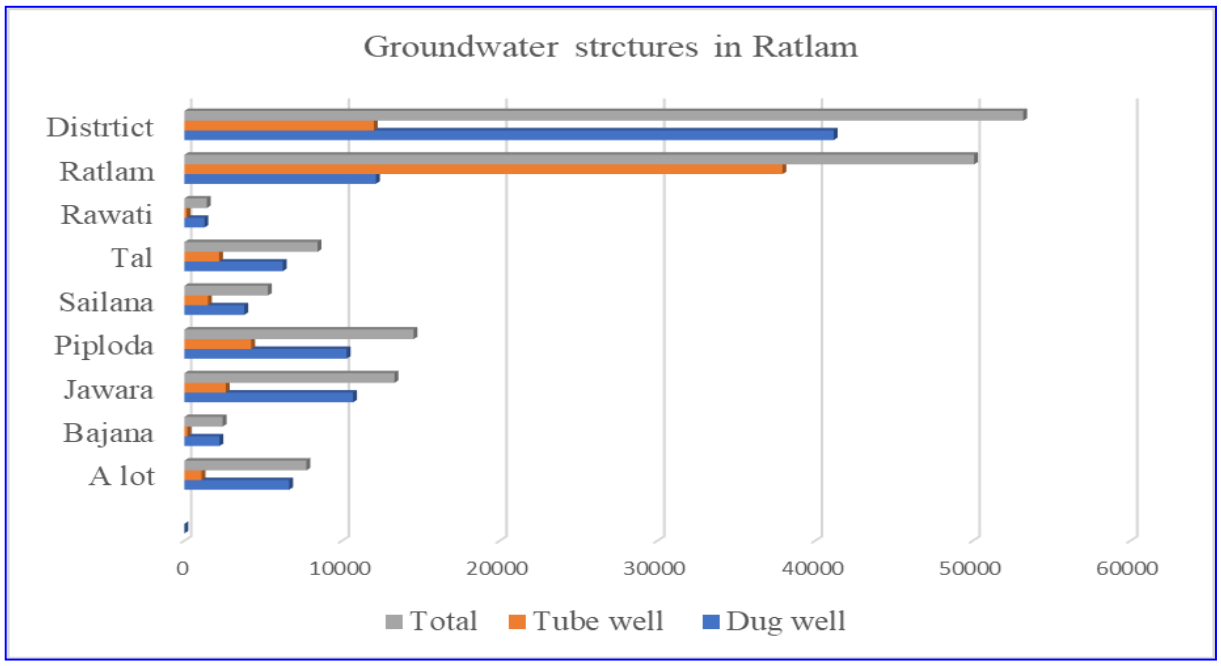

Fig. 1.14 Groundwater structures in Ratlam

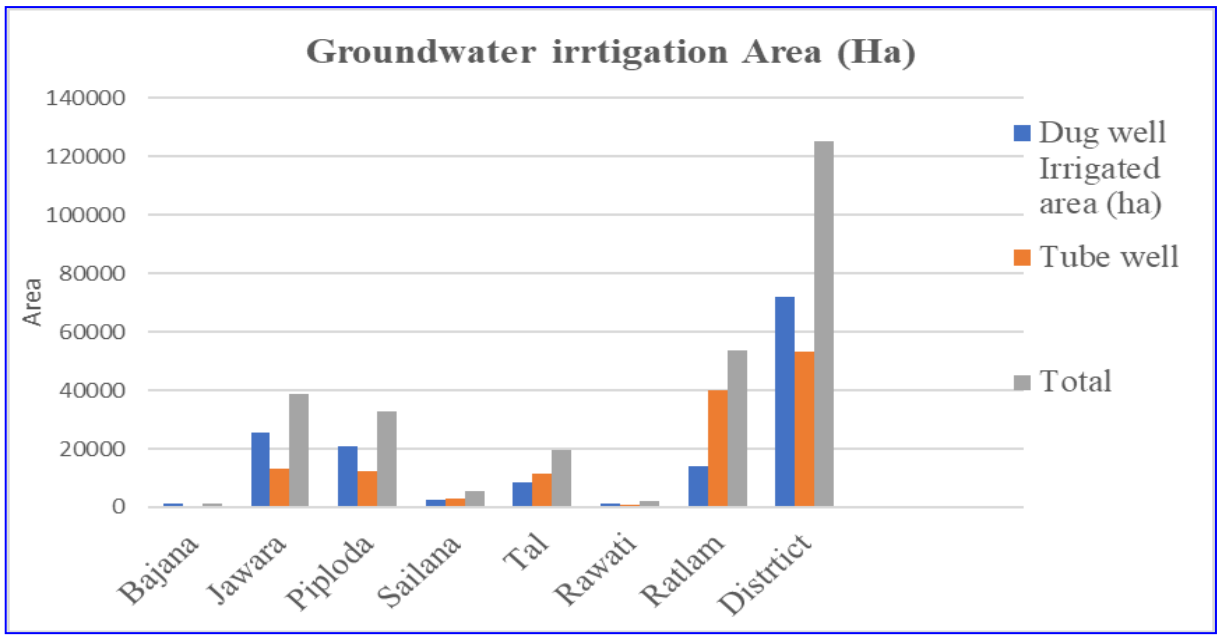

Fig. 1.15 Groundwater irrigation area of Ratlam

Table 1.20: Variation in Groundwater structures and Irrigation area in last 3 year

Year	Tube wells		Dug wells	
	Number of Irrigated Structures	Irrigation Area (Ha.)	Number of irrigated strctures	Irrigation Area (Ha.)
2014-15	47988	83110	41460	67353
2015-16	48580	92946	52765	81441
2016-17	49958	92721	53330	85647

1.13 Geology

Geology of Ratlam district is given in following table 1.21:

Table 1.21: Geological succession of Ratlam District

Succession	Formation	Age
Alluvium/ Laterite	Clay with kanker, sand and river alluvium	Recent to Pleistocene
Deccan trap	Basaltic lava flows with redbole and interappean beds	Upper cretaceous to Eocene
----------Unconformity----------		
Upper Vindhyan Bhander Group	Sandstone and Shale sequence with conglomerate	Upper pre Cambrian to Lower protoeozoic

Deccan Trap

- **Basaltic flow unit**

Each individual lava flow can be sub divided into 3 distinct units-

(i) Red bole (ii) Vesicular/Amygdular basalt

(iii) Massive and compact basalt

- **Red bole clay**: The top of the individual flows is occasional marked by reddish brown clay material, termed as "Red bole" which at places is represented by grayish clay. The thickness of red bole varies from few centimeter to few meters. The red bole in its genetic relationship is an ***insitu*** product of backing and weathering of basalts representing a time

gap between the two Successive flows. They indicate the local topographic highs during the time gap of successive flows.

- **Vesicular/ Amygdular basalt:** The vesicular unit of each flows forms the upper horizon and ranges in thickness from 1.5 meters to as much as 06 m forming 25 to 30% of the total thickness of flows. It is medium to coarse grained, softer than massive basalt and vesicles are commonly filled with secondary mineral like calcite, Zeolites and quartz.
- **Massive Basalt:** It is fine to medium grained compact, dark greenish to grey colour and form 60 to 70% of the flow unit. It weathers along joints and spheroidal weathering is commonly seen. Columnar jointing is quite common.

The intertrappen bed comprising laminated shale with siltstone bands occurs in between the bottom flows in the western part.

Laterite

Laterite/Alluvium occurs as isolated capping over the Deccan trap in the extreme north western part of area. The general level of occurrence of the laterite capping is 500m amsl. It is reddish brown , limonite soft rock.

CHAPTER-2
DATA COLLECTION AND GENERATION

2.1 Data availability, Data adequacy and Data gap analysis and Data generation

- **Data availability**

There are 61 exploratory wells have been constructed in the aquifer mapping area of Ratlam district. The total requirment of exploratory wells as per norms of aquifer mapping is 88.out of which 06 exploratory wells are in the urban area & 55 exploratory wells are in the block area of Ratlam.

Data gap analysis were carried out for Blockwise and toposheet wise. There is one sailana blocks in which there is no data gap. Exploratory wells have been constructed in the toposheet area of 46M/1, 46M/2, 46M/2 does not require any well (Table 2.1).

Table 2.1: Wells constructed by CGWB in Ratlam

Block	EW	Data gap	Total
A lot	6	14	20
Bajana	4	5	9
Jaora	14	3	17
Piploda	9	2	11
Sailana	8	0	8
Ratlam	20	3	23
total	**61**	**22+5*=27**	**88**

T sheet	EW	Data gap
46I/11	3	3
46I13	1	0
46I14	4	1
46I15	7	2
46I16	1	1
46M/1	2	0
46M/2	9	0
46M/3	6	2
46M/4	4	1
46M/5	1	4
46M/6	5	4
46M/9	1	4
46M/10	2	0
Total	46	22

05 Exploratory wells have been constructed in quardent of toposheet where already having existing EW

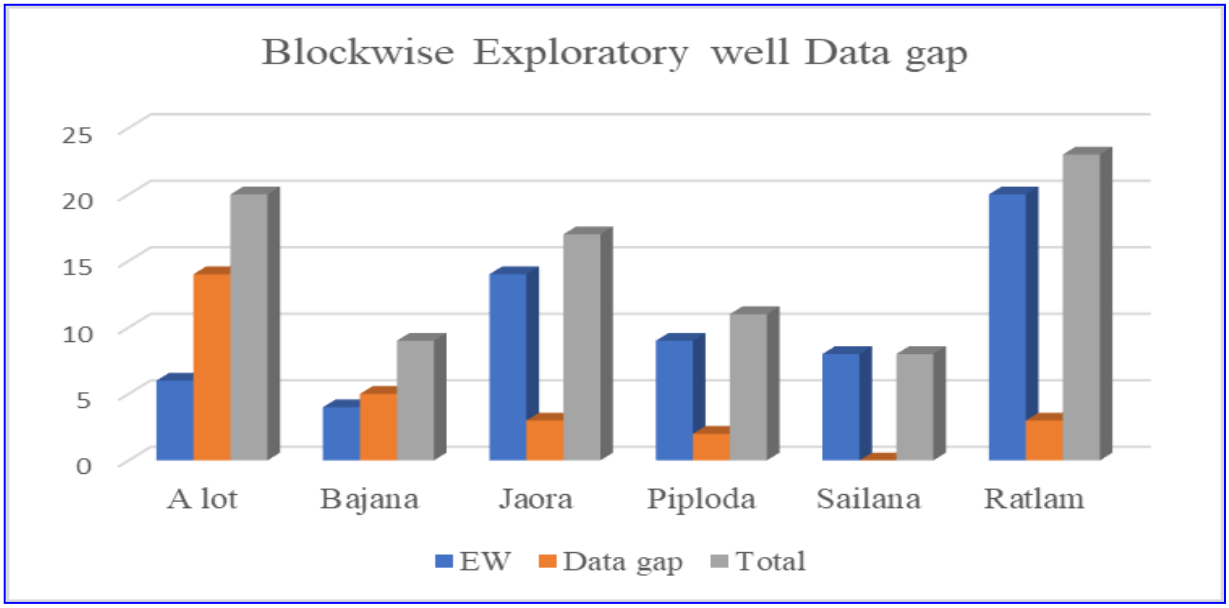

Fig.2.1 Graph showing blockwise exploratory well data gap

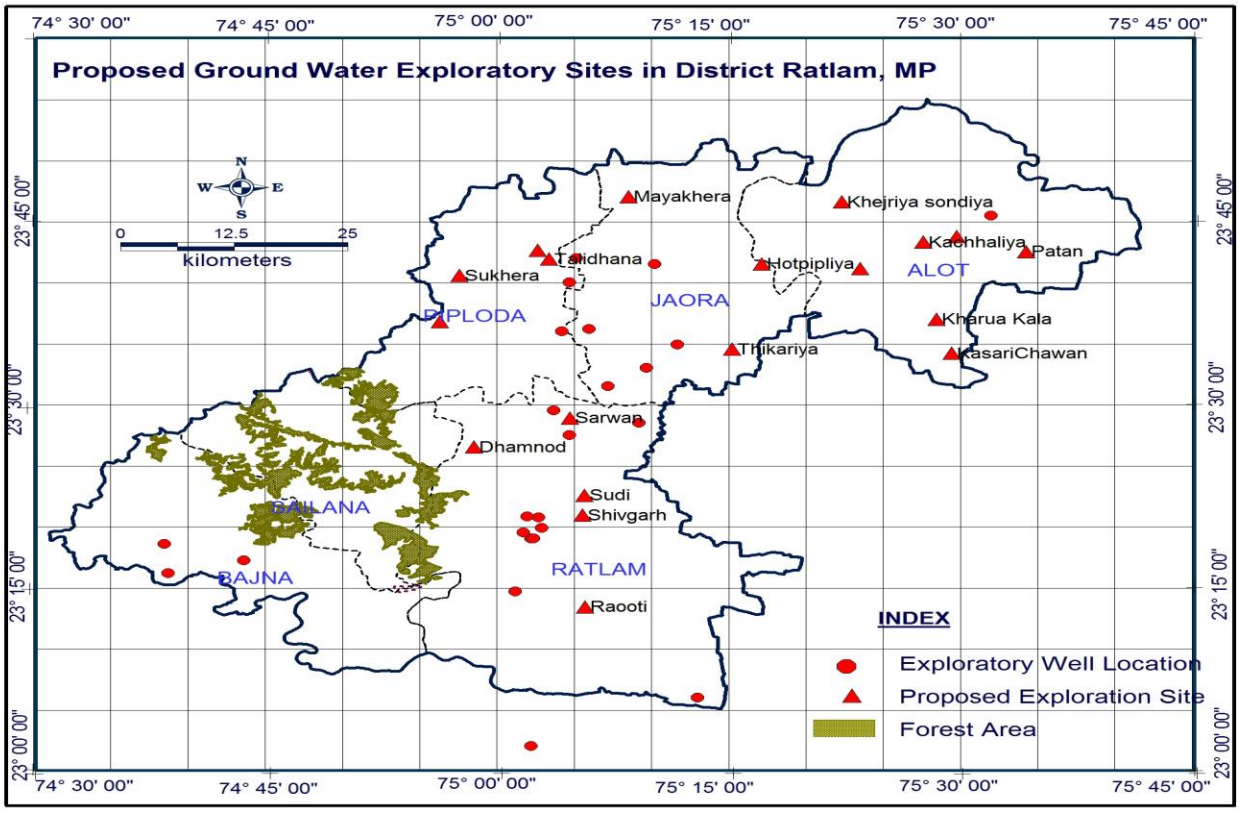

Fig.2.2 Proposed Groundwater Exploratory sites in Ratlam District

- **Data adequacy and Data gap analysis:** Data gap analysis & status as on 1st April 2017 based on EFC Norms are given below (table 2.2);

Table 2.2: Targets as per EFC norms and actual achievements

Block	Ratlam	As per EFC norms	Actual achievements
Area in sq.km	4861**sq.**		
Preparation of Sub-surface Geology (area in sq.km) **Geo-morphological analysis (area in sq.km)**	4861 4861		**Existing data & new inadequate Generate new data** **GSI layer**
Land use pattern (area in sq.km)	4861		**Layer prepared**
Vertical electrical Sounding (VES) (Nos)	41	25	41
Bore Hole Logging (Nos)	5	Need based	Need based
2-D Imaging (Line Km)			
Ground TEM (Nos)			
Heliborne TEM & Gravity (Line km)			
Preparation of Drainage Map (area in Sq.km)	4861		completed
Demarcation of water bodies (area in sq.km)	4861		completed
Soil infiltration studies (Nos.)	42	33	0
Rainfall data analysis for estimation of recharge to ground water (area in sq.km)	4861		Monthly data yet to receive
Canal flow, impact of recharge structures	4861		Existing data
Water level monitoring (No of stations* frequency) (No of monitoring stations)	*4*3		456
Exploratory Wells	**10**		**10**
Observation Wells	**08**		**2**
Slug test (Nos)	0	0	0
Specific Yield test (Nos)	0	0	0
Micro-level hydro-geological data Acquisition including Quality Monitoring	102	37	
Water Quality (sampling and Analysis) for Basic Constituent, Heavy Metals etc			
Analysis of Ground water for Pesticides, Bacteriological contamination in Ground water	0	0	0
Carbon dating (Nos)	0	0	0
Isotopic studies (Nos)	0	0	0
Core drilling (Nos)	0	Need based	

- **Data generation**

Exploratory wells in the mapping area are to constructed in the depth range of 200m or above. There are 92 quardent in the of Ratlam district area,out of which 66 doesn't have any exploration wells.The blockwise proposed data generation are given in table 2.3.

Table 2.3: Blockwise proposed data generation

Block	Target 2017-18		NAQUIM Desired	Balance	EW constructed	
	EW	OW			2003-05	2017-18
Alot	02	01	12	07	01	05
Bajana	08	04	06	04	02	01
Jaora	03	01	04	01	07	04
Piploda	02	01	09	09		03
Sailana	04	01	07	07		01
Ratlam	02	01	08	08	12	-
Total	**18**	**09**	**43**	**28**	**22**	**14**

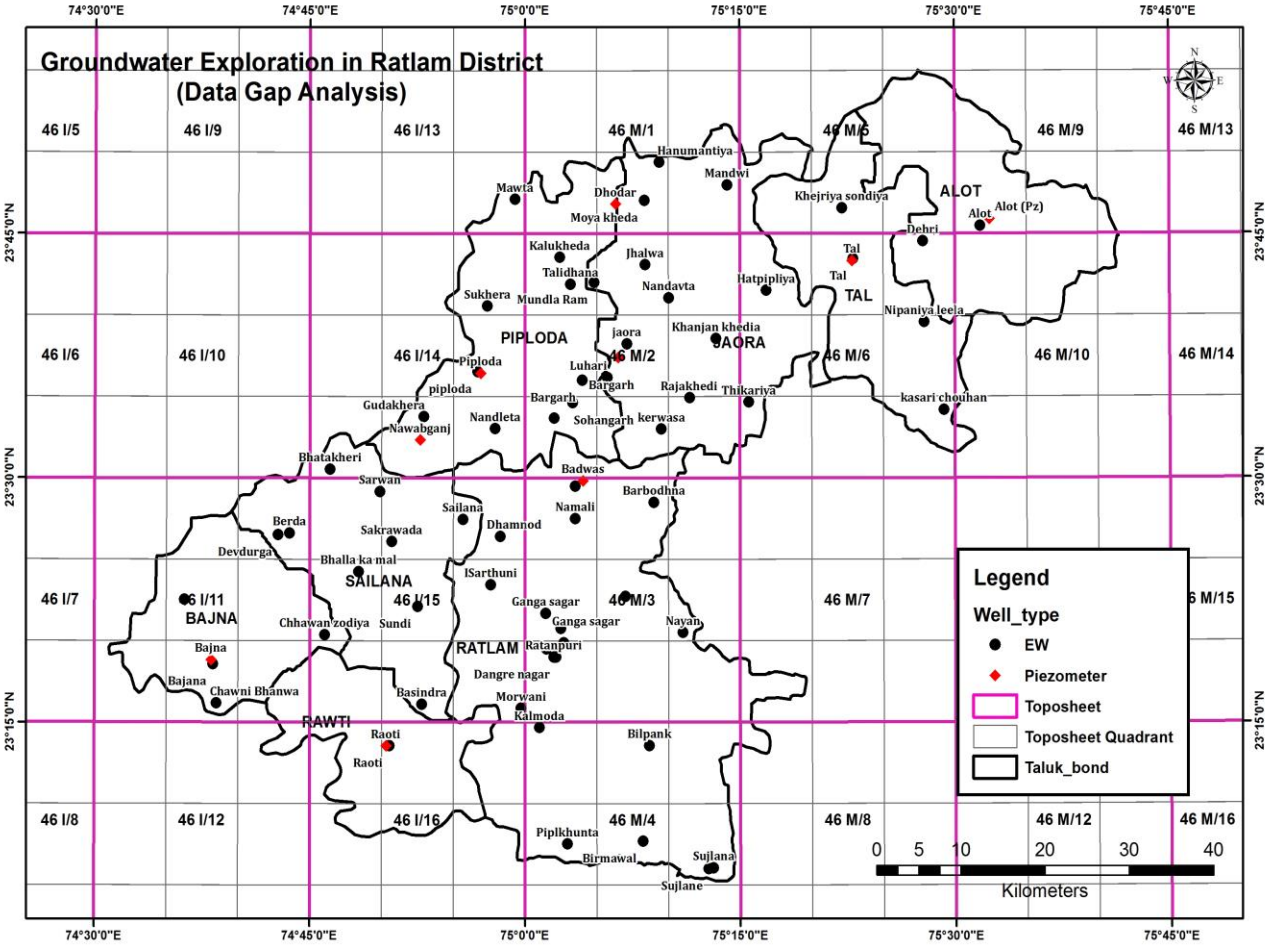

Fig.2.3 Groundwater exploration in Ratlam District

Table 2.3.1: Blockwise proposed data generation

EW No.	EW constructed	Block	Toposheet/Gap		E Well Constructed	Year
1		A lot	46 M/5 / 05	3A		
2				2B		
3	1			3B	Khejriya sandiya	2017-18
4				2C		
5				3C		
6			46 M/6 /07	3A		
7	2			1B	Tal	2017-18
8				2 B		
9				3B		
10	3			1C	Dehri	2017-18
11	4			2 C	Nipaniya leela	2017-18
12	5			3C	Kasari chowan	2017-18
13			46 M/9 / 06	1A		
14				2A		
15	6			3A	A lot	2002-03
16				1B		
17				2 B		
18				3B		
19			46 M/10 /02	1A		
20				1B		
1		Bajana	46 I/11 /06	1B		
2	7			2B	Kundanpur	2017-18
3	8			3B	Bajana	2017-18
4	9				Chawni Bhanwa	2004-05
5				1C		
6				2C		
7	10			3C	Chawani Zodiya	
8			46 I/15 /01	3A		
9	11		46I/16 / 01	1B	Raoti	2017-18
1	12	Jaora	46 I/13	**1C**	Movta	2017-18
2	13		46 M/1	3B	Mayakheri	2017-18
3	14			3C	Mandevi	2017-18
4	15		46 M/2	1A	Mudlaram	2004-05
5					Kalukhera	2017-18
6	16			1B	Jhalwa	2017-18
7	17			2B	Jaora ploytechnic	2004-05
8	18				Lohari	2004-05
9	19			3B	Kervasa	2004-05
10	20			1C	Nadlawata	2004-05
11	21			2 C	Khajankheda	2017-18
12	22			3C	Rajankhera	2004-05
13	23				Hanumantiya	2017-18

EW No.	EW constructed	Block	Toposheet/Gap		E Well Constructed	Year
14			46 M/5	3A		
15	24		46 M/6	1A	Hotpipliya	2017-18
16				2A		
17	25			3A	Thikariya	2017-18
1		Piploda	46 I/14 / 05	3A		
2	26			3B	Gudarpada	2017-18
3	27			1C	**Sukhera**	2017-18
4	28			2C	Piploda	2017-18
5	29			3C	Nadaleta	2017-18
6			46M/1 / 01	3A		
7	30		46M/2	1A	Talidhana	2017-18
8	31				Kalukherda	
9	32			2A	Bargaon	2003-04
10	33			3A	Kanchkheri	2004-05
11	34				Sohangarh	2017-18
1	35	Sailana	46 I/14		Bhatakheri	2017-18
2	36		46 I/15	1A	Sarwan	2017-18
3	37			2A	Bhalla ka mal	2017-18
4	38			3A	Babnki	2017-18
5	39			1B	Sakhdhara	2017-18
6	40			2 B	Sundi	2017-18
7	41			3B	Basindra	2017-18
8	42		46 I/11	1C	Nayan	
1	43	Ratlam	46 M/2	3A	Badwasa	2003-04
2	44		46 M/3	1A	Kandarwasa	2003-04
3	45				Namali	2003-04
4	46			2A	Kastuban	2003-04
5	47				Ratanpur	2003-04
6	48				Gangasagar	2004-05
7	49				Dongargaon	2003-04
8	50			3A	Vibahnager	2003-05
9	51			1B	Barbdna	2003-04
10	52				Sojlana	2004-05
11	53			2 B	Din dayal Nagar	2003-04
12	54			3B	Jarwasakala	2017-18
13				2 C		
14				3C		
15	55		46 M/4	!A	Kalmoda	2004-05
16	56			2A	Pipalkunta	2017-18
17	57			1B	**Bilpak**	2017-18
18	58			2 B	Birmawal	2017-18
19	59			1C		
20	60		46 I/15	1C	Dhamnod	2017-18

EW No.	EW constructed	Block	Toposheet/Gap		E Well Constructed	Year
21	61			2 C	Isarthuni	2017-18
22	62			3C	Morwani	2017-18

CHAPTER-3

DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

3.1 Hydrogeology

Geologically almost entire Ratlam district is occupied by Deccan Trap basalts except narrow patch of alluvium and sedimentary rocks of Vindhyans super group in isolated patches, which are forming different type of aquifer in the area. Occurrence and movement of groundwater in hard rock is mainly controlled by secondary porosity through joints and fractures. Presences of vesicle in basaltic lava flow of Deccan Traps play an important role in groundwater movement. Groundwater in general occurs under unconfined to semi-confined conditions.

- **Vindhyans**

The hillocks of Vindhyans sandstone occur as inlier in northwest and northern block of Piploda, Alot town, Dhodhar and Pingrala village. The sandstone is quartzitic in nature and very hard and compact. At shallow depth the sandstone forms poor aquifer system. Yield of Vindhyans sandstone formation is generally less than 2 litres per day.

- **Basalts**

The basalts underlie a major part of the district and generally groundwater occurs under phreatic conditions in shallow weathered, jointed and fractured horizons. Basalts does not exhibits uniform occurrence of groundwater both vertically and latterly. Physiographic location, thickness of weathered mantle, degree of jointing, fracture or shear zones, characteristics of vesicular horizons and their inter connection are important factor, which play a deciding role in the yield capacity of open wells tapping shallow aquifers. The deeper aquifer system appear to be under unconfined to semi-confined conditions while visualizing lava flow sequence which shows alternate units of vesicular and massive horizons. The hydrogeological regime in different tires, deeper aquifer is more likely to be governed by the secondary porosity jointed/fractured form of massive units is creating possibilities of their acting as leaky confining bed consequently resulting into semi-confined condition for water bearing vesicular units occurring below it. Yield of basalts in this is reported low to moderates (1 to 5 lps), but at some locations it is 11 lps (Vinoba Nagar), 12 lps (Rajakhedi) and 20 lps at Namli.

- **Alluvium**

The alluvium deposits are restricted to narrow linear along the river courses of Chambal, Kshipra, Maleni and Mahi. The thickness of alluvium varies from 12 to 15 meters, which is proportionately thinning away from the river line. The thickness of alluvium along the Kurel River reported about 20 meter near Rajhumgarh. The alluvium deposits consist series of consolidated, fine to medium grained sand admix in varying proportion and yield varies from 1 to 8 lps.

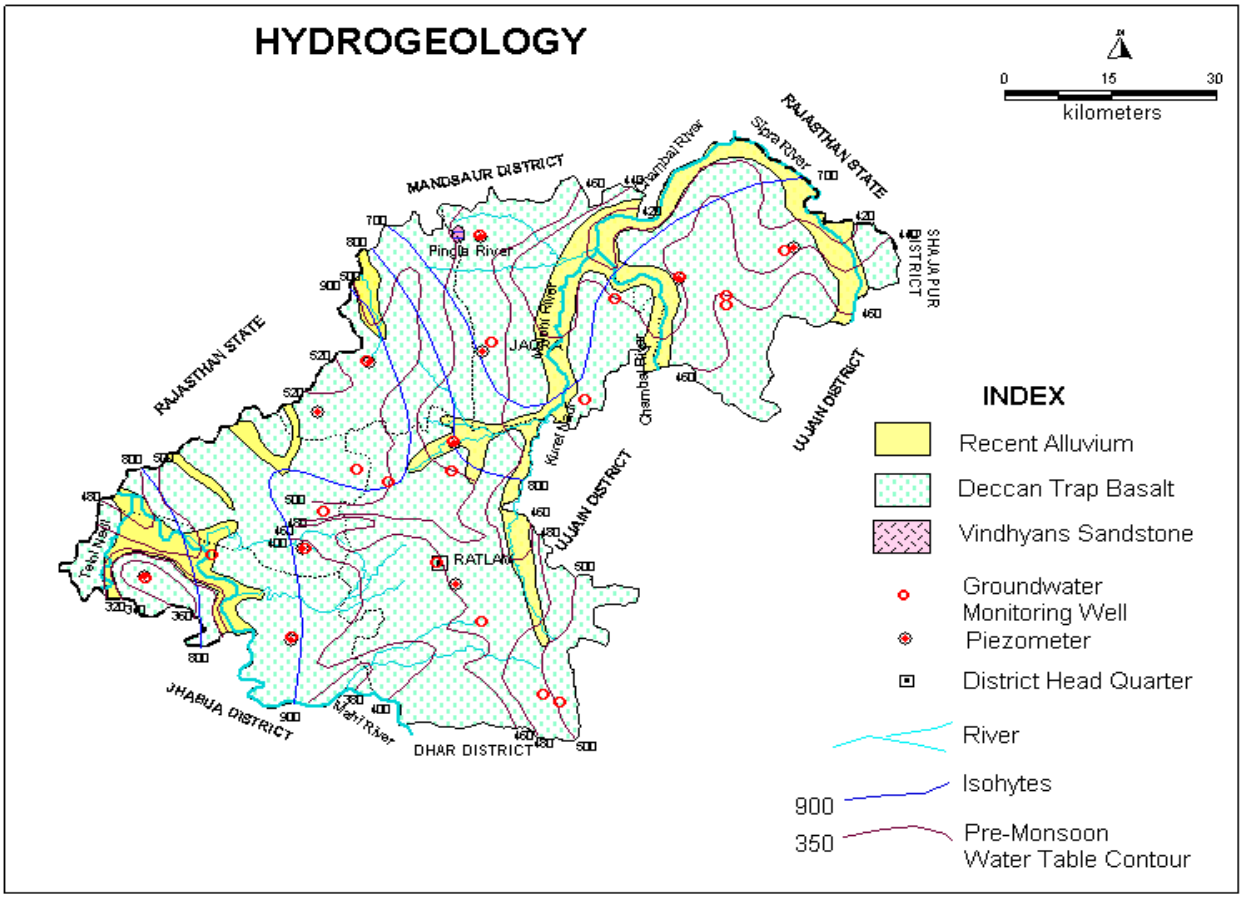

Fig.3.1 Hydrogeological map of Ratlam district

3.2 Hydrogeological data

- **Ground water level**

There are 78 Groundwater structures have been monitored in the period 2015-16. Based on the water level data the pre and post moon water with water level fluctuation map have been prepared and given below;

Table 3.1: Numbers of Groundwater monitoring structures

Block	NHS(Dug wells)	Piezometer
	Number	Number
Alot	07	09
Jaora	04	04
Piploda	02	05
Ratlam	08	06
Sailana	07	07
Bajana	13	8
Rawati	41	37`

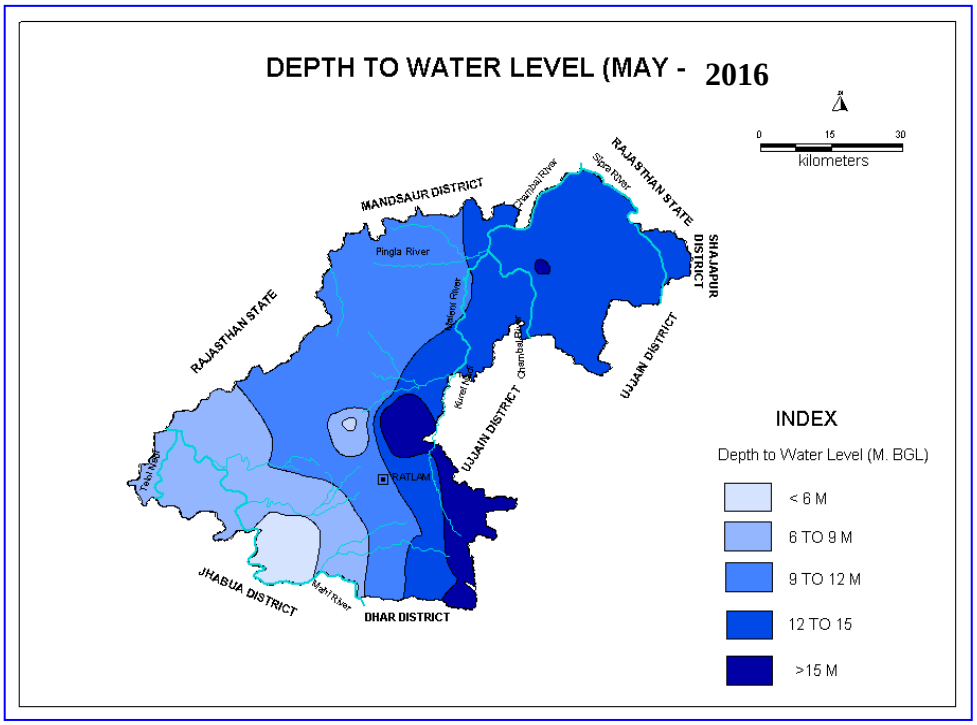

Fig.3.2 Depth to water level

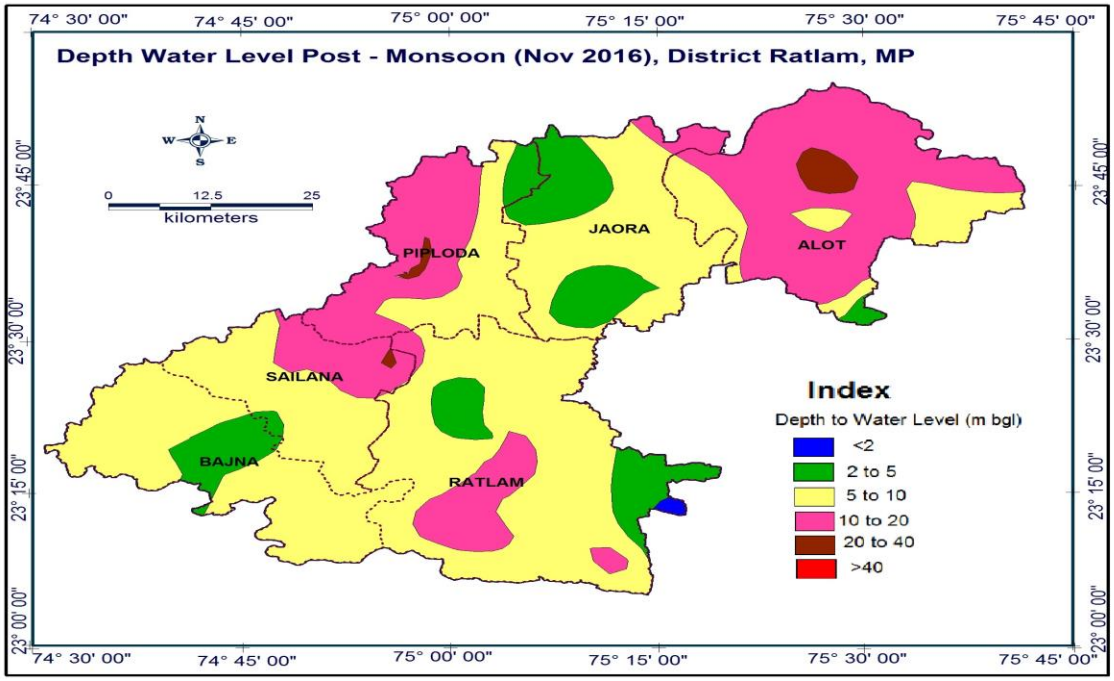

Fig.3.3 Depth to water level (Post monsoon)

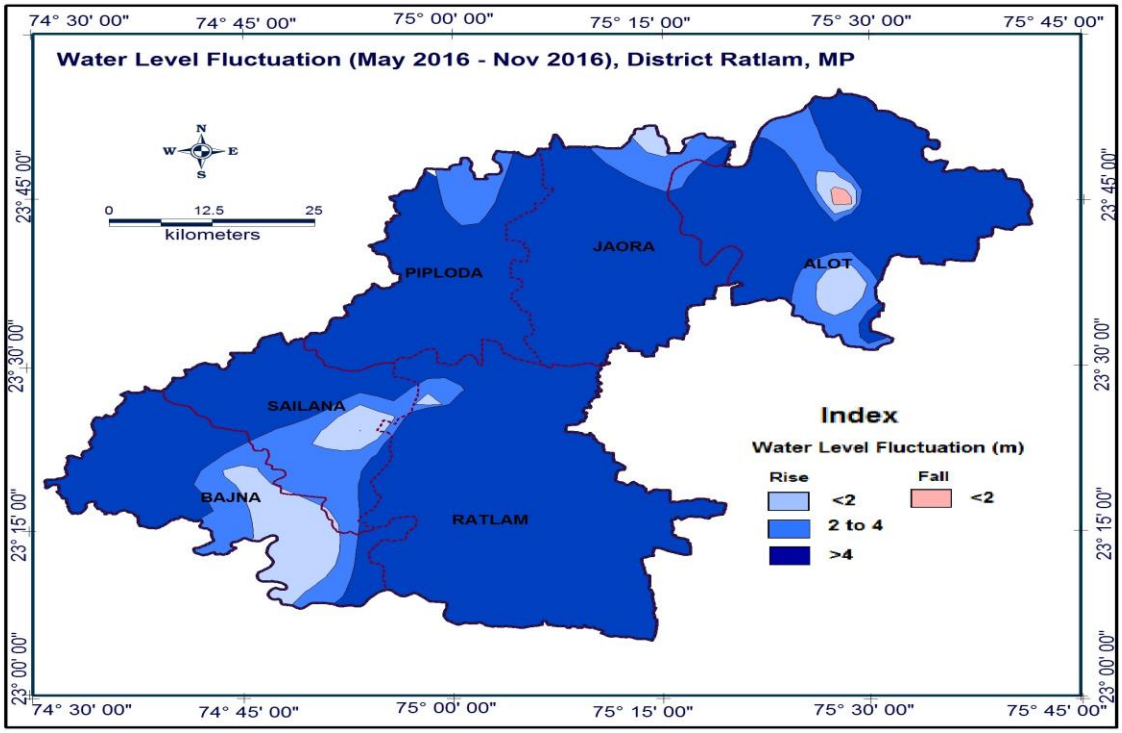

Fig.3.4 Water level fluctuation

- **Ground water Exploration**
  The depth range of the Exploratory wells are given in table 3.2.

Table 3.2: Groundwater exploration in Ratlam District

Block	No. of EW	Depth ranges	EW Elevation ranges
		mbgl	m amsl
Alot	05	148.5-203.65	485-520
Jawara	02	203.25-216.4	478-496
Piploda	01	191.25	490
Ratlam	01	203.10	495
Sailana	01	203.10	499
Bajana	06	143.30-203.35	495-518
Rawati	10	140.20-203.0	473.60-498.6
Total	**26**	**140.20-216.4**	**473.60-520**

3.3 Data Interpretation, Integration and Aquifer Mapping

Results and interpretation of all studies helps in preparation of aquifer maps- 2-D diagrams.

- **Hydro geomorphology analysis**

  The major area in Ratlam covered 64.80 % (38488.15sq km) by undissected plateau with 25.05% (1487.9 sq km) covered by moderately dissected plateau. The valley fill area as alluvium formation along the banks of river Kshipra & Chambal is about 9.47% (562.61)

Table 3.3: Ground water prospect along various geomorphic features

S. No.	Geomorphological Unit	Spectral Signature	Prospect for ground water
1.	Plateau Highly Dissected	Medium to dark brownish tone, medium texture, dendritic drainage pattern and moderate drainage density, Very gentle to gentle slope, extensively cultivated	Good prospect for ground water recharge
2.	Plateau Moderately Dissected	Medium to light bluish reddish tone, coarse texture, medium drainage density, Gentle to moderate slope, extensively cultivated	Better prospect along fracture zone
3.	Plateau Slightly Dissected	Light Bluish green tone, coarse to fine texture, dendritic drainage pattern and high drainage density, Moderately to slightly undulating, under rainfed cultivation	High priority for recharge structure
4.	Alluvial Plain	Light to medium grey tone, mottled texture, Very gentle to gentle slope, cultivated.	Good recharge from surrounding

			areas
5.	Valley Fills	Reddish tone, smooth texture, sparse vegetation, confined along stream course.	High priority for recharge structure
6.	Denudational Hills	Brownish tone, fine texture, High dissected with high relief, vegetation present.	Runoff zone, Not suitable for recharge
7.	Waterbody	Bluish tone	----

Plateaus Undissected: Large areas within the Ratlam district area covered by Undissected surfaces (64.80%). These are highly fractured and weathered surface and covers an area of **3848.15**sq km The land of these unit is severely dissected the stream of Khipr and Chambal with chotkalisindh river giving rise to a stream consist of flat topped ridges & steep scarp. In general Ground water yield of the geomorphic surface is poor to moderate in dissected plateau from 36 to 288 lpm, The yield of bore wells in range of 140 to 288 lpm are located at lineaments.

A pedimont is a gently sloping erosion surface or plain of low relief formed by running water in semiarid region at the base of a receding mountain front. A pediment is underlain by bedrock that is typically covered by a thin, discontinuous veneer of soil and alluvium derived from upland areas. Much of this alluvial material is in transit across the surface, moving during episodic storm events or blown by wind

Plateaus moderately dissected (PLM-2, PLM-622): It covers an area of **1487.97**sq km (13.28%) These are highly weathered and fractured surfaces and occurring in North east of area of Halai, Ghorapachar river. There are 27 lineaments in the area of Plateaus moderately dissected. The yields of wells are in the 36 to 60 lpm

Peneplain: Gently undulating, broad, relatively flat rock face, an extensive area of low relief formed by the joining of several pediments almost featureless plain that it may be final stage of geomorphic cycle of landform evolution., dominated by convex-up (‘bulging’) hill slopes mantled by a continuous regolith, and by wide, shallow river valleys.

Valley fill (VFS): Valley fill deposit is about 562.61sq km and found in the northern and northeastern part of the area along Kshipra & Chambal river has good potential of agriculture.. The morphometric attributer of the valley fill are such that the gradient in mordantly steep (5^0 to 8^0), valley fill deposit consist mainly of weathered product of surrounding basaltic books, mostly comprising moderately thick gravel Pebbles, sand & silt The Ground water potential ranges from

moderate to good. The water level fluctuation is ranging from 4.10 to 6.02 m. Their yield ranges from 308 to 363 lpm. They valley are developed along the fractured and such place can be exploited for groundwater through deep bore wells.

- **Hydro geological flow**:

Aquifer disposition in the 10 basaltic have been demarcated (table 3.4). The Shallow aquifers occurs in 5-Basaltic lava flows between elevation 530-421m amsl.

- ✓ Both Shallow & deep aquifer occurs in 3 flows from 503 – 440 m amsl
- ✓ Deep aquifers occurs in basaltic flows from 503- 276 m asml

Table 3.4: Basaltic lava flow wise Aquifer disposition

Basaltic Lava flows	EW	Depth of Aquifer		Elevation_ AQ	AQ elevation ranges
No	No	mbgl		m amsl	m amsl
X (487 -460 m amsl)	5	30.00	32.00	483.00	483-463.55
		35.45	42.50	463.55	
		17.45	23.55	472.55	
		47.50	58.50	467.50	
		16.9	21.1	478.10	
IX (460 -438 m amsl)	5	29.65	35.75	455.35	455.35-446.50
		23.55	29.65	454.45	
		48.5	50.2	446.50	
		39.00	41.50	460.00	
		64.70	85.00	453.30	
VIII (438 -422m amsl)	4	60.15	87.55	429.85	438-428.70
		70.3	75.0	428.70	
		69.25	75.35	437.75	
		77.00	81.00	438.00	
VII (422 -394 m amsl)	7	90.05	116.60	408.95	420.95-390.55
		124.45	136.55	390.55	
		115.40	118.40	404.60	
		57.05	69.25	420.95	
		84.0	90.0	412.00	
		93.65	108.95	396.35	
		101.00	109.20	414.00	
VI (394 -383m	3	129.50	143.30	385.50	399.50-385
		99.5	111.7	399.50	
		118.05	124.15	388.95	
V (383 -345m	4	130.25	136.35	347.75	347.75 & 371.95
		125.0	131.0	371.00	
		118.05	136.35	371.95	
		148.0	151.3	347.00	
IV (345 -326m	2	184.5	194.5	330.55	330.55-328.0
		168.0	186.0	328.00	
III(326-308 m	1	186.0	192.0	310.00	310
II(308--292 m	1	185.15	189.00	299.85	299.85
I	1	185.15	191.25	292.85	

Table 3.5: shallow and deep aquifer disposition

Aquifer	Shallow	Deep
Formation	Weathered/fractured	Deep fracture & inter flow contact with vesicular basalt
Thickness(m)	3-30	30-200
DTW (mbgl)	7-20 mbgl	11-32
Yield(m3/day)	20-40	65-324

- **Groundwater Potential Model (GPM)**
  Groundwater Favorable Zone

A groundwater favorable zonation of the study area has been analyzed by the lithological structures, lineament density, drainage density, land use, hydro-geomorphological elements, and the background of the survey of India topographical maps on 1:50,000 scale. On the basis of integration of these maps groundwater favorable zones of the study area were identified.

On the above considerations, the various hydro-geomorphic units have then been classified into **five categories of groundwater potentiality namely, very good, good, moderate, poor and very poor.**

Groundwater Potential Class	Low	Moderate	High	Very High
Area %	20.64	45.79	29.29	4.26

The hydro-geomorphological units such as Alluvial Plain, Valley Fills, Deccan Plateau, Buried Pediment (sand stone) are most favorable zones for groundwater exploration & development in the study. Hence, these areas are marked as good to very good favourable zones. These zones are distributed mostly in the north, and middle of the study area and only some few in the southern portion of the area. A glance reveals that the northern part and some of the southern part of the study area have excellent groundwater potential as compared to the upper middle basin and east-

south-eastern part of the basin. These are also verified from field check. This information is very useful for the further groundwater development in the study area.

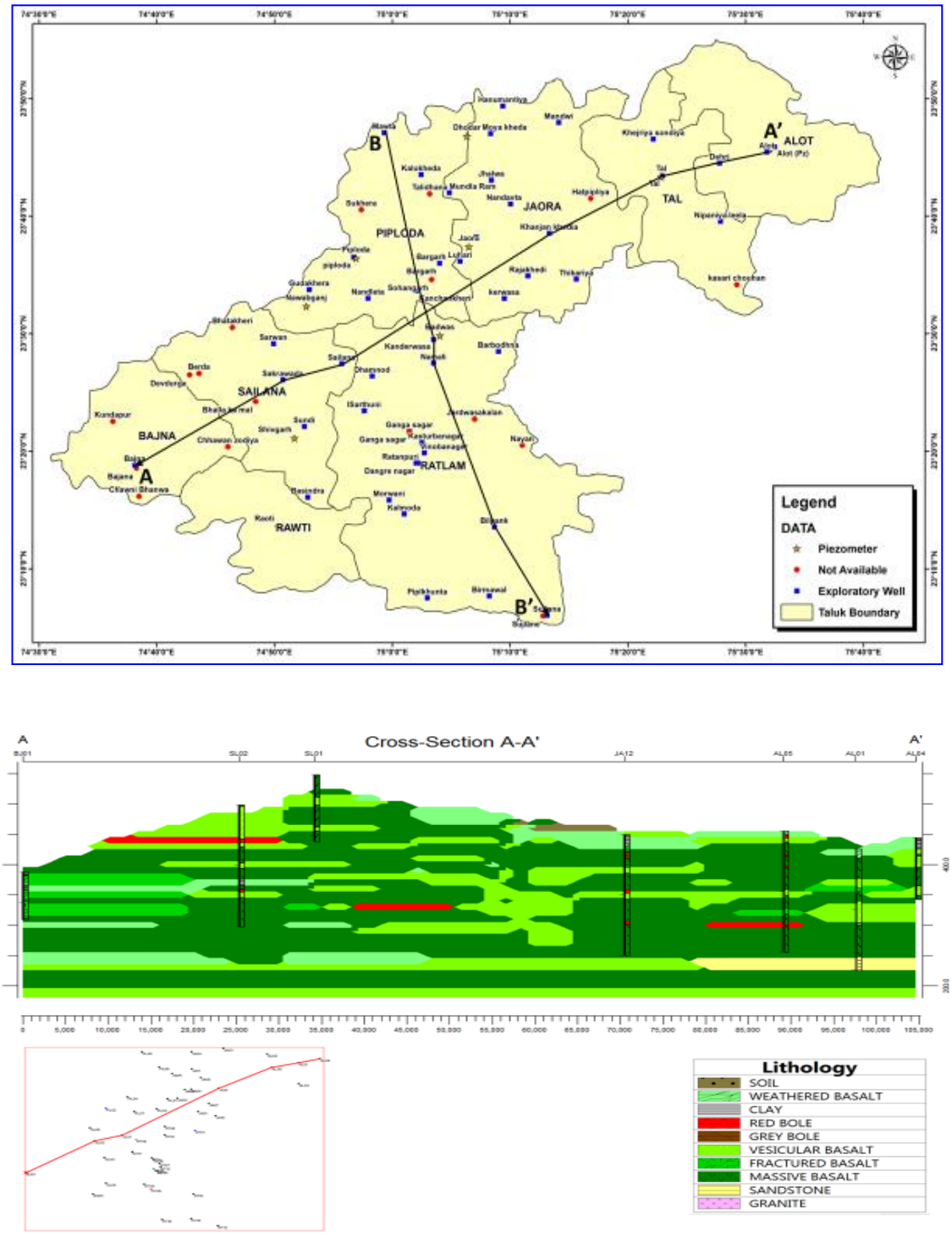

Fig.3.5 Ratlam district Lithological cross section AA'

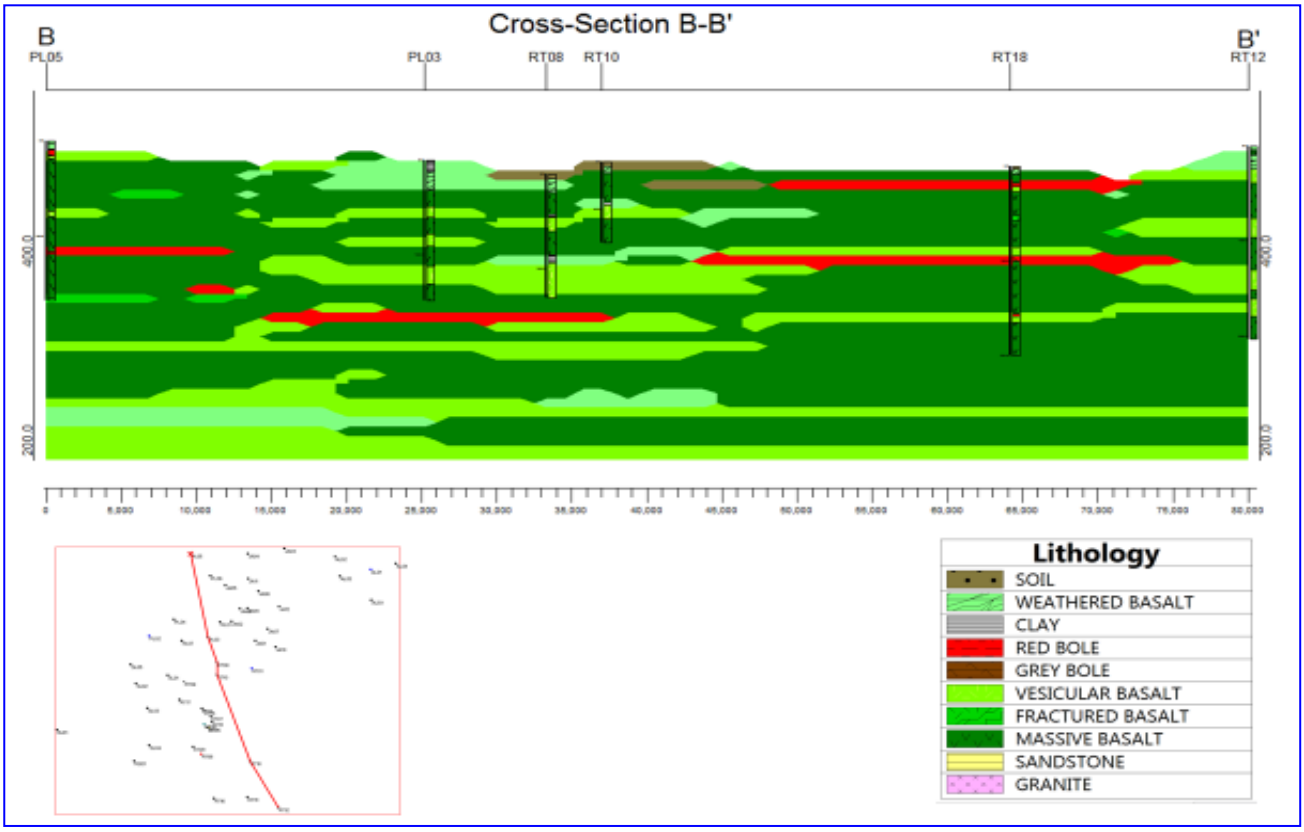

Fig.3.6 Ratlam district Lithological cross section BB'

3.4 Hydrochemical (Ground water quality) analysis

(Water quality sampling, number of samples and analysis mechanism etc.)

The water samples were collected from National Hydrograph Stations in clean double stopped poly ethylene bottles from 24 different locations of Ratlam district during May 2014.

The pH of ground water of Ratlam district ranged in between 7.26 to 8.65. As per BIS recommendation, all water samples recorded within the permissible limit of 6.5 to 8.5. In the Ratlam district, pH has been observed more than 8.5 in the dug well of Kaiytha (8.52), Khera Khajuria (8.55), Mahidpur road (8.65), Makdon (8.59) and Vijayganj Mandi (8.54). The ground water of the study area can be assessed as slightly neutral to alkaline in nature.

The electrical conductivity of ground water in Ratlam district ranged between 595 to 4085 µS/cm at 25°C. The EC values more than the 3000 µS/cm 25°C were recorded only at Kaiytha i.e. 4085

µS/cm at 25°C. The electrical conductivity shows that the ground water in Ratlam district is good to slightly saline in nature.

The fluoride concentration in Ratlam district ranged in between 0.09 to 1.57 mg/l. The BIS has set the maximum concentration of fluoride in drinking water is 1.5 mg/l as permissible limit. The maximum concentration of fluoride has been recorded in Nazarpur village i.e. 1.57 mg/l.

In the district, nitrate concentration in ground water ranged in between 5 to 225 mg/l. The 29 % ground water samples recorded nitrate concentration within the acceptable limit and 71% water samples recorded more than 45 mg/l as BIS recommendation. The highest concentration of nitrate has been detected in ground water of Ratlam Nagar Palika (225 mg/l). High nitrate in ground water appears may be due to anthropogenic activities or excessive use of fertilizers etc.

Total hardness of ground water in the study area ranged in between 150 to 1580 mg/l. The maximum concentration of was observed in the dug well of Dablahardu (605 mg/l), Ratlam Nagar Palika (810 mg/l) and Kaiythya (1580 mg/l).

In the district water is mixed type, saline in nature, temporary and permanent hardness type of water. The ***US Salinity Diagram of Ratlam*** district shows the **ground water is low to high salinity classes i.e. C_2S_1, C_3S_1, C_3S_2 and C_4S_1 classes**. C_3 and C_4 classes of water should not be used for irrigation purpose unless proper soil management.

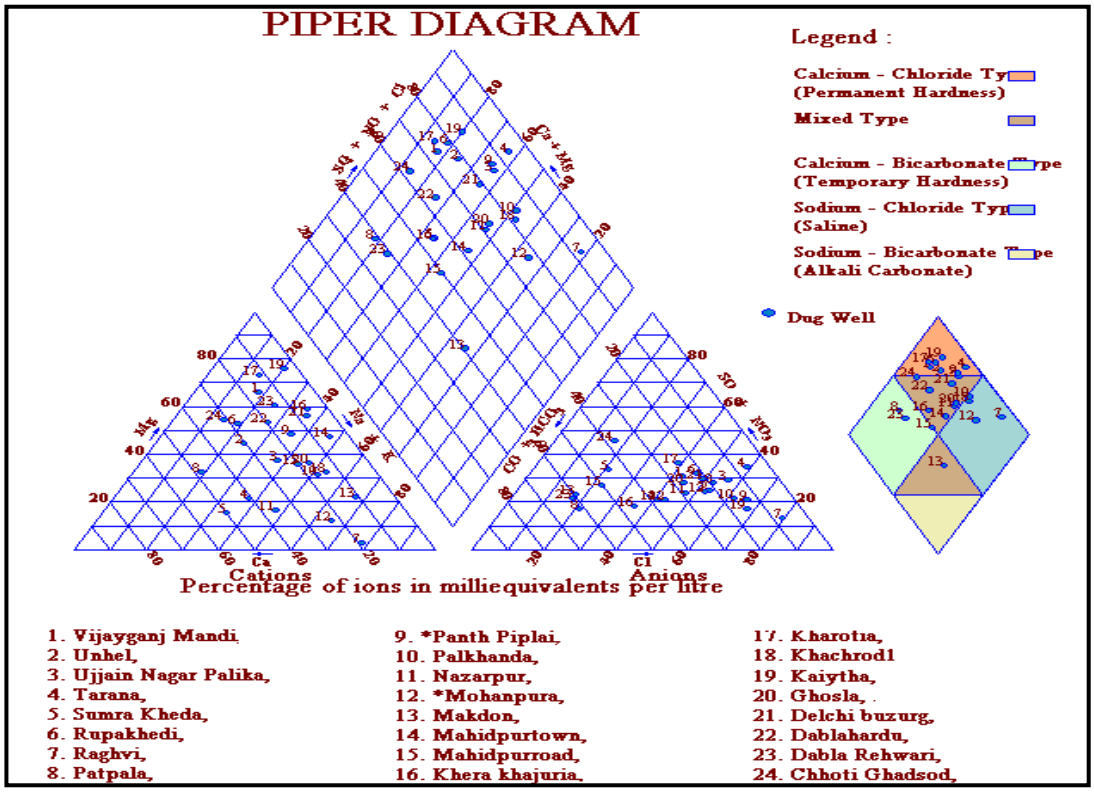

Fig.3.7 Hill Piper Diagram representing classification of water samples

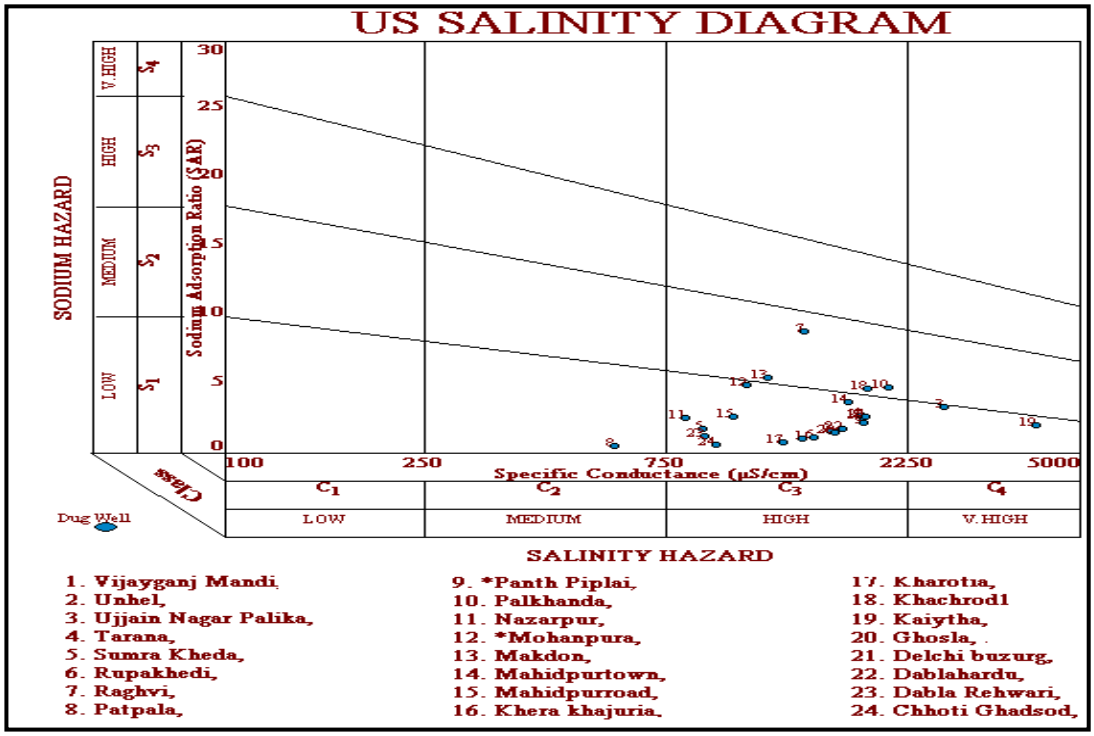

Fig.3.8 US Salinity diagram

CHAPTER-4

GROUNDWATER RESOURCES

Ratlam district is underlain by Basaltic lava flows of Deccan trap. Block-wise Dynamic ground water resources of the district have been estimated for base year -2016-17.

4.1 Recharge worthy area and Command area

Out of 4861 Sq.Km. of geographical area, 4616 Sq.Km.(95 %) is ground water recharge worthy area and 245 Sq.Km. (5 %) is hilly area. The command area in the district is 86.14 Sq.Km (1.77% of the total area) falls in Bajna Block.

Table: 4.1 Recharge worthy area and Command area

Total Geographical Area	Sq.Km.	4861
Hilly Area	Sq.Km.	245 (5%)
Ground Water Recharge Worthy Area	Sq.Km	4616 (95%)
Command area	Sq.Km	86.14 (1.77%)
Non-command area	Sq.Km	4529.86 (98.13%)

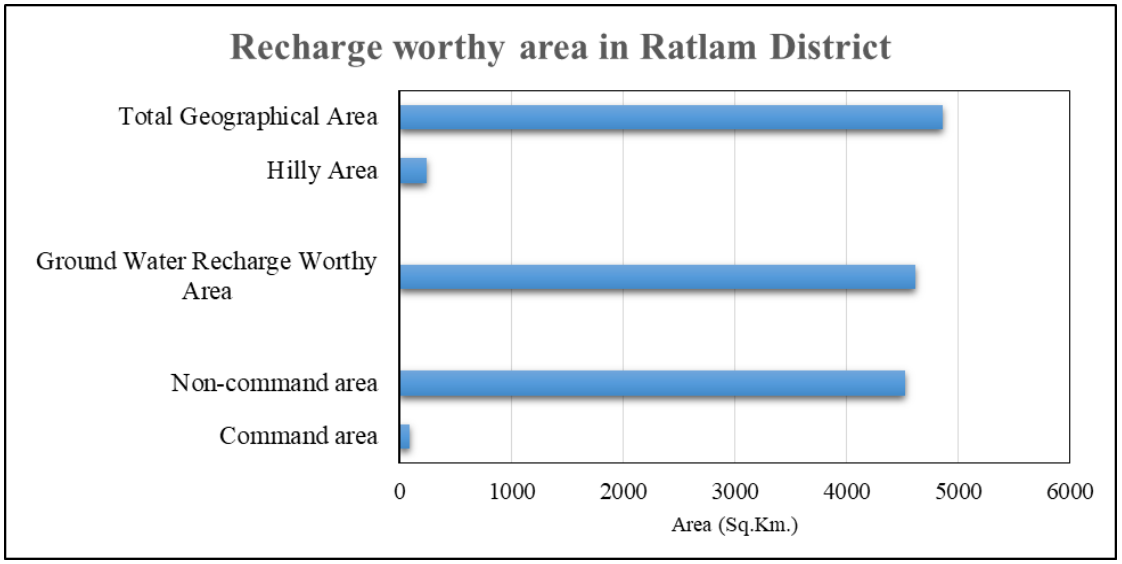

Fig.4.1 Recharge worthy area in Ratlam District

There are six number of assessment units (block) in the Ratlam district. Based on assessment of 2017, Alote, Jaora, Piploda and Ratlam blocks of the district are categorized as over exploited (same as in 2012-13), Sailana as semi critical (same as in 2012-13) and Bajna also as semi critical (safe as in 2012-13).

The net ground water availability in the district 80882.77 ham (808.827 mcm) and ground water extraction for all uses is 102423.17 ham (1024.231 mcm), making stage of ground water extraction 126.63% (127 % in 2012-13) as a whole for district. The highest stage of ground water extraction is computed as 167.50 % in Jaora block. After making allocation for future domestic and industrial supply for year 2025, balance available ground water for future irrigation would be 2764.16 ham (27.641 mcm).

4.2 Parameters used in the assessment of dynamic ground water resources

Specific yield and rainfall infiltration factors used as parameters for groundwater resource assessment.

Rainfall Infiltration Factor (in fraction) 0.13/.06
Specific Yield (in fraction) 0.02/.015

Table: 4.2 Specific yield and Rainfall infiltration factor

Formation	Sp. Yield	Rainfall Infiltration Factor
Weathered / Vesicular jointed Basalt.	0.015	0.13 (Non-Command area) 0.07 (Command area)

Annual Rainfall (mm)	992.9
Average Pre-monsoon Water level (mbgl) Range	3.35-12.62
Average Post-monsoon Water Level (mbgl) Range	0.95-9.56
Average Fluctuation (m) Range	3.03-7.7

Number for Irrigation structure

DW with electric /diesel pump	64788
Bore well	73550

4.3 Recharge

Total recharge and net ground water availability is given in table 4.3.

Table: 4.3 Recharge & Net Ground water Availability

Recharge From Rain Fall During Monsoon Season	mcm	585.676
Recharge From Other Sources During Monsoon Season	mcm	58.814
Recharge From Rain Fall During Non-Monsoon Season	mcm	00
Recharge From Other Sources During Non-Monsoon Season	mcm	206.906
Total Annual Recharge	mcm	851.397
Natural Discharge During Non-Monsoon Period	mcm	42.57
Net Ground Water Availability	mcm	**808.827**

4.4 Groundwater Extraction

Ground Water extraction for domestic and industrial water supply has been computed on the basis of block wise population for the base year. The population figures were available for the year 2011 and same was projected for year 2016 and 2025, considering decadal growth rate between 2001 and 2011. The average per capita consumption has been considered 60 litres per day. Population getting water supply from surface water has been not considered for ground water draft calculation.

Draft during monsoon and non-monsoon periods have been calculated separately taking 4 months as monsoon period and 8 months as non-monsoon period.

Table: 4.4 Seasonal Irrigation unit extraction

District/ Assessment Unit	**Sub-unit Command/ Non-Command**	**Type of Structures**	**Season-wise Unit extraction**	
			Irrigation (Ham.)	
			Monsoon	Non-Monsoon
Alot	Non-Command	DW with electric /diesel pump	0.05	0.18
		Bore well	0.19	0.78
Bajna	Command	DW with electric /diesel pump	0.14	0.36
		Bore well	0	0
	Non-Command	DW with electric /diesel pump	0.15	0.6
		Bore well	0.3	1.21
Jaora	Non-Command	DW with electric /diesel pump	0.06	0.26
		Bore well	0.34	1.35

District/ Assessment Unit	Sub-unit Command/ Non-Command	Type of Structures	Season-wise Unit extraction	
			Irrigation (Ham.)	
			Monsoon	Non-Monsoon
Piploda	Non-Command	DW with electric /diesel pump	0.04	0.16
		Bore well	0.29	1.17
Ratlam	Non-Command	DW with electric /diesel pump	0.03	0.13
		Bore well	0.15	0.6
Sailana	Non-Command	DW with electric /diesel pump	0.13	0.52
		Bore well	0.19	0.78

- **Norms Used In Ground Water Draft for Irrigation**

Block wise ground water draft for irrigation has been calculated based on the number of ground water structures and the unit extraction of different types of structures. Number of ground water structures data was obtained from State Land Records for the year 2012, 2013, 2014, 2015 and 2016.

The unit extraction of different ground water abstraction structures in each assessment unit for irrigation was determined in the field considering discharge of the well, pumping hours, number of running hours, days during monsoon and non monsoon seasons in command and non command area separately. The unit extraction is also validated with the delta factor of crop water requirement and irrigated area. Dug wells and bore wells/tube wells are main structures, which are used for irrigation in the Ratlam District.

The unit extraction of different ground water structures used for various purposes during monsoon and non-monsoon season are given in Table 4.5.

Table 4.5: Groundwater extraction

Assessment Unit / District	Command / Non Command	Existing Gross Ground Water extraction for Irrigation	Existing Gross Ground Water extraction for Industrial Water Supply	Existing Gross Ground Water extraction for Domestic Water Supply	Existing Gross Ground Water extraction for All Uses
		Ham			
Alot	Non-Command	17374.89	86.44	489.85	17951.19

Assessment Unit / District	Command / Non Command	Existing Gross Ground Water extraction for Irrigation	Existing Gross Ground Water extraction for Industrial Water Supply	Existing Gross Ground Water extraction for Domestic Water Supply	Existing Gross Ground Water extraction for All Uses
		Ham			
Bajna	Command	217.05	2.04	11.56	230.65
	Non-Command	3438.6	78.32	443.82	3960.74
Jaora	Non-Command	28724.35	67.97	385.19	29177.51
Piploda	Non-Command	21514.83	49.87	282.63	21847.34
Ratlam	Non-Command	23766.6	123.4	759.29	24649.29
Sailana	Non-Command	4250.88	53.34	302.23	4606.45
Total (Ham.)		**99287.2**	**461.38**	**2674.57**	**102423.17**
Total (mcm.)		**992.872**	**4.613**	**26.745**	**1024.231**

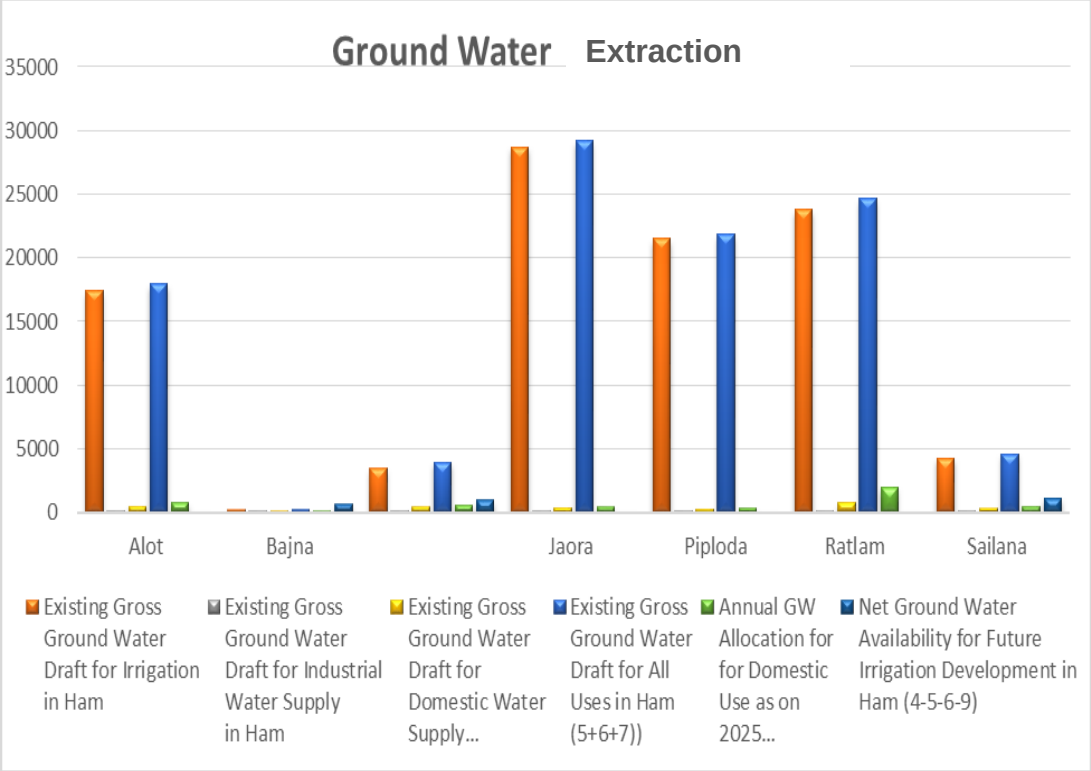

Fig 4.2 Groundwater Extraction of Ratlam District

Table: 4.6 Groundwater Resource and extraction for a period (2011-2017)

Year	Net Ground Water Availability (mcm)	Existing Gross Ground Water extraction for Irrigation (mcm)	Existing Gross Ground Water extraction for Domestic & Industrial Water Supply (mcm)
2011	736.87	902.18	23.82
2013	771.5033	956.569	25.9292
2015	791.2477	972.4267	28.3797
2017	808.8277	992.872	46.1304

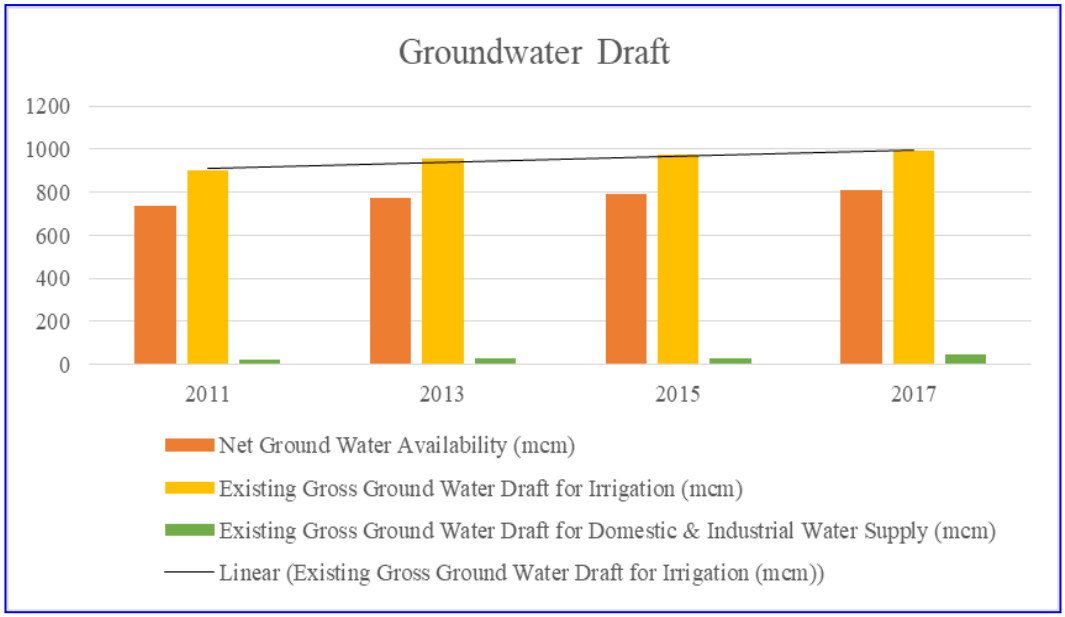

Fig. 4.3 Yearwise groundwater extraction

4.5 Static resources

Static resources and extraction from unconfined aquifer as well as in/from deeper aquifers, if any.

Table 4.7: Static resources

District	Shallow aquifer			Deep aquifer	Shallow & deep aquifer
	Dynamic	**Static**	**total**	**Static**	**Static**
Ratlam	**962.66**	**259.917**	**1222.559**	**497.251**	**757.168**

Table 4.8: Groundwater extraction through different structures

Block	Number		Unit extraction		Extraction		Total
			Ham.				
	DW	BW	DW	BW	DW	BW	
Alot	14556	14479	0.18	0.78	2620.08	11293.6	13913.7
Bajna	435	0	0.36	0	156.6	0	156.6
	12439	460	0.6	1.21	7463.4	556.6	8020
Jaora	12439	14657	0.26	1.35	3234.14	19787	23021.1
Piploda	16098	12610	0.16	1.17	2575.68	14753.7	17329.4
Ratlam	15129	28604	0.13	0.6	1966.77	17162.4	19129.2
Sailana	2450	2740	0.52	0.78	1274	2137.2	3411.2
District	73546	73550	-	-	19290.7	65690.5	84981.1
District (mcm)					**192.907**	**656.905**	**849.811**

4.6 Ground Water Related Issues

1 Identification of issues,

- **Limited Yield Potential:**

During Rabi period yield of Groundwater abstraction structure reduces & do not meet crop water requirement. Bore wells yield reduces in peak Rabi season (From 324-65m^3/day during start of Rabi to 162-22 m^3/day during Peak Rabi Season).

- **Aquifers –Shallow:** Low to medium potential in Basalt aquifers.
- **Aquifers-deep:** Limited vesicles/fracture thickness resulting into low yield of bore wells.
- **Declining Water levels:** Water level 4.35-8.40m (Premonsoon 2005) to 7.70-18.34m (Premonsoon 2015).
- **Dependency of Irrigation on Ground Water:** 57.14% of irrigation requirement from Ground Water.

Surface water irrigation	**226730 ha (42.85%)**
Groundwater irrigation	**302338 ha(57.14%)**

- Geographical distribution and quantification with respect to ground water resources

Table 4.9: Geographical distribution and quantification with respect to ground water resources

Block	Shallow Aquifer			Deep AQ	SAQ+DAQ
	Dynamic	Static	total	Static	Static
	MCM				
Alot	210.494	7.33	217.824	102.559	109.889
Jaora	114.77	10.137	124.907	46.967	57.104
Piploda	191.84	83.514	275.354	79.768	163.282
Ratlam	163.88	73.744	237.624	93.485	167.229
Sailana	145.628	52.224	197.852	98.053	150.277
Bajana	136.03	32.968	168.998	76.419	109.387
Rawati	**962.66**	**259.917**	**1222.559**	**497.251**	**757.168**

- Future demand (for 2025 and 2030) scenario and stress aspects of the aquifer

Groundwater Demand of projected population @ increase of growth of 16.21%/year .The demand of water in 2025 will be 436974 cum.

Table 4.10: Future demand (for 2025 and 2030) scenario

Present Population 2011)		Projected population 2025@16.12%/year	Water requirement @ liter	Water demand (Cum)
Rural	1207651	2725427	70	190780
Urban	779213	1758528	140	246194
Total	1986864	4483955		436974

CHAPTER-5

MANAGEMENT STRATEGY

Based on National Hydrograph Monitoring Wells data of Ratlam district showing administrative boundary and post monsoon, 2017, depth to water level zones varying from 0-3, 3-6, 6-9,9-12,12-15 and more than 15 meters below ground level with post monsoon declining trend of >0.10 meters/year for 10 years from 2007 to 2017 were prepared to visualize and identify the feasible areas.

5.1 Area suitable for Artificial recharge in water level range

Areas showing depth to water level between 0 and 3 m bgl have not been considered for computing the potential zones available for recharge. The area of water level of <3m is about 16.95 sq km in the northern part of Piploda block.

Table 5.1: Area suitable for Artificial recharge in water level range

Block	Area suitable for recharge in water level range					Total Area suitable for recharge
	3 to 6	6 to 9	9 to 12	12 to 15	> 15	
	(sq km)					
Alot	39.4	82	143.7	420.5	259.4	945
Bajana	519	163				682
Jaora	253.1	190.9	282.5	30.13		756.63
Piploda	160.1	220.9	161.9	50.49		593.39
Sailana	139.8	214.7	131.8			486.3
Ratlam	149.3	545.3	613.3	13.66		1321.56
Total	**1260.7**	**1416.8**	**1333.2**	**514.78**	**259.4**	**4784.88**
%	**26.348**	**29.610**	**27.863**	**10.758**	**5.421**	**100.000**

About 83.82% of the suitable area (4011 sqkm) having water level of less than 12 m while 16.18 % of area (774.18 sq km) showing water level of more than 12m.

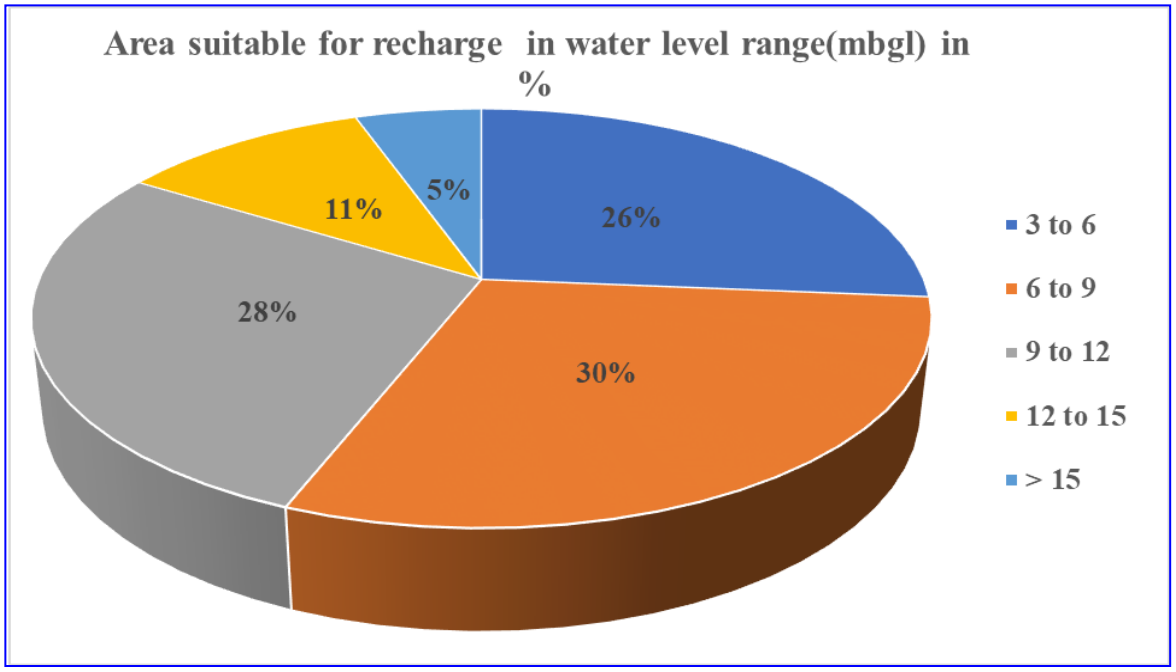

Fig.5.1 Area suitable for Artificial Recharge in Ratlam District

The area suitable for artificial recharge has been segregated into 2-categories as follows:

1. Depth to water level between < 3 m bgl and declining trend of 0.10m /year.
2. Depth to water level more than > 3 and declining trend of 0.10m /year.

The areas of above 2 categories are demarcated on base map and areas with water level more than 2 m bgl are identified for artificial recharge to ground water.

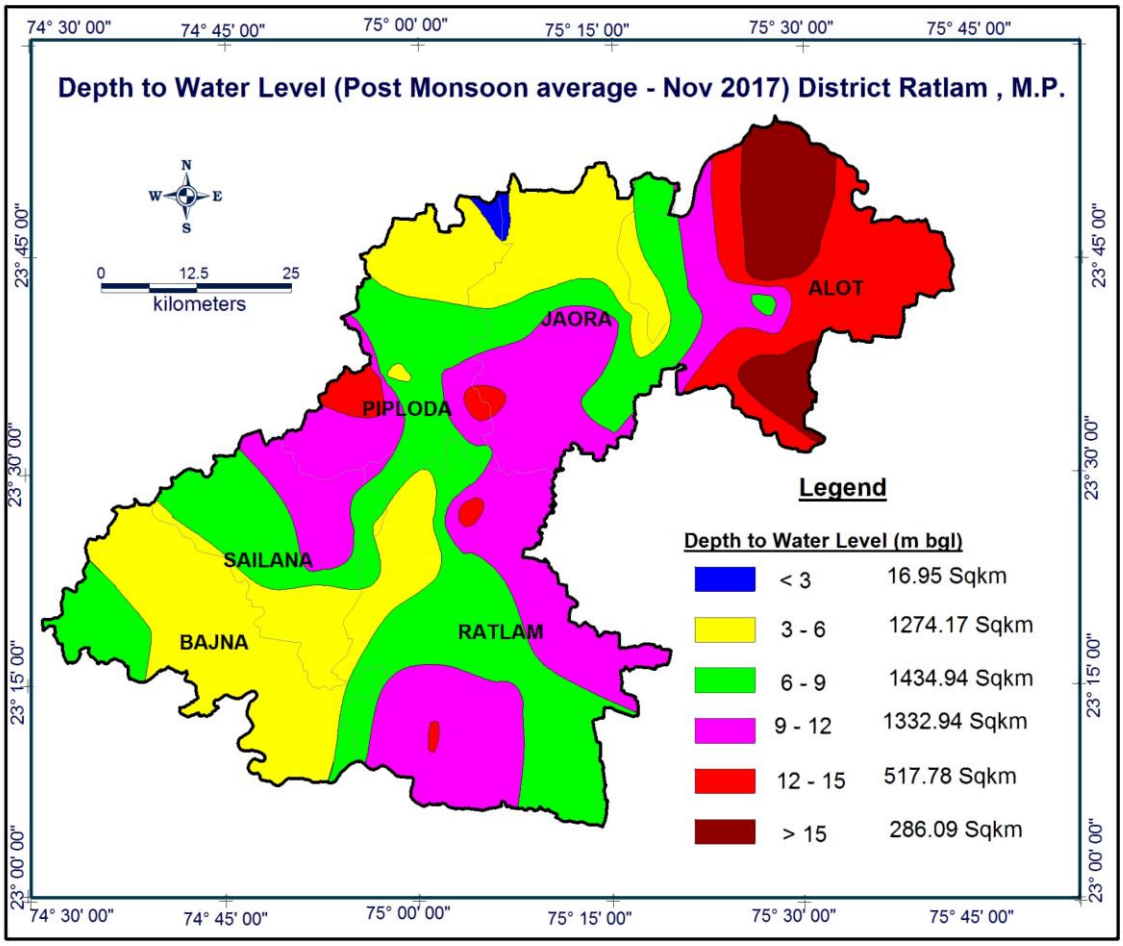

Fig.5.2 Post monsoon average Depth to water level (2017)

5.2 Estimation of Available Sub Surface Storage Potential

The area of availability of unsaturated zone is about **4784.88** sq km. The thickness of available unsaturated zone (below 3 m bgl) of above categories is estimated by considering the different ranges of water level. The total volume of unsaturated strata is calculated by considering the above categories and unsaturated thickness of different range. This volume was then multiplied by average specific yield i.e. 1.5 % for hard rock on area specific basis to arrive at the net amount of water required which is to be recharged by artificial recharge to saturate the aquifer up to 3 m bgl.

Table 5.2: Storage potential of available unsaturated zone

Block	Sub-surface storage Potential (mcm)					Total
	3 to 6	6 to 9	9 to 12	12 to 15	> 15	mcm
	(sq km)					
Alot	1.773	5.535	16.166	66.229	46.692	**136.395**
Bajana	23.355	11.003				**34.358**
Jaora	5.695	12.886	31.781	4.745		**55.107**
Piploda	3.602	14.911	18.214	6.816		**43.543**
Sailana	6.291	14.492	14.828			**35.611**
Ratlam	3.359	36.808	68.996	1.844		**111.007**
Total	**44.075**	**95.634**	**149.985**	**79.634**	**46.692**	**416.021**
%	**10.594**	**22.988**	**36.052**	**19.142**	**11.223**	**100.000**

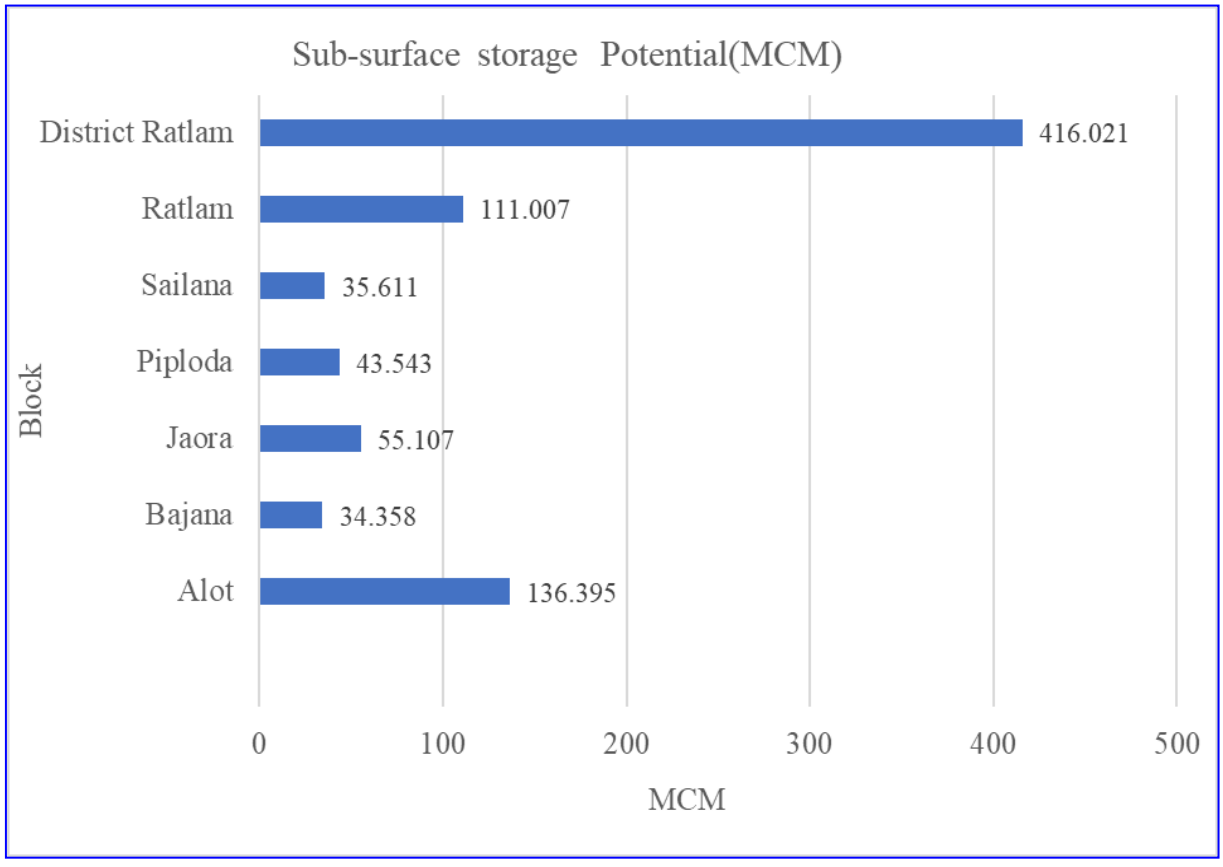

Fig.5.3 Subsurface storage potential of Ratlam District

5.3 Surface Water Requirement

After assessing the actual volume of water required for saturating the vadose zone, the requirement of source water is to be estimated. Based on the experience gained in the field experiments, an average recharge efficiency of 75% of the individual structure is only possible. Therefore, to arrive at the total volume of actual source water required at the surface, the volume of water required for artificial recharge calculated is multiplied by 1.33 (i.e. reciprocal of 0.75).

Table 5.3: Surface water availability for Artificial recharge structures

Water availability for Recharge	Unit	Management plan
Volume of Surface Water available for AR	mcm	**1032.36**
Volume of Water required for recharge	mcm	**528.60**
Proportionate Surface water for planning AR	mcm	**397.44**
Area Suitable for AR	Sq km	**4784.88**

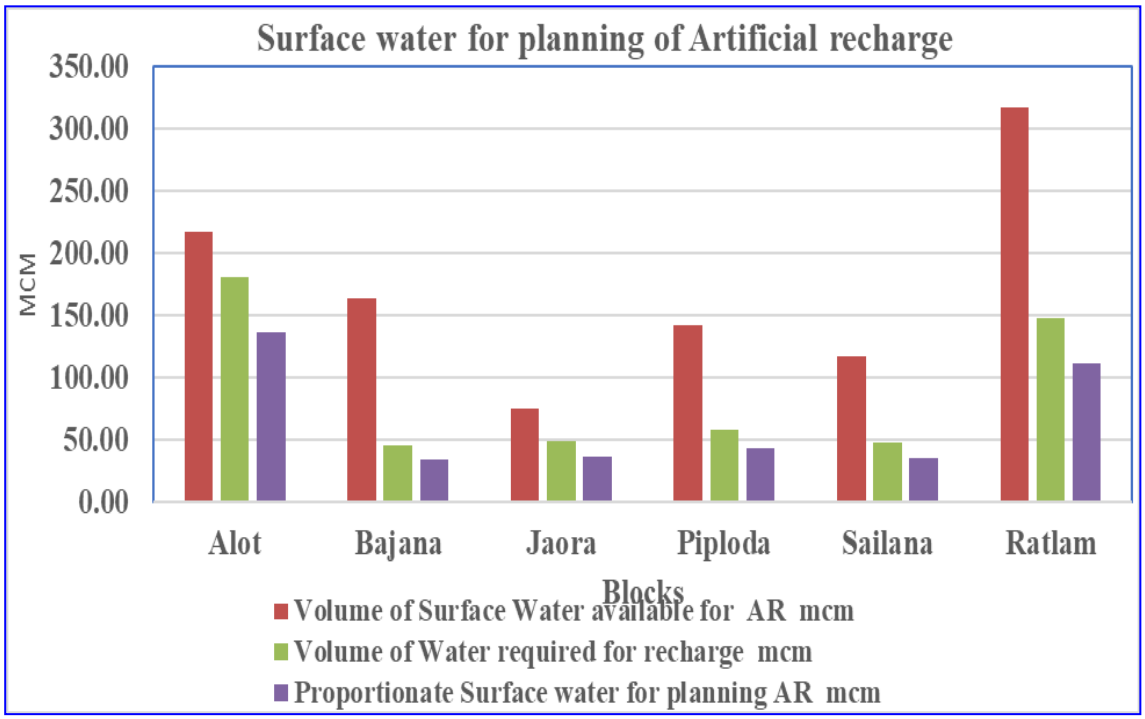

Fig.5.4 Surface water for planning of Artificial Recharge

5.4 Augmentation plan of the resource through artificial recharge and water conservation

Groundwater management plan of Ratlam block have been evaluate based on area suitable for recharge, average pos-monsoon water level and Average SP Yield. Sub Storage potential of Unsaturated zone and Surface Water Requirement were calculated.

Area suitable for recharge (sq km) : 4784.88

Average pos-monsoon water level (m) : 13.12 (Alot)

6.75 (Bajana)

8-9 (Jaora, Piploda, Sailana, Ratlam)

Average SP Yield (%) : 0.015

Table 5.4: Area suitable for recharge (sq km)

Block	Water Level Range (m)	Total Area suitable for recharge (sq km)	Area suitable for recharge in water level range (sq km)
Alot	< 6	945	39.4
	6 to 9		82
	9 to 12		143.7
	12 to 15		420.5
	> 15		259.4
Bajana	< 6	682	519
	> 6		163
Jaora	3 to 6	756.63	253.1
	6 to 9		190.9
	9 to 12		282.5
	12 to 15		30.13
Piploda	3 to 6	593.39	160.1
	6 to 9		220.9
	9 to 12		161.9
	> 12		50.49
Sailana	< 6	486.3	139.8
	6 to 9		214.7
	9 to 12		131.8
Ratlam	< 6	1321.56	149.3
	6 to 9		545.3
	9 to 12		613.3
	12 to 15		13.66
TOTAL		4784.88	Sq km

Table 5.5: Surface Water for Artificial Recharge

Sub-surface storage	Surface water required	Surface water (Run-off) available	Non-committed Run-off
mcm			
813.46	1081.903	2171.282	**652.848**

Table 5.6: Proposed Number of Recharge Structure

Type of Structures	Proposed structures
Percolation Tanks	580
Recharge shaft/ Tube well	831
Step recharge trench	1027
Dug well recharge	1143
NB/ CD/ CP	1713
subsurface dyke	241
Farm Pond	343
Village Pond	653
Total	**6531**

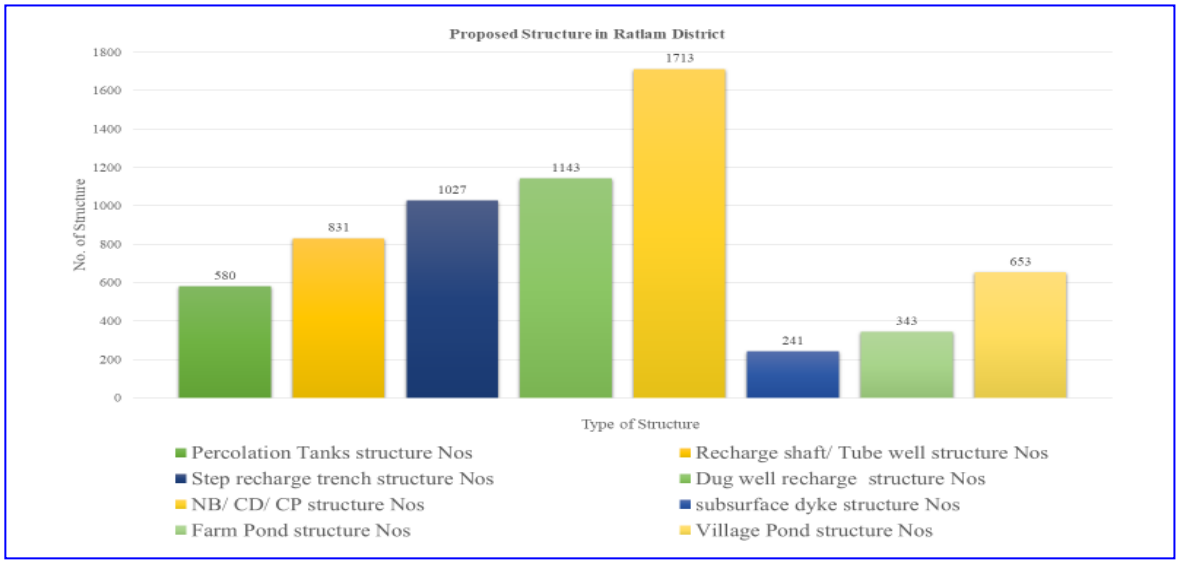

Fig.5.5 Proposed artificial recharge structures in Ratlam District

Table 5.7: Proposed artificial recharge structures and their cost in Ratlam District

Type of Structures	Cost of structure (Cr)
Percolation Tanks	81.2
Recharge shaft/ Tube well	11.6
Step recharge trench	3.1
Dug well recharge	4.6
NB/ CD/ CP	119.9
subsurface dyke	2.9
Farm Pond	10.3
Village Pond	78.4
Total	**311.9**

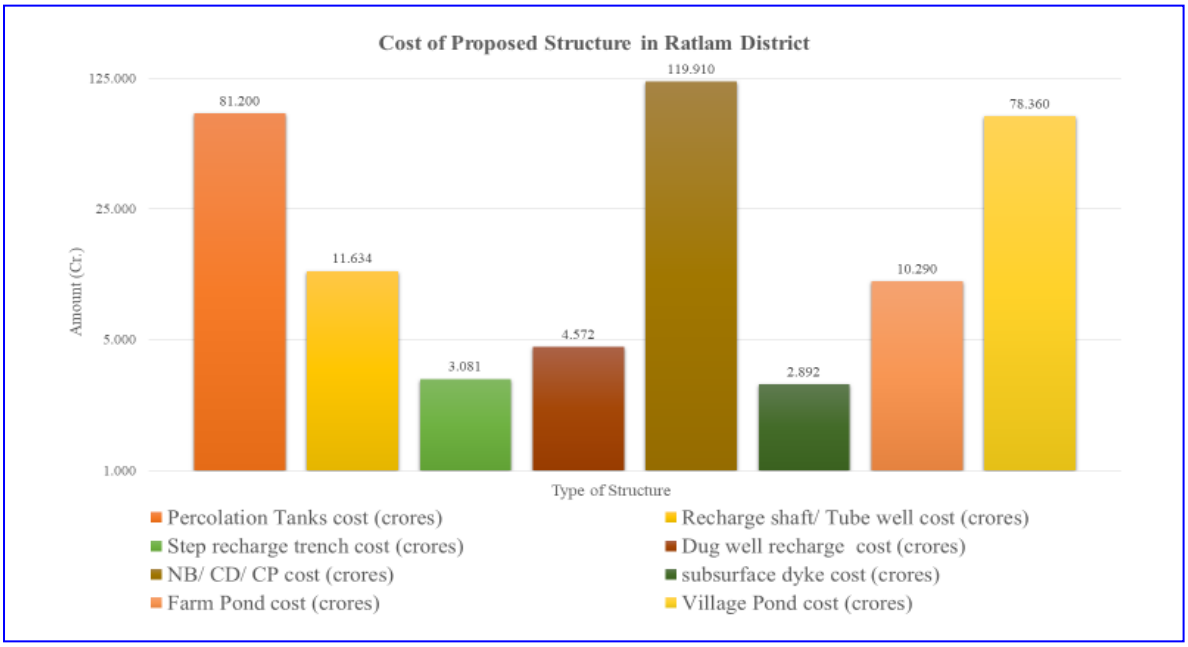

Fig.5.6 Cost of proposed Artificial Recharge structures in Ratlam District

Table 5.8: Block wise Proposed Intervention

Proposed Intervention of Ground Water Managment (Blockwise)												
Block	**Alot**		**Bajana**		**Jaora**		**Piploda**		**Sailana**		**Ratlam**	
Type of Structures	**Structure Nos**	**Cost (Cr)**	**Structure Nos**	**Cost (Cr)**	**Structure Nos**	**Cost (Cr)**	**Structure Nos**	**Cost (Cr)**	**Structure Nos**	**Cost (Cr)**	**Structure Nos**	**Cost (Cr)**
Percolation Tanks	130	18.20	69	9.660	82	11.480	67	9.380	61	8.540	171	23.940
Recharge shaft/ Tube well	272	3.81	69	0.966	109	1.526	87	1.218	72	1.008	222	3.108
Step recharge trench	198	0.59	147	0.441	164	0.492	129	0.387	104	0.312	285	0.855
Dug well recharge	220	0.88	164	0.656	182	0.728	142	0.568	118	0.472	317	1.268
NB/ CD/ CP	330	23.10	246	17.220	273	19.110	214	14.980	174	12.180	476	33.320
subsurface dyke	47	0.56	34	0.408	39	0.468	30	0.360	25	0.300	66	0.792
Farm Pond	67	2.01	49	1.470	54	1.620	44	1.320	34	1.020	95	2.850
Village Pond	131	15.72	98	11.760	108	12.960	85	10.200	70	8.400	161	19.320
Total Cost of RS in crores	**1395**	**64.88**	**876**	**42.581**	**1011**	**48.384**	**798**	**38.413**	**658**	**32.232**	**1793**	**85.453**
Total No of Structures in Ratlam district												**6531.00**
Total cost for Structures (Cr)												**311.939**

5.5 Demand side management (through change in Crop Pattern)

Water requirement for groundwater irrigation in the Ratlam area for rabi crop season predominately of wheat and Gram. The proposed saving in the volume of Ground water irrigation is based on reduction in irrigation for wheat area to 50 % i.e. 59619 Ha and increase in the Gram crop area from 47278 ha to 106897ha i.e. 56 %. Total water requirement wheat& Gram is 33.3032 mcm that reduced to 21.3794mcm.

Table 5.9: Proposed change in water use for Groundwater irrigation

Crop area (Ha)		**Wheat**	119238
		50% of Wheat crop	59619
		Gram	47278
		Proposed increase in Gram area	**106897**
Water requirement for Wheat crop mcm	Present	Wheat	47.6952
	Proposed change	Wheat	23.8476
Water requirement for Gram crop mcm	Present	Gram	9.4556
	Proposed change	Gram	21.3794
Total water requirement for wheat+ Gram in mcm	Present	Wheat Gram	33.3032
	Proposed change	Wheat Gram	21.3794
Saving of Groundwater in mcm	Proposed	Change in crop pattern	11.9238

5.6 Demand side management (through change in irrigation practices)

The 50 % proposed reduction in Ground water irrigation for irrigation practice through Sprinkler is from 166516 ha to 83258 ha. The 20% Groundwater irrigation saving by Sprinkler is about 1143 mcm.

Table 5.10: Groundwater irrigation by Sprinkler

Ground water irrigated area	166516 ha
50 % of Ground water irrigated area proposed through Sprinkler	83258 ha
No. of sprinklers proposed	41629
20% Groundwater irrigation saving by Sprinkler	1143 mcm

Saving GW In sprinkler irrigation 1143 mcm)&change in crop area from wheat to Gram(11.9238 mcm)	**1154.9232 mcm**

5.7 Projected status of Ground water Resources & Utilization

After Intervention dynamic ground water resources are given in table 5.11.

Table 5.11: Dynamic groundwater resources after intervention

Total Annual Recharge	mcm	**851.3977**
Net Ground Water Availability	mcm	808.827
Existing Gross Ground Water Extraction for All Uses	mcm	4613.04
Net Ground Water Availability for Future Irrigation Development	mcm	**27.64**
Saving GW In sprinkler irrigation 1143 mcm)+change in crop area from wheat to Gram(11.923mcm)	mcm	334.74
Stage of Ground Water Extraction	%	126.63 %

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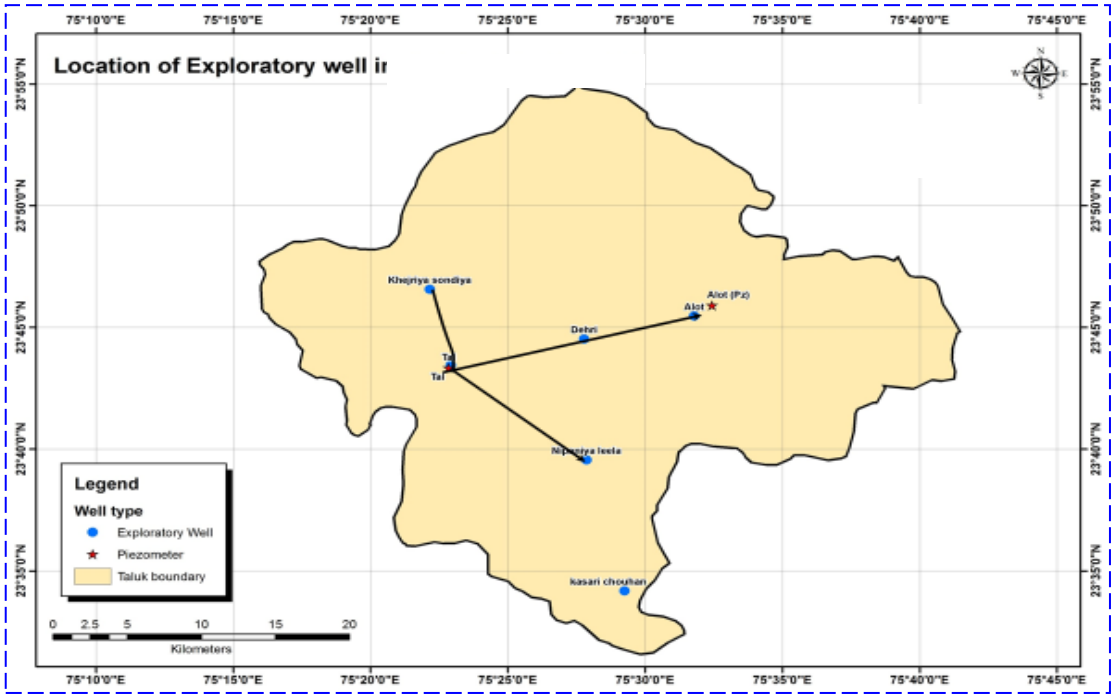
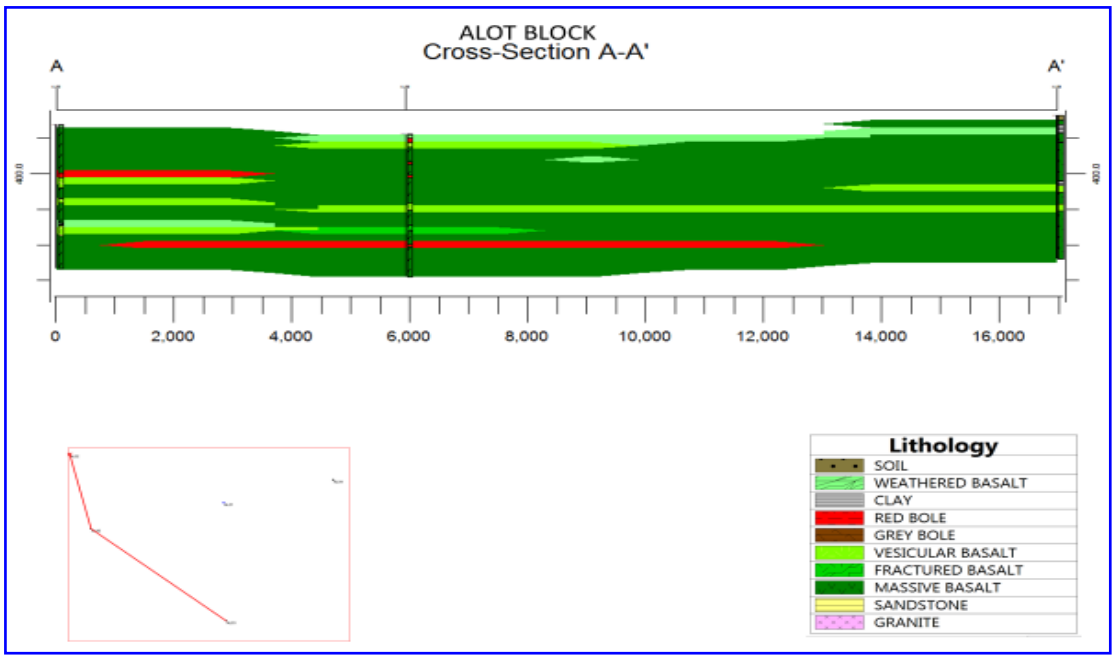
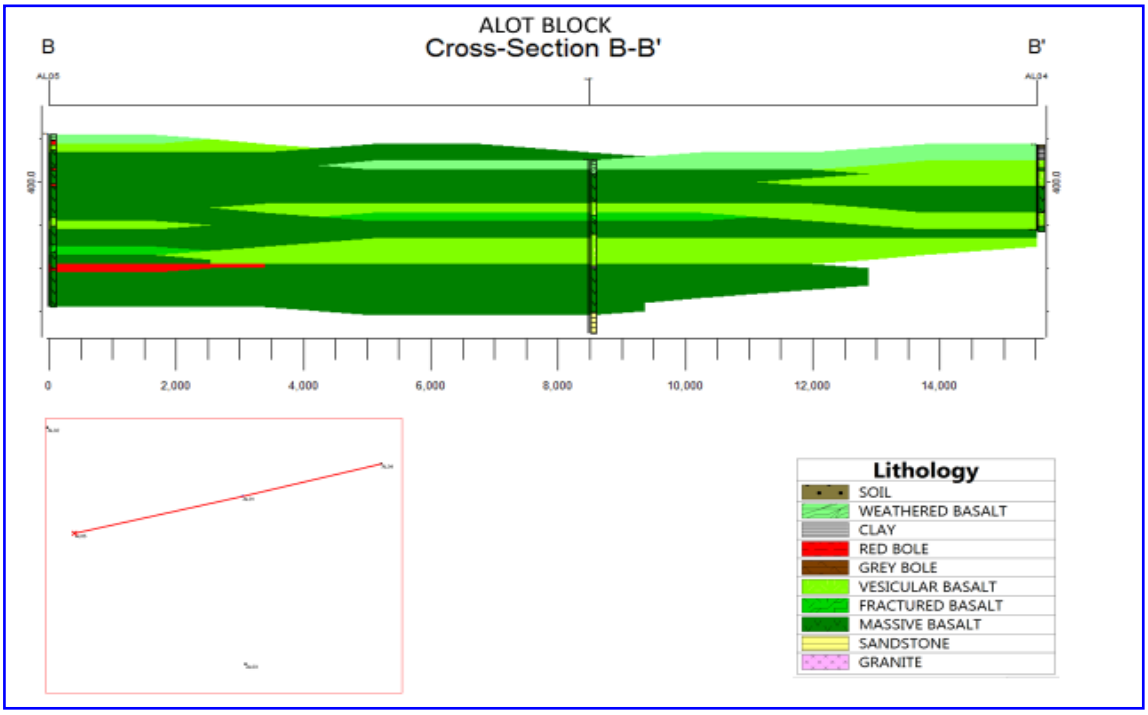
ANNEXURE

Lithological cross sections of different blocks of Ratlam District

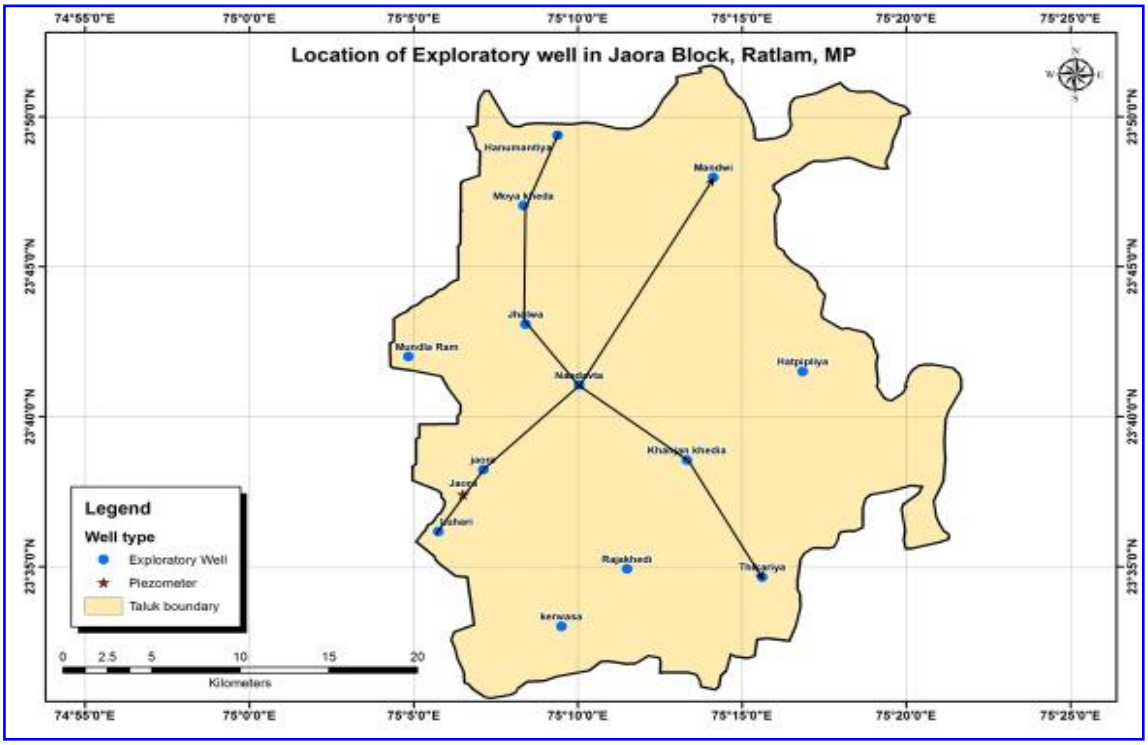
Alot Block

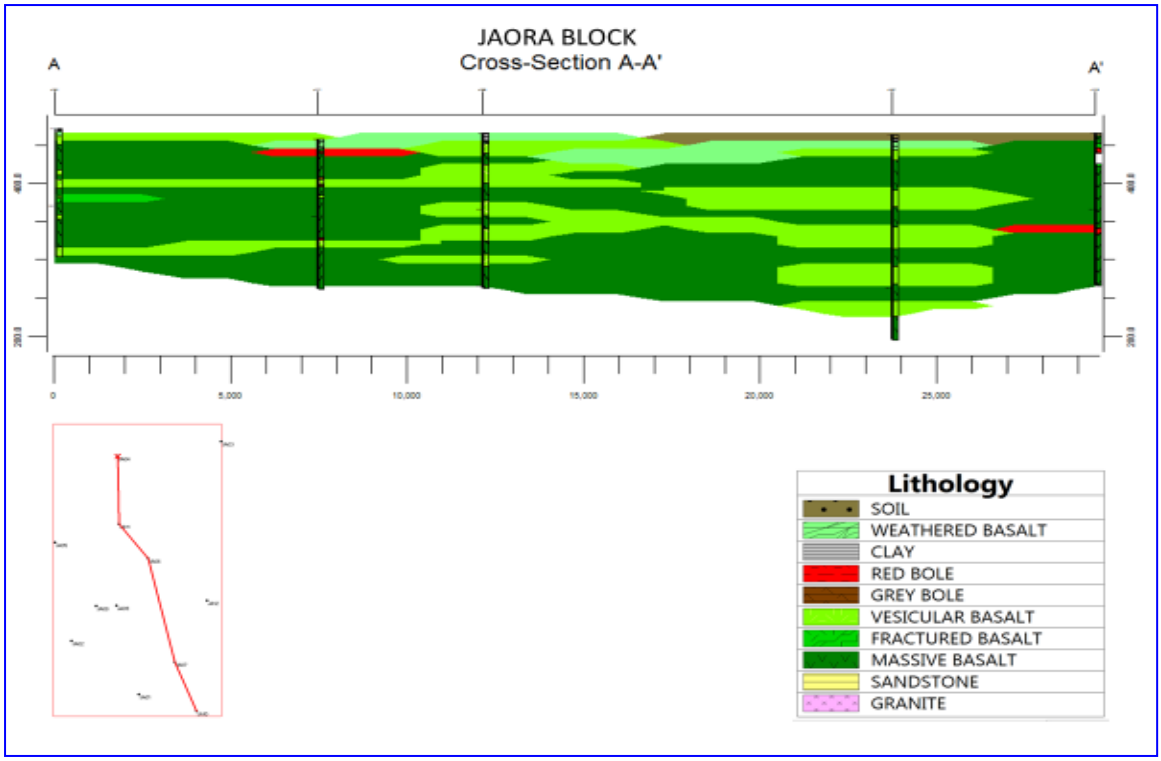


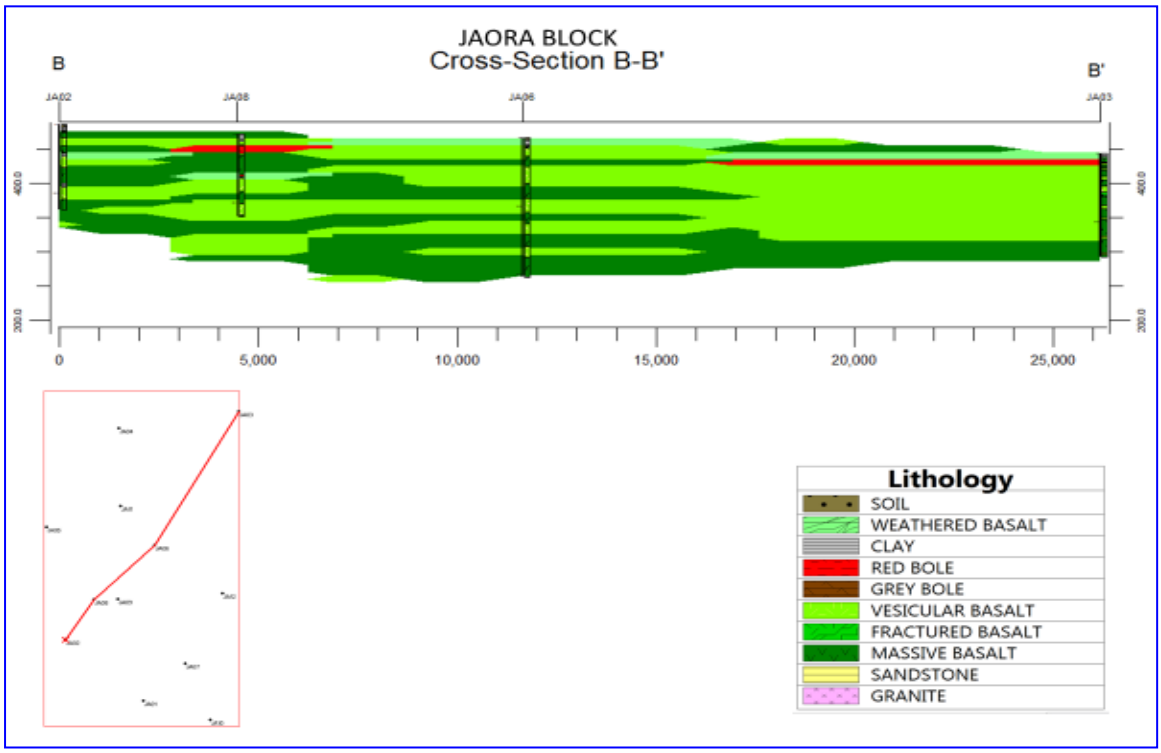



ALOT BLOCK
Cross-Section B-B'
B
B'
AL05
AL04
400.0
400.0
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
Lithology
SOIL
WEATHERED BASALT
CLAY
RED BOLE
GREY BOLE
VESICULAR BASALT
FRACTURED BASALT
MASSIVE BASALT
SANDSTONE
GRANITE

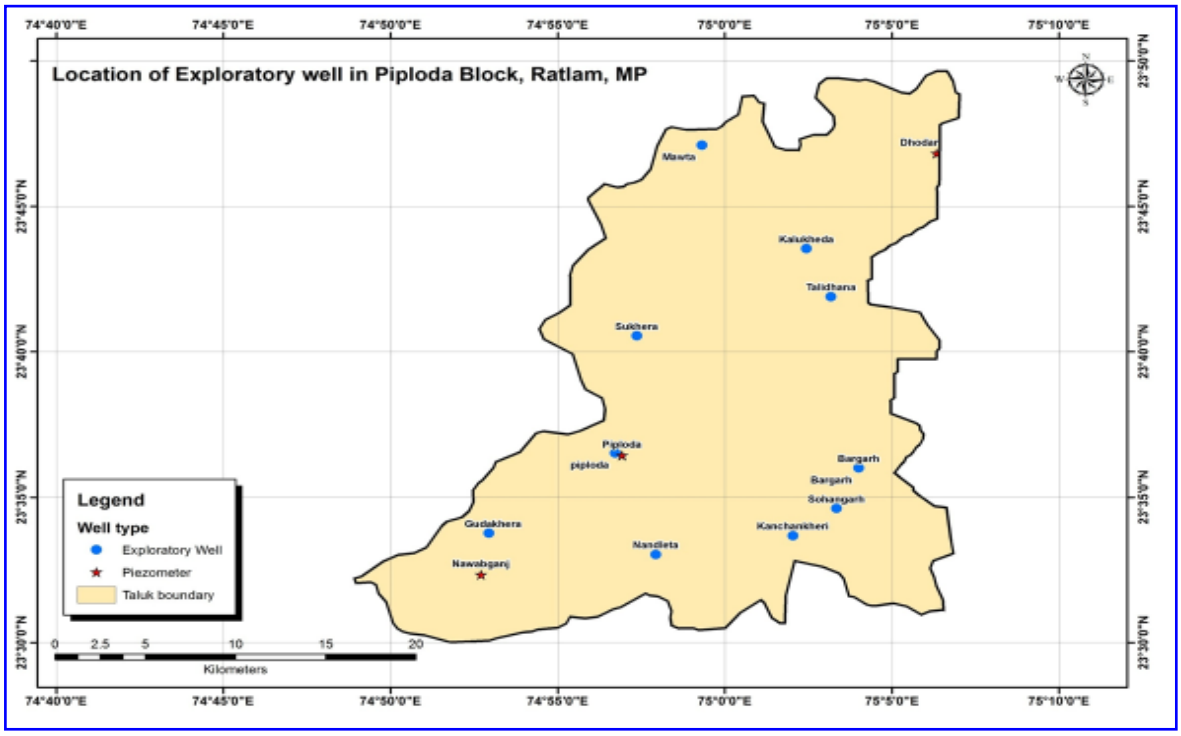
Jaora Block

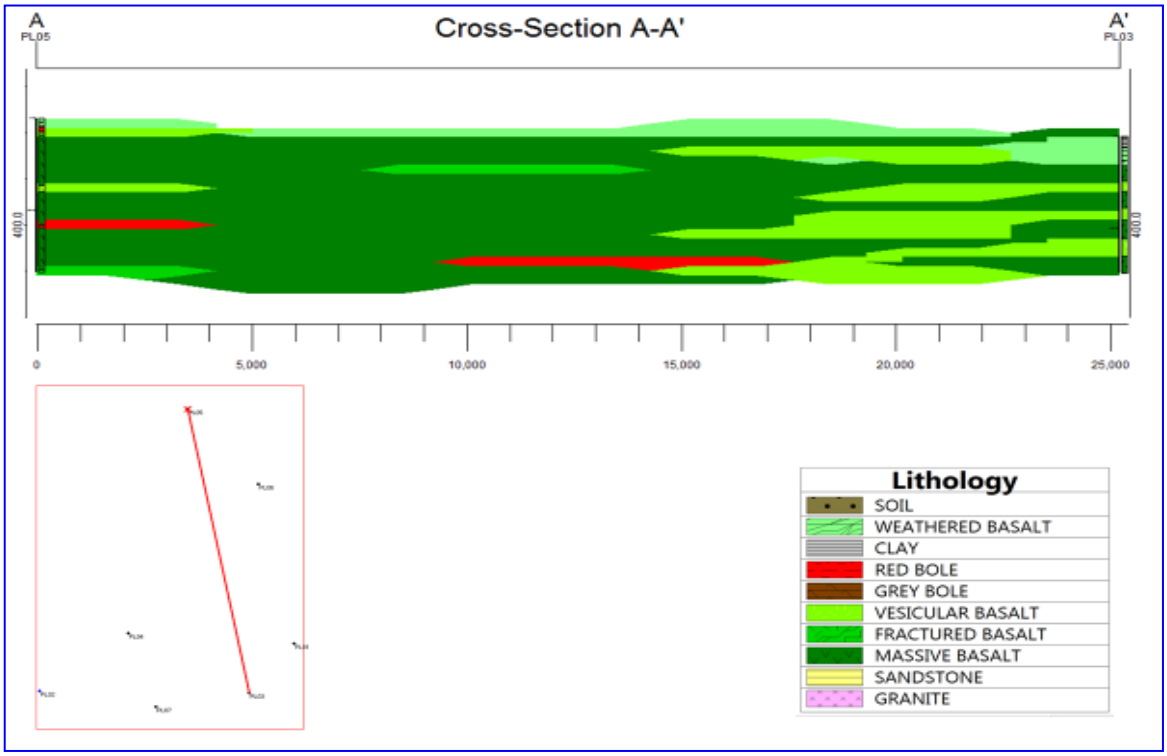

Location of Exploratory well in Jaora Block, Ratlam, MP
74°55'0"E
75°0'0"E
75°5'0"E
75°10'0"E
75°15'0"E
75°20'0"E
75°25'0"E
23°50'0"N
23°45'0"N
23°40'0"N
23°35'0"N
Hanumantiya
Maidwi
Moya kheda
Jhalwa
Mandla Ram
Hatpipliya
Khajuri khedia
Jaora
Rajakhedi
Tikaniya
kerwasa
Legend
Well type
Exploratory Well
Piezometer
Taluk boundary
0
2.5
5
10
15
20
Kilometers

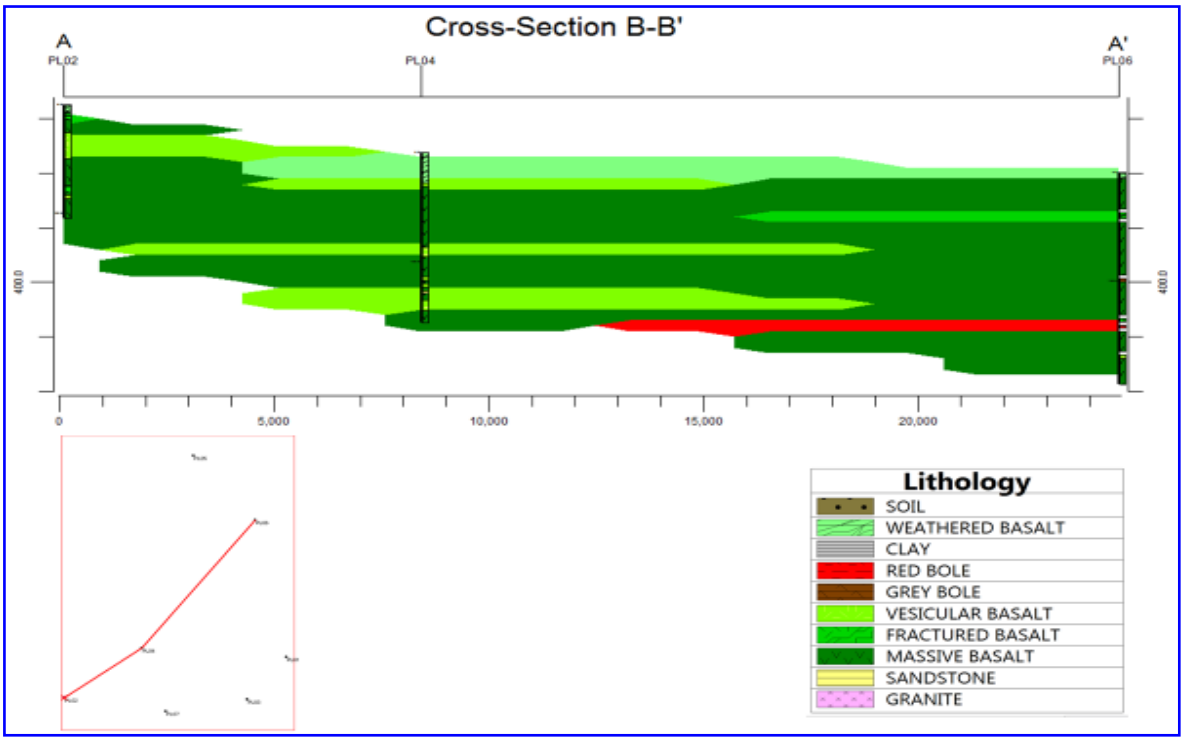

JAORA BLOCK
Cross-Section A-A'
A
A'
0
5,000
10,000
15,000
20,000
25,000
Lithology
SOIL
WEATHERED BASALT
CLAY
RED BOLE
GREY BOLE
VESICULAR BASALT
FRACTURED BASALT
MASSIVE BASALT
SANDSTONE
GRANITE


JAORA BLOCK
Cross-Section B-B'
B
B'
JA02
JA08
JA06
JA03
0
5,000
10,000
15,000
20,000
25,000
Lithology
SOIL
WEATHERED BASALT
CLAY
RED BOLE
GREY BOLE
VESICULAR BASALT
FRACTURED BASALT
MASSIVE BASALT
SANDSTONE
GRANITE

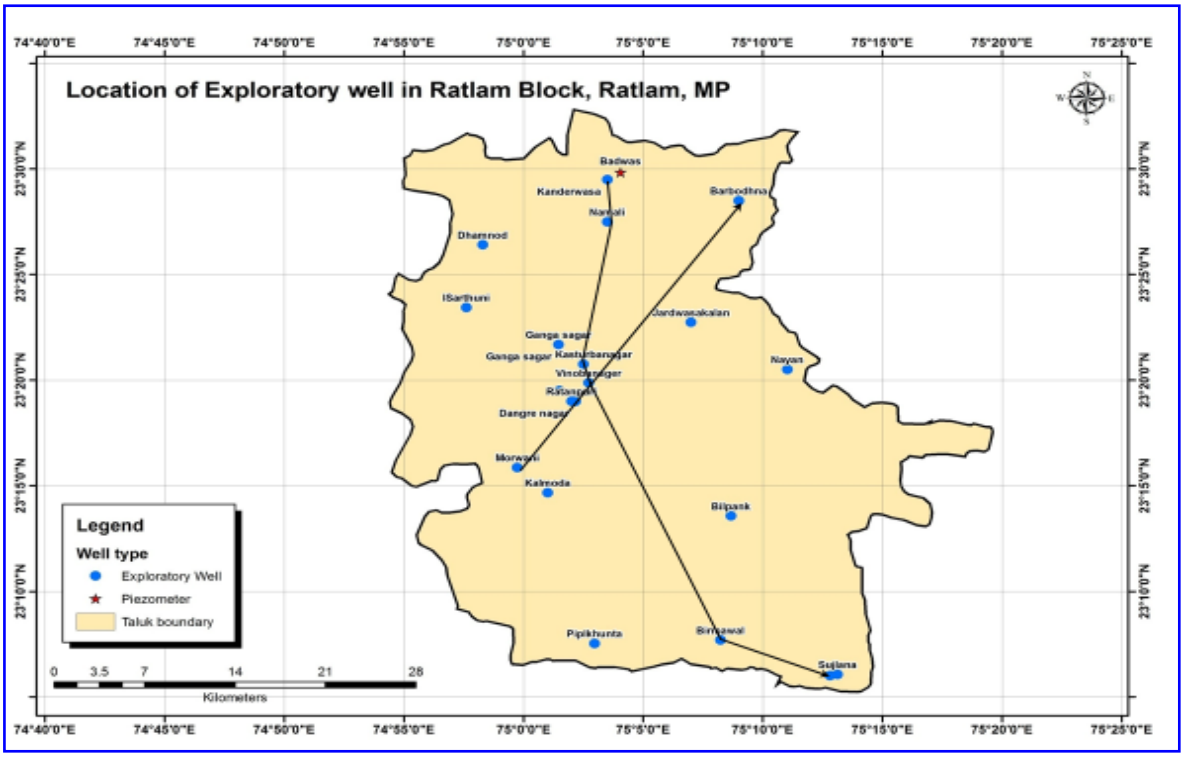
Piploda block

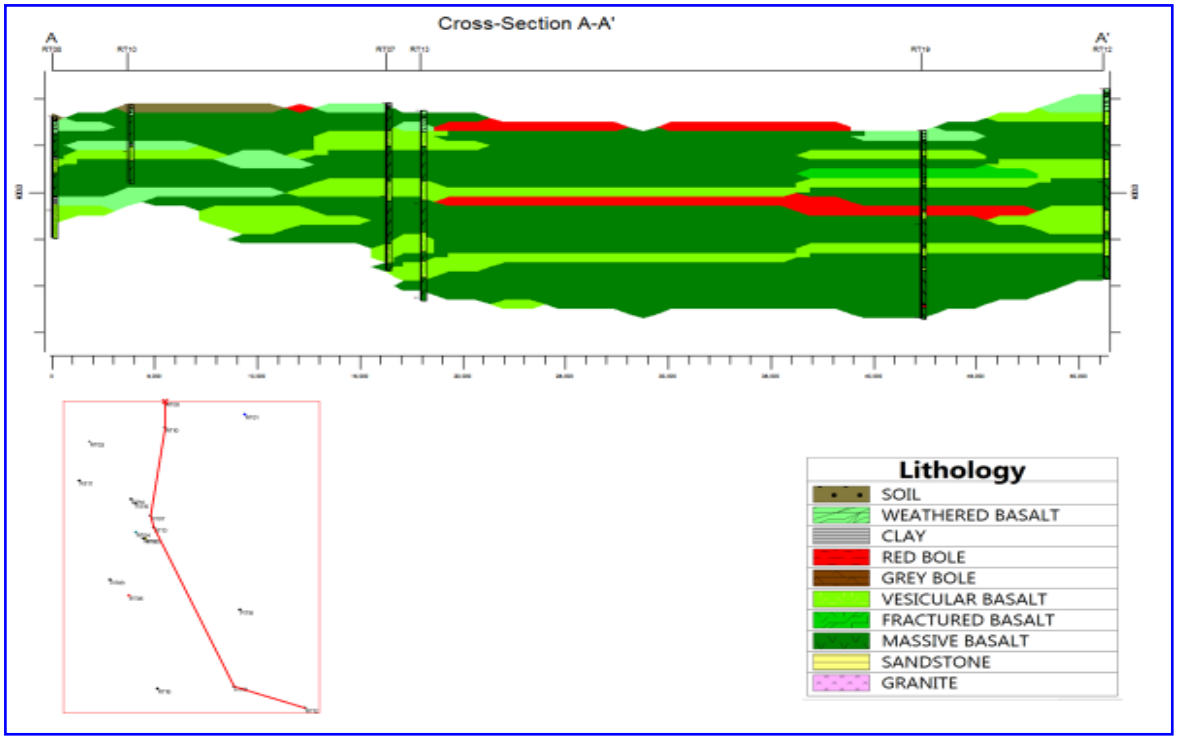


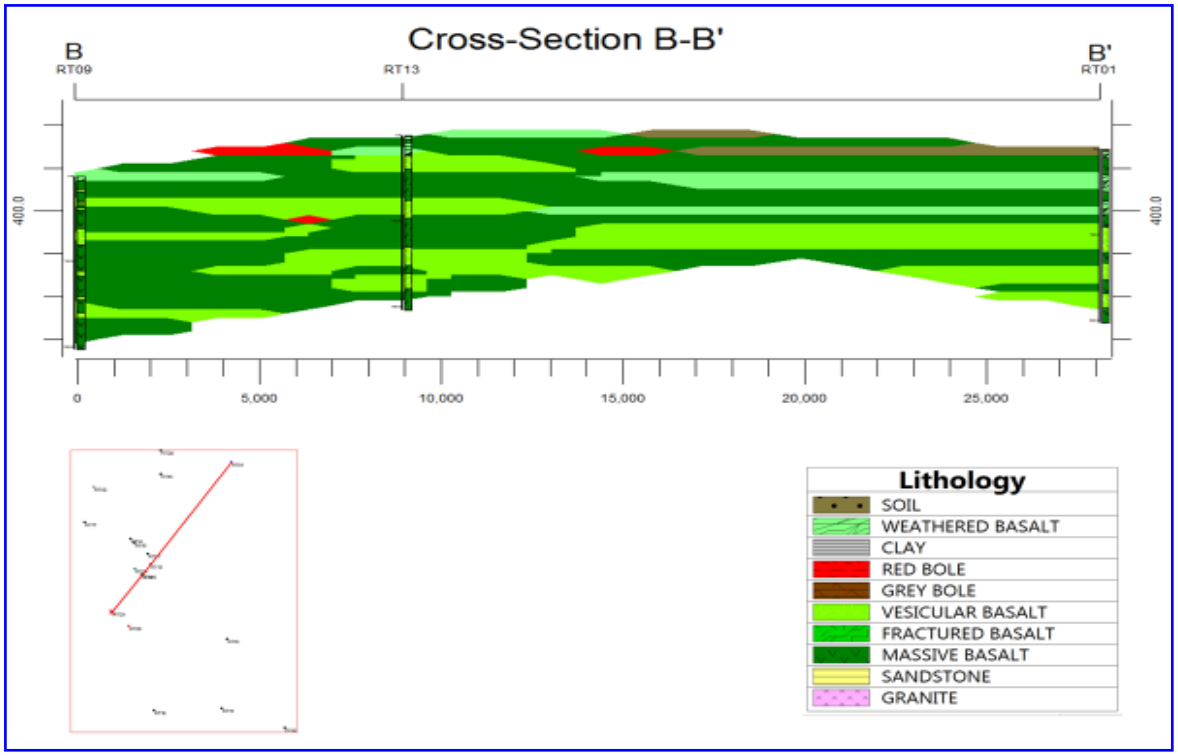




Ratlam Block




Cross-Section A-A'
A
A'
Lithology
SOIL
WEATHERED BASALT
CLAY
RED BOLE
GREY BOLE
VESICULAR BASALT
FRACTURED BASALT
MASSIVE BASALT
SANDSTONE
GRANITE


Cross-Section B-B'
B
RT09
RT13
B'
RT01
400.0
400.0
0
5,000
10,000
15,000
20,000
25,000
Lithology
SOIL
WEATHERED BASALT
CLAY
RED BOLE
GREY BOLE
VESICULAR BASALT
FRACTURED BASALT
MASSIVE BASALT
SANDSTONE
GRANITE

Sailana Block