REPORT ON SUSTAINABILITY OF AQUIFER SYSTEM IN PARTS OF BEMETERA DISTRICT, CHHATTISGARH - A MATHEMATICAL MODELLING BASED APPROACH

जल बचत - जल संचय

Rajiv Gandhi National Ground Water Training & Research Institute
Raipur – 492 001
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Prepared by

Dr. Prabir K. Naik, Scientist D (Sr. Hydrogeologist)

Sh. Rajiv Tripathy, Scientist B (Jr. Hydrogeologist)

Sh. Sambit Samantray, Scientist C(Jr. Hydrogeologist)

Sh. A. V. S. S. Anand, Scientist D (Sr. Hydrogeologist)

Sh. Gulab Prasad, Scientist D (Jr. Hydrogeologist)

Dr. A. Mukherjee, Scientist D (Jr. Hydrogeologist)

Under the Supervision of

Sh. Alok K. Dube, Regional Director

Sh. Sunil Kumar, Regional Director

Dr Pradeep K. Naik, Superintending Hydrogeologist

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- Authors

Executive Summary

Bemetera district has a geographical area of 2855 sq. km. and 4 community development blocks. In this area the aquifer is highly productive and agriculture is intensively practiced. Two crops such as Kharif and Rabi are practiced and in some areas summer crops is also taken up by farmers. There are around 39,000 (2016) bore wells in Bemetera district, which are mainly irrigation bore wells. The stage of ground water development is 72% and has been categorized as semi-critical (2013).The main objective of the study is to evolve a sustainable ground water management plan of the area.

The total geographical area of the study area is 857 sq. km. covering most parts of Bemetera block (643.4 sq. km.), parts of Saja (154.4 sq. km.) and Berla block (59.31 sq. km.).The study area is part of the Central Chhattisgarh Plain and is represented by structural plain having Proterozoic rocks. The study area falls in Mahanadi basin. The Seonath river which flows in SW-NE direction forms the eastern border of the district and is a tributary to river Mahanadi. The Hanp river which flows in NW-SE direction forms the northern boundary of the study area is a tributary to river Seonath. The Dotu river which flows in NW-SE direction forms the south western boundary of the study area which is a tributary to river Seonath.

The average annual rainfall of Bemetera district is 968.5 mm. Rainfall is highly variable in different districts of the state as well as the 4 blocks of Bemetera district.

The study area is consisting litho unit of Proterozoic age. The different rock types exposed in the area are Chandi limestone, Tarenga shale, Hirri dolomite and Maniari shale. Maniari shale are the youngest.

Both shallow and deeper aquifer are exploited in the area. In dug well water level varies from 1.3 to 15 mbgl in pre- monsoon (May- 2016) and the average water level is 7.33 mbgl. In bore well the water level varies from 8.93 to 42.35 mbgl in pre-monsoon (May- 2016) and the average water level is 24.23 mbgl.

The yield of bore wells drilled by CGWB varies from 0.77 to 18.97 lps Most of the fractures occur between 20 to 100 m depth. Average transmissivity of bore wells varies from 100 to 600 m^2/day. Storativity values varies from 7.9 X10^{-2} to 5.93 X 10^{-7}. Maniari Shale is gypsiferous in nature. A number of solution cavities are present rising the yield of bore wells to as high as 18 lps.This zone is largely tapped by farmers for irrigation purpose. As per USSL and WILCOX diagram, water is suitable for irrigation purpose.

Both phreatic and deeper aquifer of the study area is affected with high electrical conductivity. In phreatic aquifer EC varies from 220 to 3220 µS/cm and in deeper aquifer varies from 273 to 3180 µS/cm. High EC is mainly due to occurrence of SO_4 in ground water and the source is gypsum occurring in Maniari Formation. Sulphate concentration in ground water varies from 12 to 1163 mg/l. Maniari Formation is the youngest formation of Chhattisgarh Supergroup and consists of gypsiferous purple to pink shale and argillaceous dolomite. State Govt. has installed RO plant for supply of potable water to different villages.

In the study area it is a common practice to fill up village pond with bore well water. There is indiscriminate exploitation of deeper aquifer leading to decline of water level. Also bore well water is highly exploited for irrigation purpose. Different crops like paddy, wheat, sugarcane, soyabean, pulses, black gram, banana, papaya and different types of vegetables are cultivated in the region. As a result there is decline in water level and in some of the areas dug wells has gone dry as in shale area the natural recharge is a very slow process.

Ground water modelling study reveals that monsoon draft in the study area is 59101.5 m^3/day and non-monsoon draft is 97933.5 m^3/day. In Simga area average monsoon recharge is 47.67 mm and average non-monsoon recharge is 10.40 mm. In Andhiarkhor area average monsoon and non-monsoon recharge are 42.73 mm and 25.84 mm respectively. In Bemetera area average monsoon and non-monsoon recharge are 78.36 mm and 27.85 mm respectively.

There is a threat of declining ground water levels and depletion of ground water resources in future with the scenario of decreasing recharge and increasing extraction. Hence the following strategies may be adopted for facing the future challenges. Various demand side measures like drip and sprinkler irrigation should be encouraged by government. Artificial recharge measures has to be implemented in the study area to enhance recharge. Bore well recharge should be practiced in the area as there is very high withdrawal of ground water from deeper aquifer. Roof Top Rain Water Harvesting (RTRWH).should be made mandatory in the area where ever feasible,

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REPORT ON SUSTAINABILITY OF AQUIFER SYSTEM IN PARTS OF BEMETERA DISTRICT, CHHATTISGARH - A MATHEMATICAL MODELLING BASED APPROACH

1.Background

The study area is a part of Bemetera district of Chhattisgarh state in the Seonath sub-basin of Mahanadi River basin. The area is registering decline in ground water level in phreatic aquifer as well as in deeper fractured aquifer. The stage of ground water development is 72% and has been categorized as semi-critical (Dynamic Ground Water Resources of India, 2013). Of late, ground water withdrawal pattern has shifted from phreatic to deeper aquifer. There is a large scale ground water withdrawal for irrigation, which is a matter of concern. Agriculture is intensively practiced in the region. Two types of crops such as Kharif and Rabi is common in the area and at some places summer crop is also harvested. Different crops in the area are paddy, wheat, sugarcane, soyabean, pulses,blackgram, banana, papaya and vegetables. In the study area there is no major or medium irrigation project. Agriculture is mainly dependent on bore well irrigation.Also in the study area, it is a common practice to fill up the village pond from bore wells. As a result, there is indiscriminate exploitation of the invaluable deeper aquifer and decline in water level. In many places hand pumps have been replaced by submersible pumps.

Low infiltration capacity of soil takes long time to replenish deeper aquifer once it is dewatered to critical level. Sustainability is a matter of deep concern as ground water potential of aquifer system is low. Taking these facts into consideration, the area has been selected for the present study. It is a collaborative study between resource persons of both Rajiv Gandhi National Ground Water Training & Research Institute (RGNGWTRI) & North Central Chhattisgarh Region (NCCR). The officers involved are Dr Prabir K. Naik, Sc-D (Sr. Hg), Shri Sambit Samantray, Sc-B (AHG), Shri A. V. S.

S. Anand, Sc-D (Sr. Hg),RGNGWTRI, Shri Rajiv Tripathy (AHG), NCCR,CGWB, Raipur, Shri Gulab Prasad, Sc-D (Jr. Hg), SER, CGWB, Bhubaneshwar and Dr A. Mukherjee Sc-D(Jr. Hg), CHQ, Faridabad

2. Scope of work

The present work "Sustainability of aquifer system in parts of Bemetera district, Chhattisgarh- a mathematical modelling based approach" has a wide scope in terms of its general as well as specific utilities.

The main objective is:

- To address sustainability issues of both the aquifers and evolve a sustainable ground water management plan for Bemetara block and adjoining areas which are bounded between Seonath, Hanp and Dotu Rivers.
- Detail study will be carried out and a computer based ground water flow model will be developed to simulate the ground water flow.
- Alternative development plans of ground water utilisation will be suggested for optimal utilisation of the ground water from the appropriate aquifer to have maximum positive impact on ground water system.

3. Field visit

Monthly monitoring of both dug wells and bore wells were carried out since May-2016 to April-2017 for 24 times. Total 84 number of dug wells and 12 number of bore wells are being monitored. Seventy number of ground water samples have been collected by NCCR, Raipur for analysis in NCCR chemical laboratory. In situ measurement of Electrical conductivity, pH and temperature were carried out by potable instrument.

Different data were collected from field such as: Agriculture office, Water Resources office, Collectorate office, PHED, Electricity office of Govt. of Chhattisgarh.

Data was also collected from Central Water Commission office at Simga and Andhiarkhor.

4. Location brief of project area

The study area is situated in the western part of Chhattisgarh state, adjacent to Raipur district and northern part of Durg district **(Fig.1)**. It falls in Survey of India Toposheet No. 64G/5 (F44P5) 64G/6 (F 44P6), 64G/9 (F 44P9), 64G/9 (F 44P10) and lies within North latitudes 21° 30' - 22° 00' N and East longitudes 81° 15' - 81° 50' E. It is delimited by Durg district in the south, bordered by Raipur and Baloda Bazar district in the east, Mungeli district in the north and Kabirdham and Rajnandgaon district in the west. The total geographical area of the study area is about 857 sq. km. covering most parts of Bemetera block (643.4 sq. km.), parts of Saja (154.4 sq. km.) and Berla block (59.31 sq. km.). It covers 88.4 % of Bemetera, 34.2 % of Saja and 7.6 % of block. Rivers and water bodies of the study area is given in **(Fig. 2)** and proposed area for ground water modelling studies is given in **(Fig. 3)**.

5. Physiographic set up

The study area is part of the Central Chhattisgarh Plain and is represented by structural plain covered by Proterozoic rocks. It is characterized by a plateau with land elevation varying between 250 to 300 m above mean sea level (amsl). The central part of the study area forms the water divide for the Hanp and Dotu rivers and the highway from Tilda to Kawardha is follow the water divide.

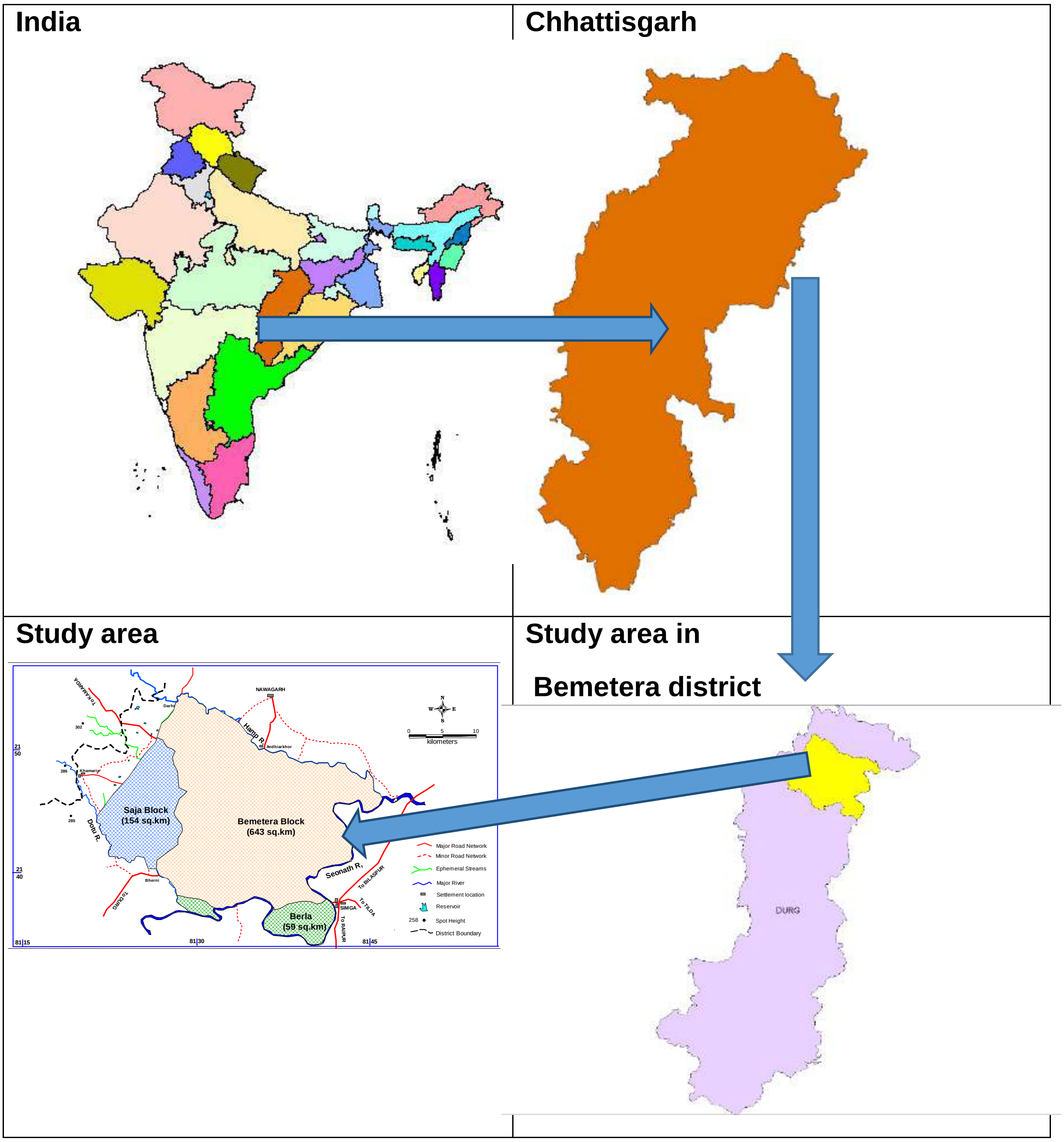


Fig.1 Location of the study area.

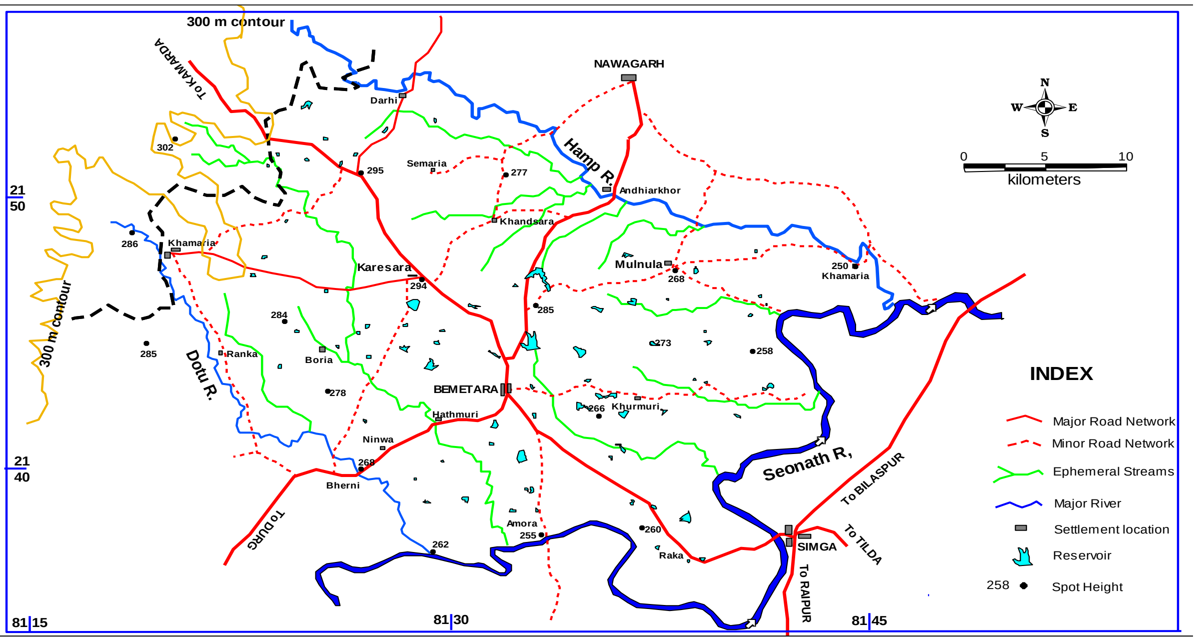


Fig.2 Rivers and water bodies of the study area.

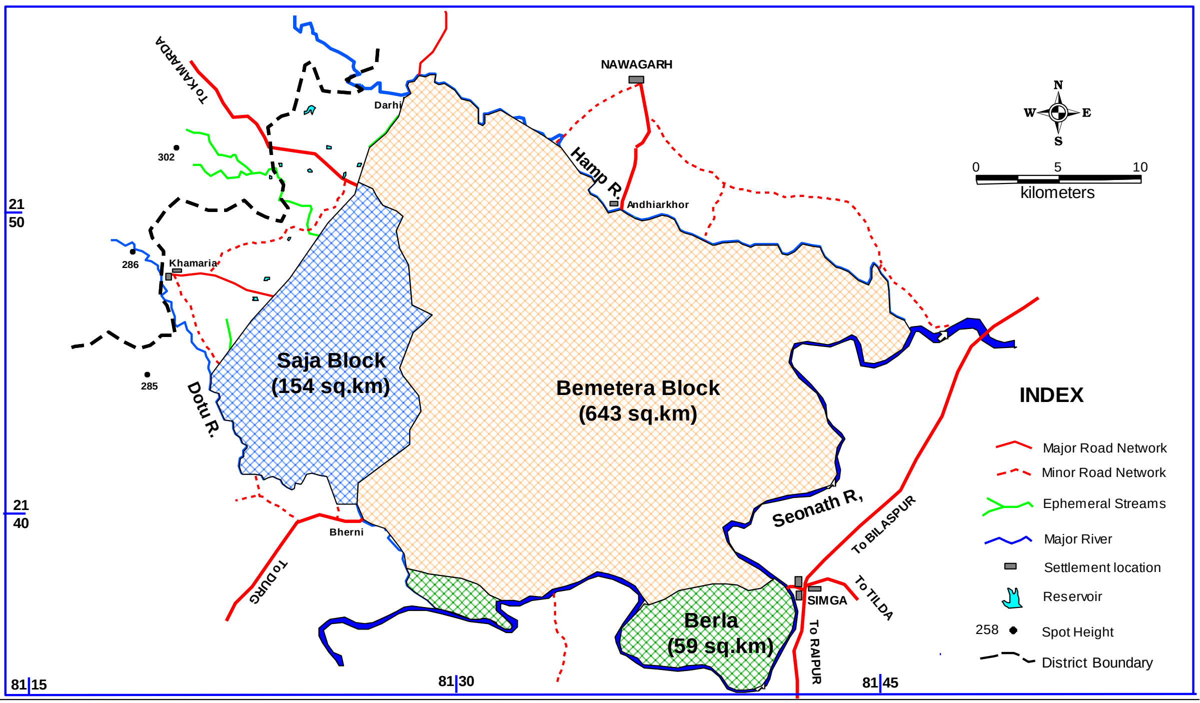


Fig. 3 Proposed area for ground water modelling studies.

6. Soil type

Soils of various types are found in the district and have a large aerial variation. There is no distinct boundary between different types of soil. The red colored residual soil is derived from the laterisation of shale, limestone, dolomite and sandstones. The black coloured soils are locally known as Kanhar. Similarly there are pale yellow, sandy loamy soils which are locally known as Matasi and Dorsa. The development of the soil profile is controlled by the drainage, climate and geomorphology of the area.

The rate of recharge to ground water is controlled by the type of soils, presence of soil moisture and rate of infiltration. Soil properties influence the process of infiltration and generation of run off from rainfall. Soil of the district can be classified based on these hydrological properties into two groups.

I. Hydrologic soil group B (Moderately low runoff potential)

Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderate to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

II. Hydrologic soil group D (High Runoff potential)

It consists of soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clayey soils, soils with a clay pan or clay layer at or near the surface.

As per the US soil taxonomy and their Indian equivalents , Vertisols and Ultisols are found in the area which are described below:

Sl. No.	US soil taxonomy	Indian equivalents
1	Vertisol	Deep black soil
		Medium black soil
2	Ultisol	Lateritic soil
		Red and yellow soil

Vertisols

A vertisol is a soil in which the content of clay size particles is 30 percent or more by mass in all horizons (layers) of the upper half-metre of the soil profile. They are characterized by a high content of expanding and shrinking clay known as montmorillonite that forms deep cracks in certain seasons. They may also be characterized by salinity and well-defined layers of calcium carbonate or gypsum. The Indian equivalent of Vertisols which are available in the area are deep and medium black soils. These are mainly distributed in all parts of the study area.

Ultisols

This is a highly weathered and leached acid soil with high levels of clay below the top layer. They are characterized by a humus-rich surface horizon (the uppermost layer) and by a layer of clay that has migrated below the surface horizon. Ultisols can have a variety of clay minerals, but in many cases the dominant mineral is kaolinite. This clay has good bearing capacity and no shrink-swell property. The Indian equivalent of Ultisols which are available in the area are lateritic soil and red & yellow soils. They mainly occur as patches in the study area.

7.Climate

The study area of Bemetera district experiences sub-tropical climate, which is characterized by hot summer from March to May and well distributed rainfall during the southwest monsoon from June to September. Winter season in the area is marked by dry and cold weather with intermittent showers during the month of December to February.

7.1 Temperature

Long-term data of temperature shows that temperature decreases progressively after October. The winter season lasts till February. January is the coldest month with the mean daily maximum temperature at 30°C and the mean daily minimum temperature at 14.9°C. During winter, the night temperatures may sometimes drop below 10°C. From about mid-February both day and night temperatures increase rapidly till May which is the hottest month of the year with mean daily maximum temperature at 46°C. However, nights are slightly warmer during May and June than in April. During summer season, day temperatures often go above 45°C as given in **(Fig. 4)**.The monsoon period is generally pleasant. With the withdrawal of the monsoon by the end of September, day temperatures rise a little and then both day and night temperatures begin to drop rapidly.

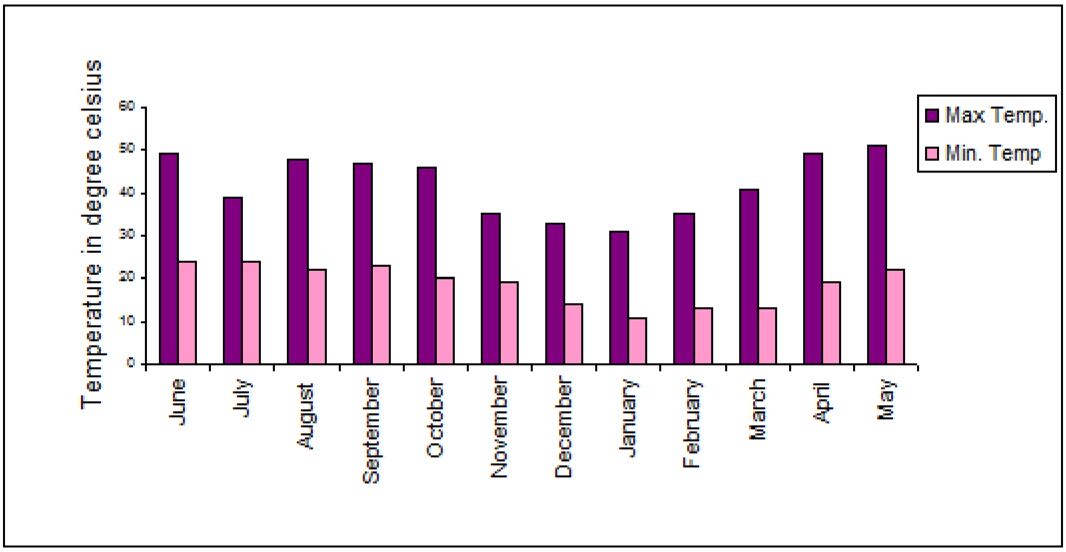


Fig. 4 Monthly minimum and maximum temperature.

7.2 Evaporation

The trend of evaporation is related with the variation of temperature as given in **(Fig. 5)**.Evaporation is maximum in the month of May, which is more than 250mm. and minimum during the month of December and January.

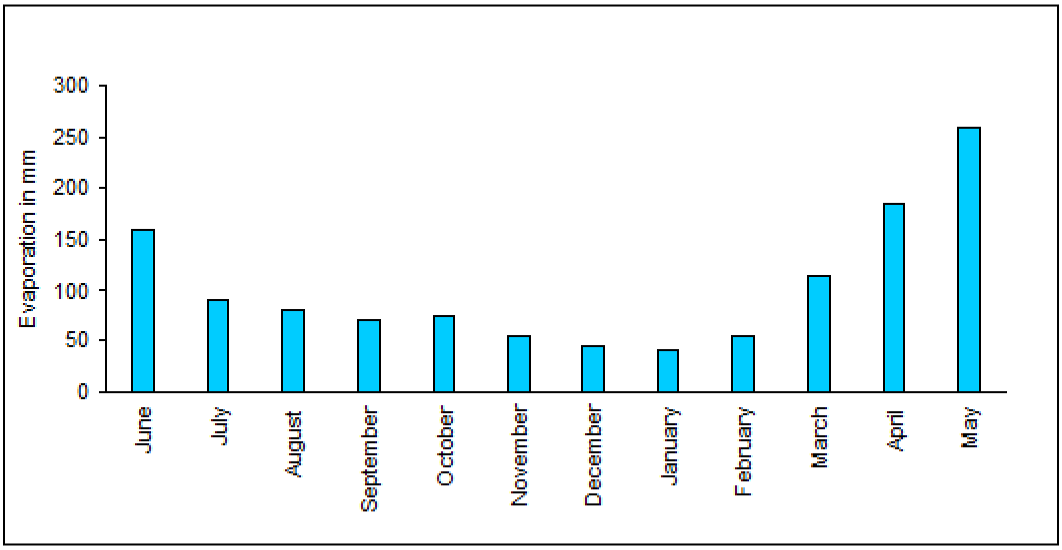


Fig. 5 Monthly evaporation data of Andhiarkhor, Nawagarh block.

7.3 Humidity

In the district summer season humidity is the lowest, i.e. about 36% while it is higher during the monsoon period, i.e. about 86%. The humidity again decreases from October onwards due to rise in temperature and also due to receding monsoon.

7.4 Wind velocity

The monthly maximum and minimum wind velocity recorded is given in **(Fig.6)**.The wind speed of more than 8 km/hr is recorded during the monsoon months from June to September. In the post monsoon and winter months from October to February, the wind speed of less than 5 km/hr is observed and in the summer month of March to May the wind speed of more than 7 km/hr is recorded.

7.5 Rainfall

Bemetera district receives rainfall starting from the month of June and extending till September. The monsoon sets in around 10 th June in the southern most point of Dantewada district and finally extends over the entire state. Rainfall during July and August is high (about 300-350 mm). Monsoon is active still mid-September.

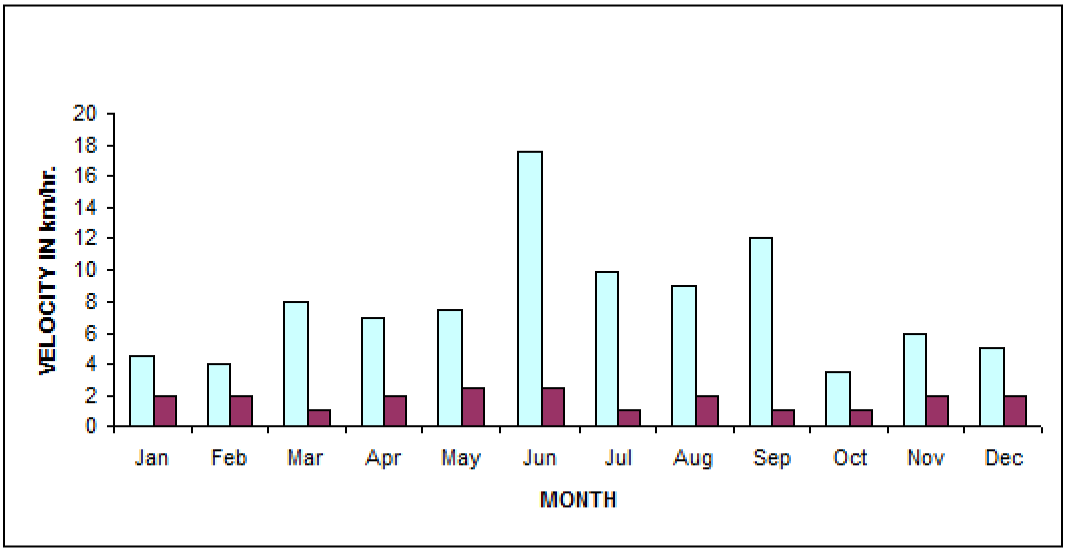


Fig. 6 Monthly maximum and minimum wind velocity.

Monsoon normally starts withdrawing from 15th September and withdraws from the entire Chhattisgarh state by 1st October.

Bemetera district have four community development blocks such as Bemetera, Saja, Berla and Nawagarh where raing auge stations are present. Rainfall data was collected from Collectorate office Bemetera. Two river gauge stations are also present which is operated by Central Water Comission (CWC). One is located in the Hanp River at Andhiarkhor of Bemetera district and other in the Seonath River, located at Simga, presently in Balodabazar district. Long term rainfall data were also collected from these two stations.

7.6 Long term rainfall analysis

The average historical rainfall for the period 1975-2011 of Chhattisgarh state is 1159.14 mm and Bemetera district is 968.5 mm (State hydrogeological report, CGWB, NCCR, 2014). Rainfall is highly variable in different districts of the state as well as the 4 blocks of Bemetera district. Long term rainfall data of Bemetera, Andhiarkhor and Simga is given in **Table 1** and plotted in (**Fig. 7 to 9).** In a single station rainfall varies in different years and also in same year aerially varies in different rain gauge stations.

Sl No	Block	Minimum	Maximum	Average	Std Deviation
1	**Bemetera**	584	2054	1215.3	359.1
2	**Andhiarkhor**	635.6	1612	960	233.8
3	**Simga**	768.8	1534.2	1089.7	182.2

In Bemetera block rainfall is minimum of 584 mm (in 2007) and maximum of 2054 mm (in 2013). Similarly in Andhiarkhor block rainfall is minimum of 635.6 mm (in 1997) and maximum of 1612 mm (in 2003). In Simga block rainfall is minimum of 768.8 mm (in 1992) and maximum of 1534.2mm (in 2007). The average annual rainfall is 1215.3 mm, 960 mm and 1089.7 mm and standard deviation is 359.1, 233.8 1nd 182.2 for Bemetera, Andhiarkhor and Simga block, respectively. The different parameters are summarised below:

8. Hydrology

8.1 Drainage

The study area is a part of the Mahanadi River basin. The Seonath River which flows in SW-NE direction forms the eastern border of the Bemetera district and is a tributary to river Mahanadi. The Hanp River which flows in NW-SE direction forms the northern boundary of the study area is a tributary to river Seonath. The Dotu River which flows in NW-SE direction forms the south western boundary of the study area is a tributary to river Seonath. Dotu River is ephemeral in nature. The drainage pattern is mainly sub-dendritic but at places controlled by structure.

Table 1 Long term rainfall data of the study area

Sl No	Year	Bemetera Rainfall in (mm)	Andhiarkhor Rainfall in (mm)	Simga Rainfall in (mm)
1	1981			955.8
2	1982		755.6	1037.9
3	1983		1010.48	913.3
4	1984		799.8	1253.4
5	1985		899	1190
6	1986	848.7	938	1042
7	1987	875.4	777.9	1003.3
8	1988	817.56	866.9	882.9
9	1989	951.4	823.9	926.64
10	1990	1417.4	1355.4	976.6
11	1991	946.6	797.5	973.2
12	1992	1290.6	680.7	768.8
13	1993	1354.3	758.6	1019.8
14	1994	1650.8	1069.3	1218
15	1995	1341.8	1024	1061.6
16	1996	1383.8	769.8	933.6
17	1997	1450.07	635.6	854.9
18	1998	1441	996.6	1181.4
19	1999	1978.8	942.3	1236.2
20	2000	1176	733.8	979.2
21	2001	1084.9	1263.6	1147
22	2002	787	882.2	808
23	2003	1621	1612	1457.2
24	2004	1078	1065.8	1113.6
25	2005	1252	1601.8	1235.2
26	2006	996	987.2	1280.6
27	2007	584	1235.8	1534.2
28	2008	839	809.6	1003.6
29	2009	690	871.6	1109.8
30	2010	932	928.2	975.6
31	2011	1463.3	1140.2	1404.4
32	2012	1130	738.4	1079.6
33	2013	2054	1008.8	1343.8
34	2014	1582	1156.4	1248.6
35	2015	1510.6	804.2	1168.4
36	2016	1146.1	859.4	910.4

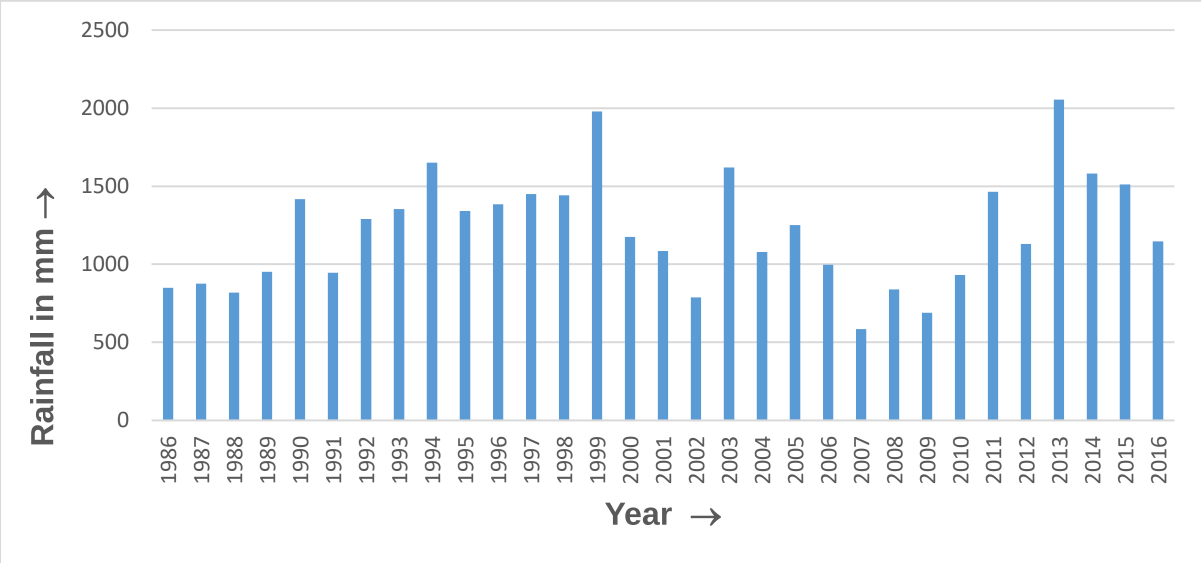


Fig. 7Rainfall pattern of Bemetera rain gauge station

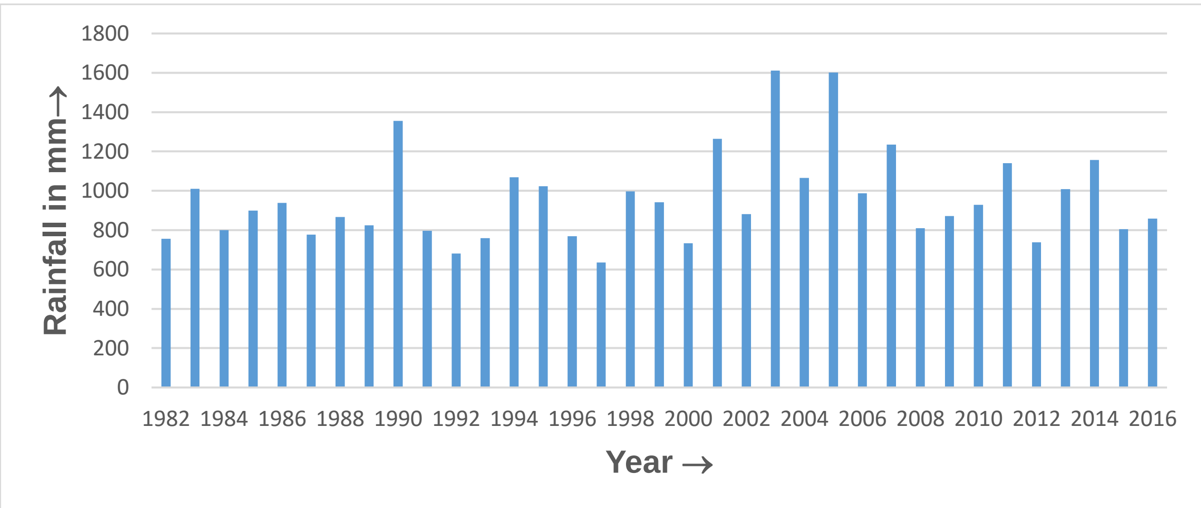


Fig. 8. Rainfall pattern of Andhiarkhor rain gauge station

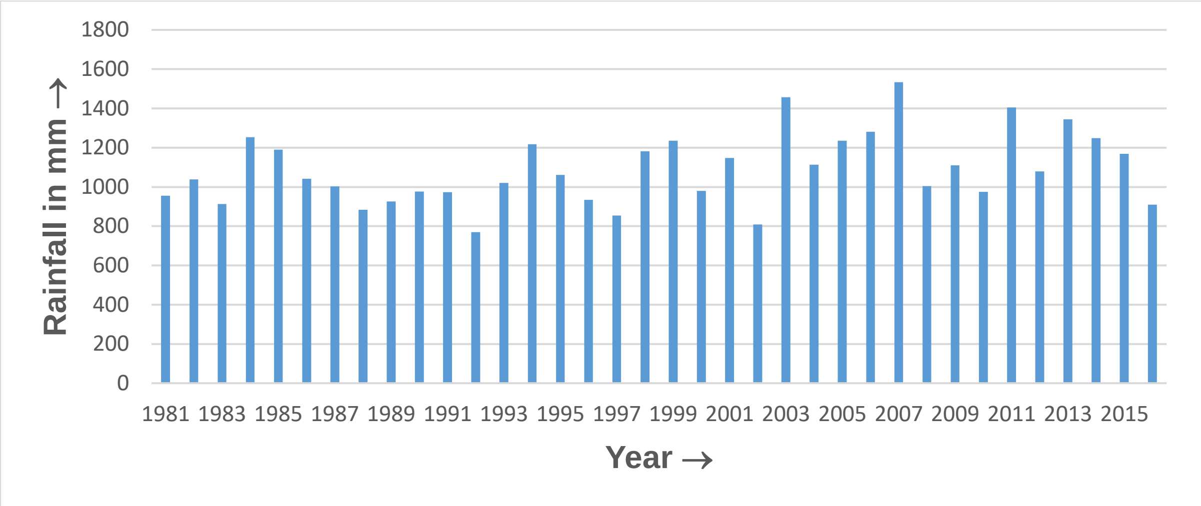


Fig. 9 Rainfall pattern of Simga rain gauge

8.2 Water bodies

The area is having a number of ponds of varying size. In summer season some of the ponds go dry but some are full of water. Some minor irrigation structures are also present.

9. Geology

The study area is part of Indian shield consisting of litho units ranging in age from Proterozoic to Recent. The area is a part of Bastar province (Craton) which is constituted sequence of Meso-neo Proterozoic “Purana Basin”. Laterite and alluvium of Recent age are developed over this province sporadically. The geological sequence of the area is described as under:

9.1 Chhattisgarh Supergroup

The crescent shaped Chhattisgarh basin within the Central Indian Craton can be subdivided into a small Baradwar sub basin in east and main Hirri sub basin in west. The entire succession of Chhattisgarh Supergroup is divided into three groups (Das et al, 1992). Geology is depicted in **Table 2** and geological map in **(Fig.10).** The lower most Singhora Group consists of four formations of arenite, argillite and carbonates. Singhora Group is developed in the Baradwar Sub-basin. The

Chanderpur Group unconformablyoverlyingthe Singhora Group or older basement consists of three arenite formations and Raipur Group at the top, comprising argillite–carbonate suite which is subdivided into six formations. An abridged account of the various litho units occurring in the study area is given below.

Chandi Formation: This comprises a major stromatolitic limestone sequence developed around the southern side of depocentre of Hirri sub-basin as arcuate outcrop pattern. Chandi Formation had been classified into three major carbonate members based on dominant carbonate facies (Murti, 1987). The Deodongar arenite

Table 2 Geology of the study area

Proter-ozoic	Chhattisgarh Supergroup	Raipur Group	Maniari	Gypsiferous Shale	
			Hirri	Dolomite	
			Tarenga	Shale & Dolomite	
			Chandi	Limestone & Shale	
			Gunderdihi	Shale	
			Charmuria	Limestone & Shale	
		Chandrapur Group		Sandstone, Siltstone, Shale & Conglomerate	
		Singhora Group		Limestone, Shale, Sandstone & Siltstone	

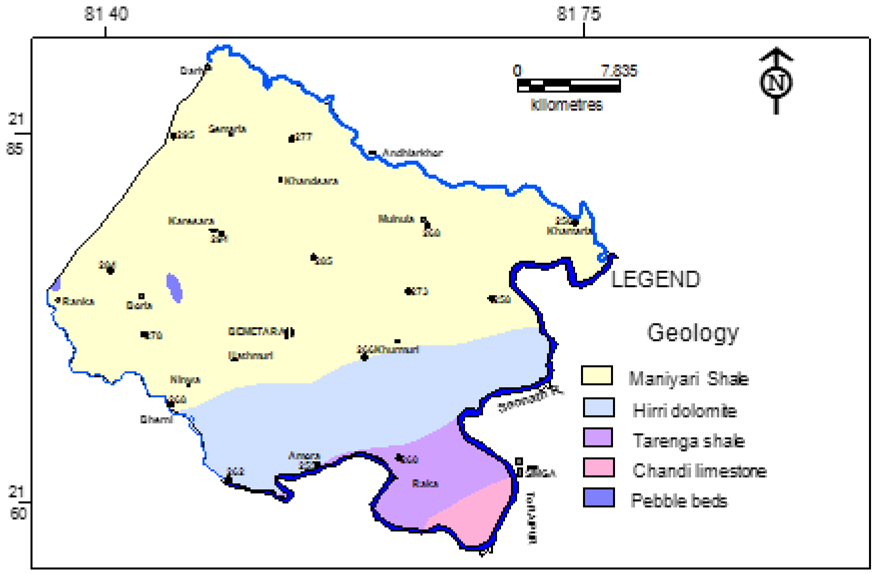


Fig. 10 Geology of the study area.

Include lensoidal pockets of siliciclastic rocks within Chandi Formation. They, however occupy a definite stratigraphic level within the formation.

Tarenga Formation: The Chandi Formation is conformably overlain by Tarenga Formation which is classified into Kusmi argillite, Dagauri green clay-chert and Bilha dolomitic argillite from bottom to top.

The Kusmi Member is developed in southern part of Hirri sub-basin. It consists of cherty shale, calcareous shale, brown-coloured bedded argillaceous dolomite and splintery violet shale. At places, intra-formational flat pebble conglomerate are present. The argillite contains 30-40% silt-size grains, 20-25% clay and muscovite, and intraclasts of carbonate. The argillaceous limestone is composed of 75-80% micritic calcite and ferruginous clay and silts. Das et al. (1989) reported the occurrences of phosphorite band.

Dagauri Member is about 3-10 m. thick and is developed as a key horizon in southern part of the sub-basin. The member comprises green and white clay of suspected volcanic origin associated with chert and carbonate bands.

Bilha Member, the topmost unit of Tarenga is a monotonous dolomite argillite. The rock is medium to fine grained, purple coloured and bedded in character. It is predominantly composed of argillaceous material with considerable amount of dolomite. At places, the rock is dolomitic containing 90% of dolomite crystals.

Hirri Formation: This is well developed around the central part of Hirri sub-basin and forms an oval-shaped outcrop pattern. Although, it attains a considerable thickness in south, it is very thin along the northern fringes and is interpreted from outcrop exposures and/ or local excavations. Das et al., (1990a) designated the formation after the village Kodwa. However, Das et.al (1992) propose to retain the formational name as Hirri, first introduced by Schnizer (1969). The formation conformably overlies the Tarenga Formation in the south and Pandaria Formation in the north. At places, intraformational conglomerate, dolomite and black shale contain gypsum as layers, parallel to bedding and as disseminated grains/ crystals. Stromatolitic dolomite is exposed in Hirri and Kodwa mines. The stromatolites are columnar having a wide inter columnar space.

Maniari Formation: It is named after the Maniari River along which the rock is best developed, and shows an oval-shaped outcrop in the central part of the sub-basin. It represents the closing phase of deposition in Chhattisgarh basin and consists of lower gypsiferous grey siltstone and shale followed by reddish brown calcareous and non-calcareous shale with limestone and dolomite. The laminated grey shale is composed of clay and silt in the ratios from 80: 20 to 70: 30 and the silt fraction contains quartz and feldspar with cross-lamination. The alternate silt and clay define the laminated character. The red shale is less fissile and is both calcareous and non-calcareous containing gypsum lenses and veins. The major constitutes are quartz, clay and carbonate. Cross-lamination and mud cracks are the common sedimentary structures. Minor argillaceous limestone and oolitic limestone occur as lenses in shale. The non-oolitic argillite carbonate is composed of 60% to 70 % micrite.

Pebble bed: The Quaternary Formation along major river occasionally have pebble bed exposures in the Bemetera area. However, the Quaternary Formations are sporadic and not observed in exploratory drilling. The total thickness of alluvium is not more than few meters.

10. Hydrogeology

10.1 Ground water occurrence

The aquifer can be divided into two zones shallow and deeper aquifers. Their disposition has been established through hydrogeological studies, exploration and the surface geophysical studies in the area covering all the geological formations. Depth of shallow aquifer is upto20 m and that of deeper aquifer is upto 150m.

Monthly monitoring of both dug wells and bore wells were carried out since May-2016 to April-2017 for 24 times .Out of 84 number of dug wells and 12 number of bore wells were monitored only 71 number of dug wells and 12 number of bore wells were used in analysis after verification.

10.2 Shallow aquifer

The shallow aquifers are being tapped through dug wells, dug- cum- bore wells or shallow bore wells drilled up to depth of 20 m. The weathered mantle and shallow fractures mainly constitute the shallow aquifer. The list of key wells of dug wells is given in Annexure-I and that of bore well is given in Annexure-II.

The depth of dug wells varies from 5.6 to 15.7.The analyses of water level data are given in **Tables 3 & 4**. Water level varies from 1 to 14.9 mbgl and 1.3 to 15 mbgl in May-15 and May-16 respectively. Similarly water level varies from from 1 to 12.9 mbgl and 1.3 to 11.5 mbgl in Nov.-15 and Nov.-16 respectively. The average water level was 7.83 m and 7.33 m respectively in May.-15 and in May.-16.The average water level was 5.93 m and 5.71 m respectively in Nov.-15 and in Nov.-16.

Histogram of water level of Pre- and Post-monsoon is given from **Figs.11.1a to 11.1e**. Average water level is given in **Fig. 11.1f.** Depth to water level and fluctuation map of phreatic aquifer is given in **Figs.12 to 14**. Water table contour map is given in **Figs.15 to 16**.

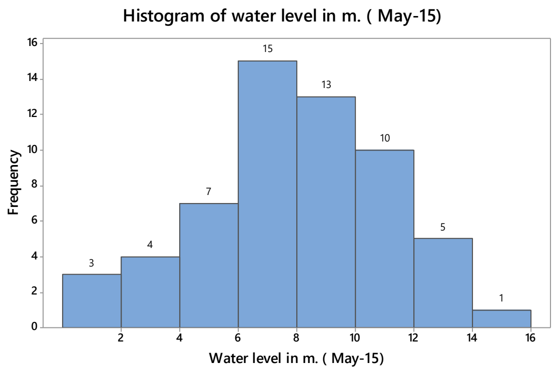


Fig.11.1a Histogram of water level of Aquifer-I (May-15)

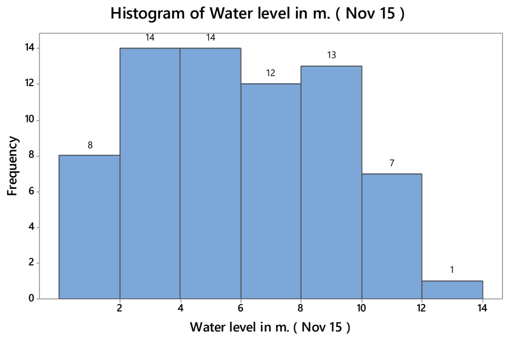


Fig 11.1b Histogram of water level of Aquifer-I(Nov.15)

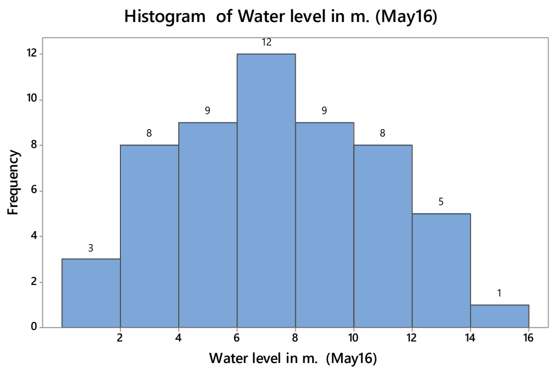


Fig.11.1c Histogram of water level of Aquifer-I (May -16)

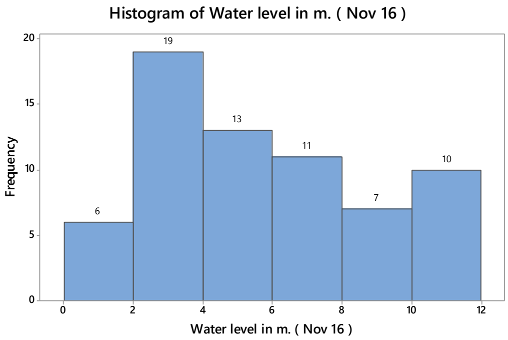


Fig.11.1d Histogram of water level of Aquifer-I Nov -16)

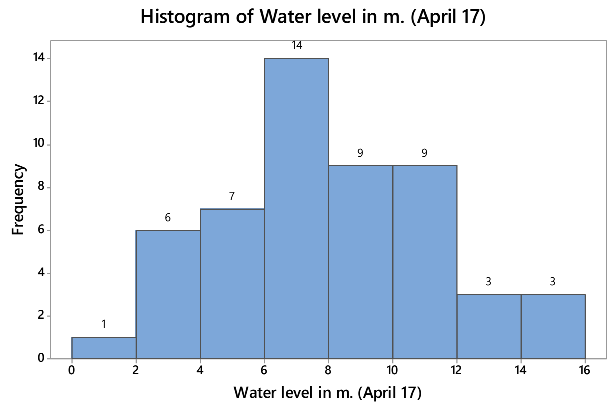


Fig.11.1e Histogram of water level of Aquifer-I (April -17)

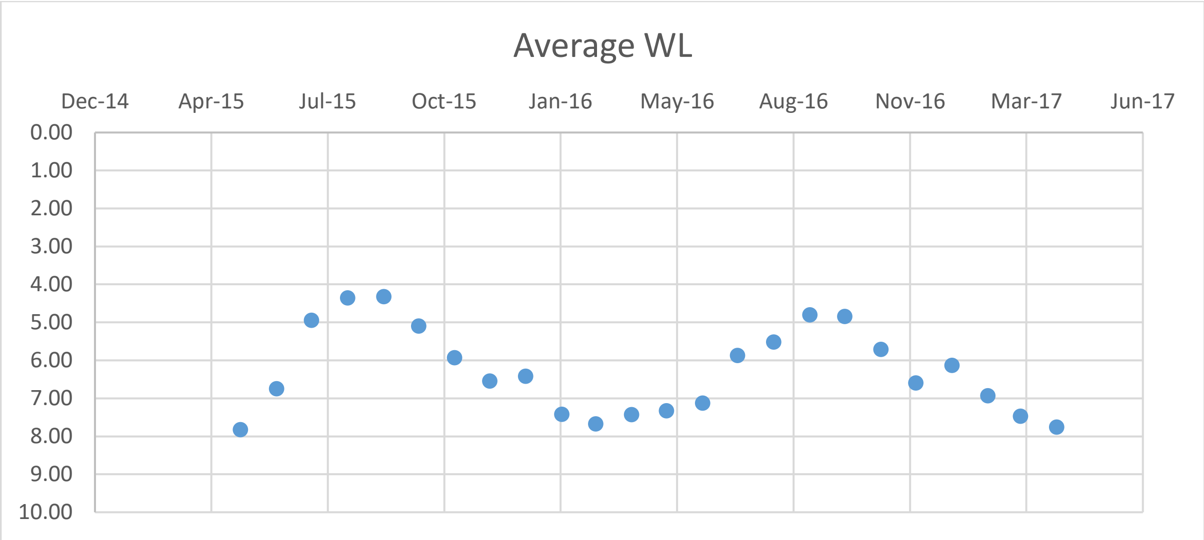


Fig. 11.1f. Plot of average water level of dug wells

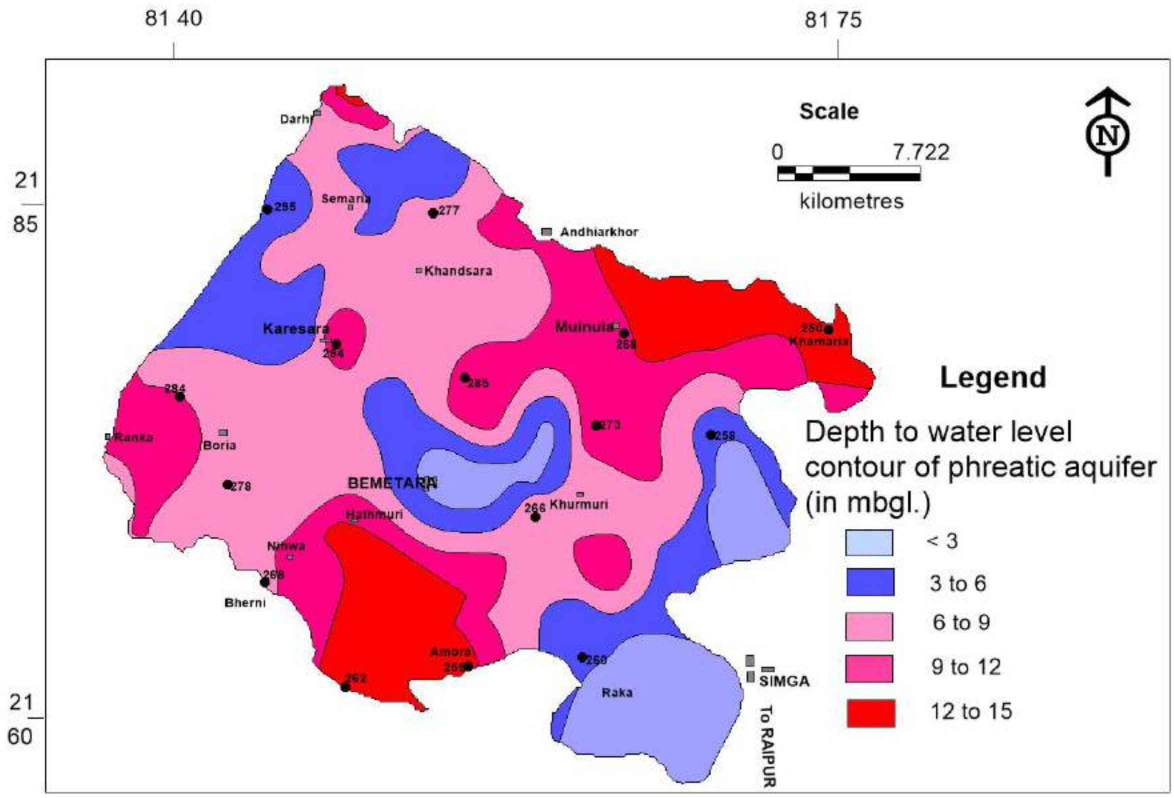


Fig.12 Depth to water level contour of phreatic aquifer (Aquifer- I, May -16)

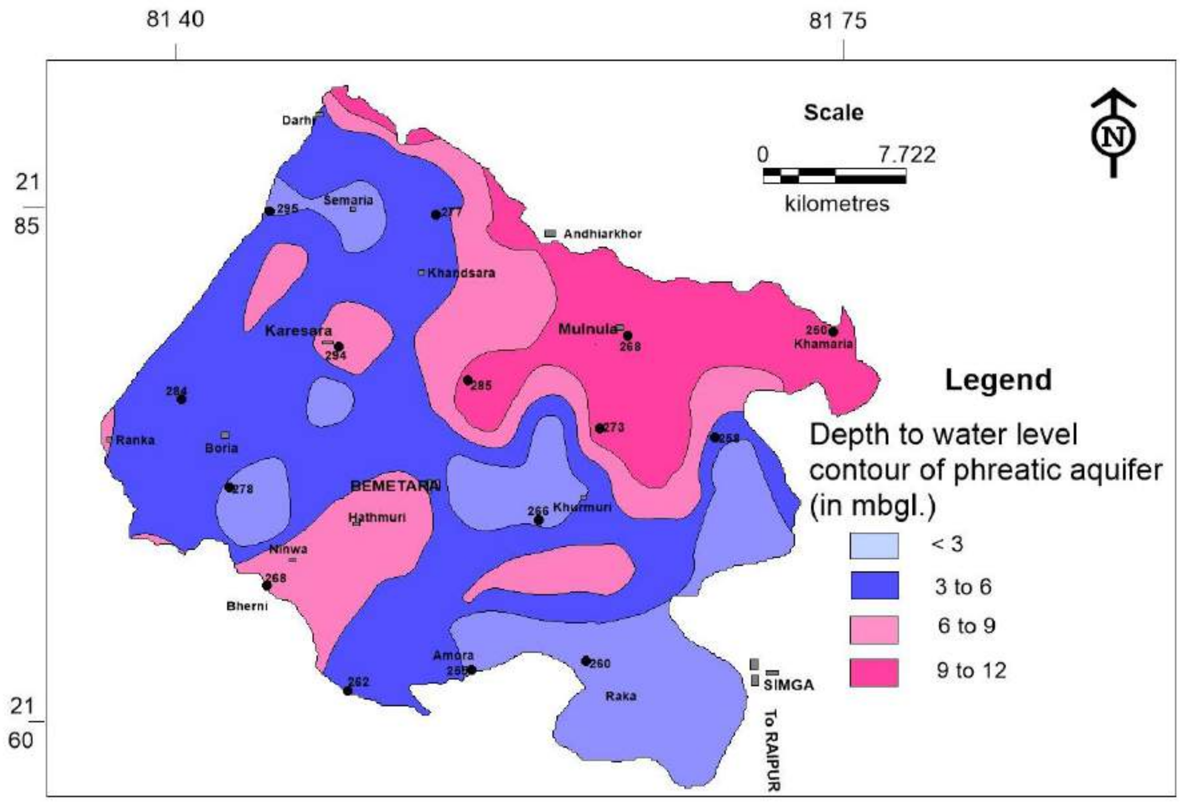


Fig.13 Depth to water level contour of phreatic aquifer (Aquifer- I, Nov. -16)

Table 3 Analysis of depth to water level of dug well

Month	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16
Minimum WL (in mbgl)	1	0.37	0.38	0.5	0.75	0.74	1	1.12	1.16	1.32	1.05	1.45
Maximum WL (in mbgl)	14.9	12.15	12.9	10.2	11.7	12.97	12.9	12.92	12.95	14.9	14.5	14.9
Average WL (in mbgl)	7.83	6.75	4.95	4.36	4.33	5.10	5.93	6.55	6.42	7.43	7.67	7.43
Standard Deviation	3.2	3.2	3.4	2.8	3.0	3.3	3.1	3.3	3.3	3.5	3.7	3.4
Month	**May-16**	**Jun-16**	**Jul-16**	**Aug-16**	**Sep-16**	**Oct-16**	**Nov-16**	**Dec-16**	**Jan-17**	**Feb-17**	**Mar-17**	**Apr-17**
Minimum WL (in mbgl)	1.3	1.3	0.3	0.6	0.12	0.24	1.3	0.94	1.1	1.23	1.38	1.95
Maximum WL (in mbgl)	15	14.8	12.75	14.5	12.2	12.62	11.5	14.55	14.01	14.48	14.5	14.5
Average WL (in mbgl)	7.33	7.13	5.87	5.52	4.81	4.85	5.71	6.60	6.14	6.94	7.48	7.76
Standard Deviation	3.4	3.5	3.4	3.9	3.6	3.5	3.1	3.4	2.8	3.2	3.6	3.2

Table 4 Analysis of depth to water level of dug well falling in different ranges

	Water level (in m)	May-15	Nov-15	May-16	Nov-16	Apr-17	% in May -15	% in Nov -15	% in May -16	% in Nov -16	% in April -17
1	0-2	3	8	3	6	1	5.2	11.6	5.5	9.1	1.9
2	2-4	4	14	8	19	6	6.9	20.3	14.5	28.8	11.5
3	4-6	7	14	9	13	7	12.1	20.3	16.4	19.7	13.5
4	6-8	15	12	12	11	14	25.9	17.4	21.8	16.7	26.9
5	8-10	13	13	9	7	9	22.4	18.8	16.4	10.6	17.3
6	10-12	10	7	8	10	9	17.2	10.1	14.5	15.2	17.3
7	12-14	5	1	5		3	8.6	1.4	9.1		5.8
8	14-16	1		1		3	1.7		1.8		5.8
Total no of dug wells		**58**	**69**	**55**	**66**	**52**					

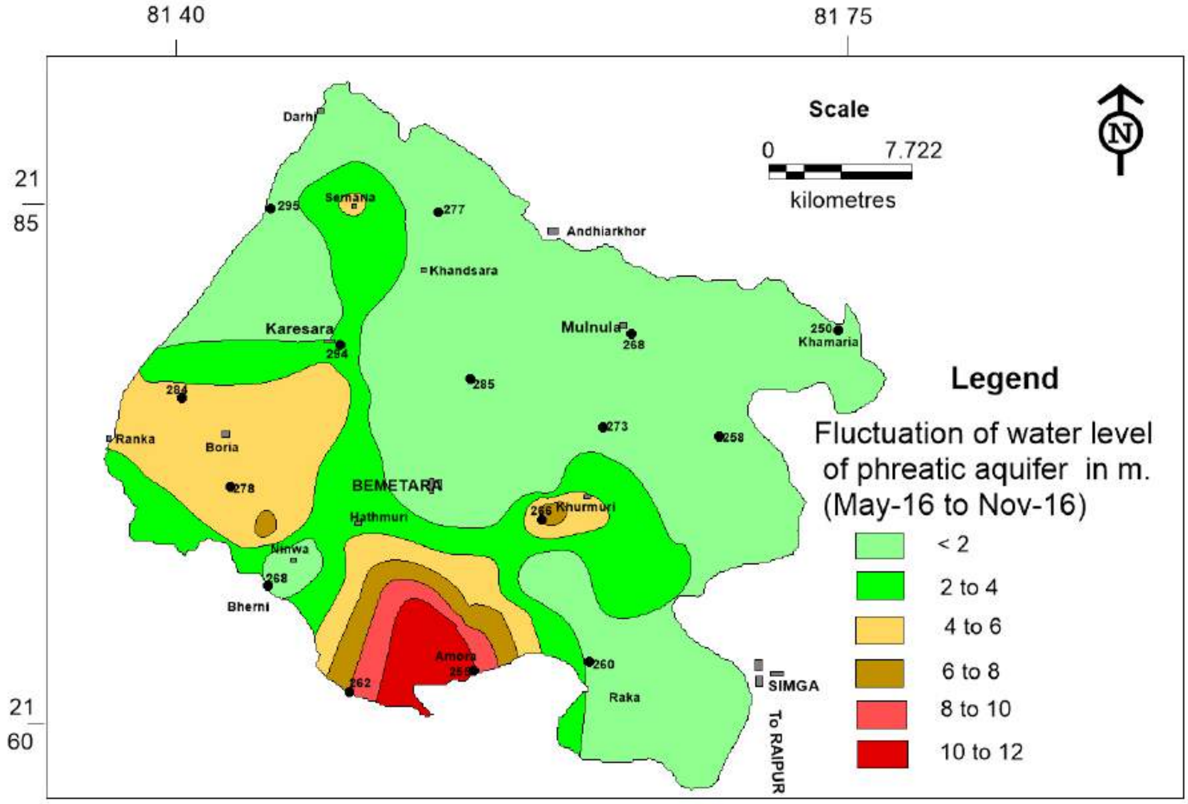


Fig.14 Water level fluctuation of phreatic aquifer (Aquifer- I, 2016)

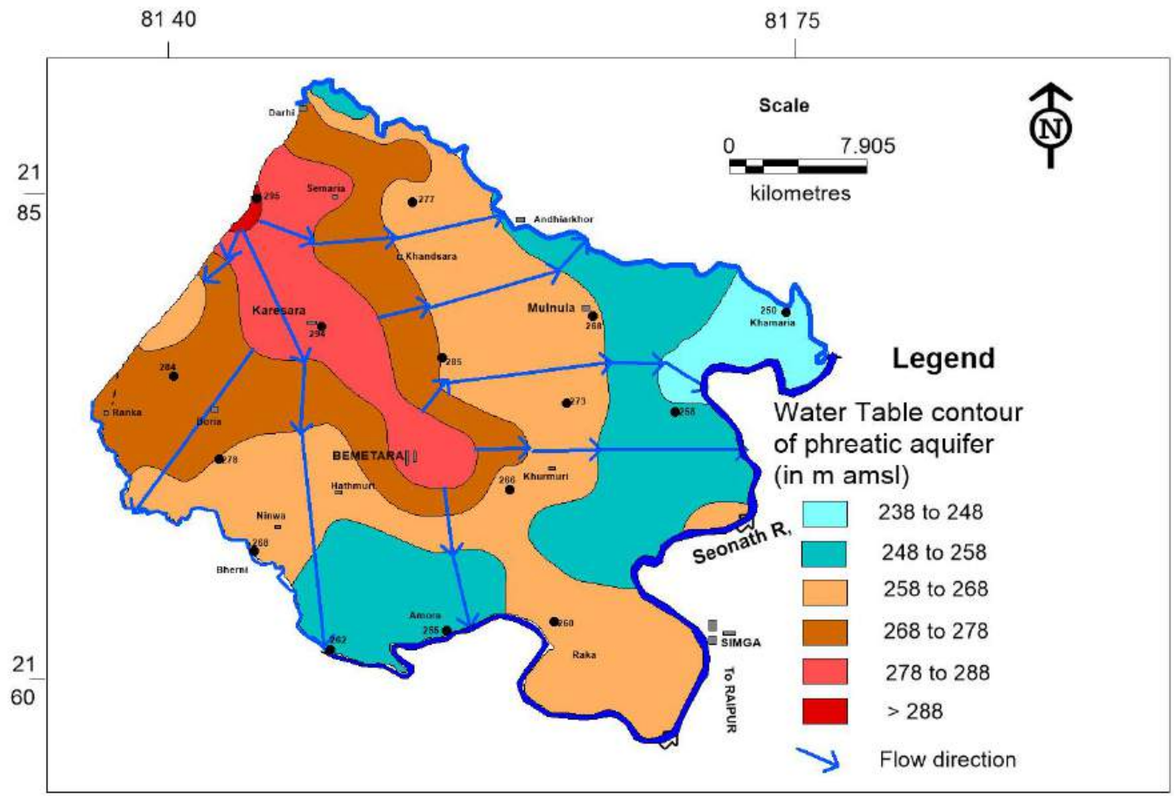


Fig.15 Water table contour of phreatic aquifer (Aquifer- I, May -16)

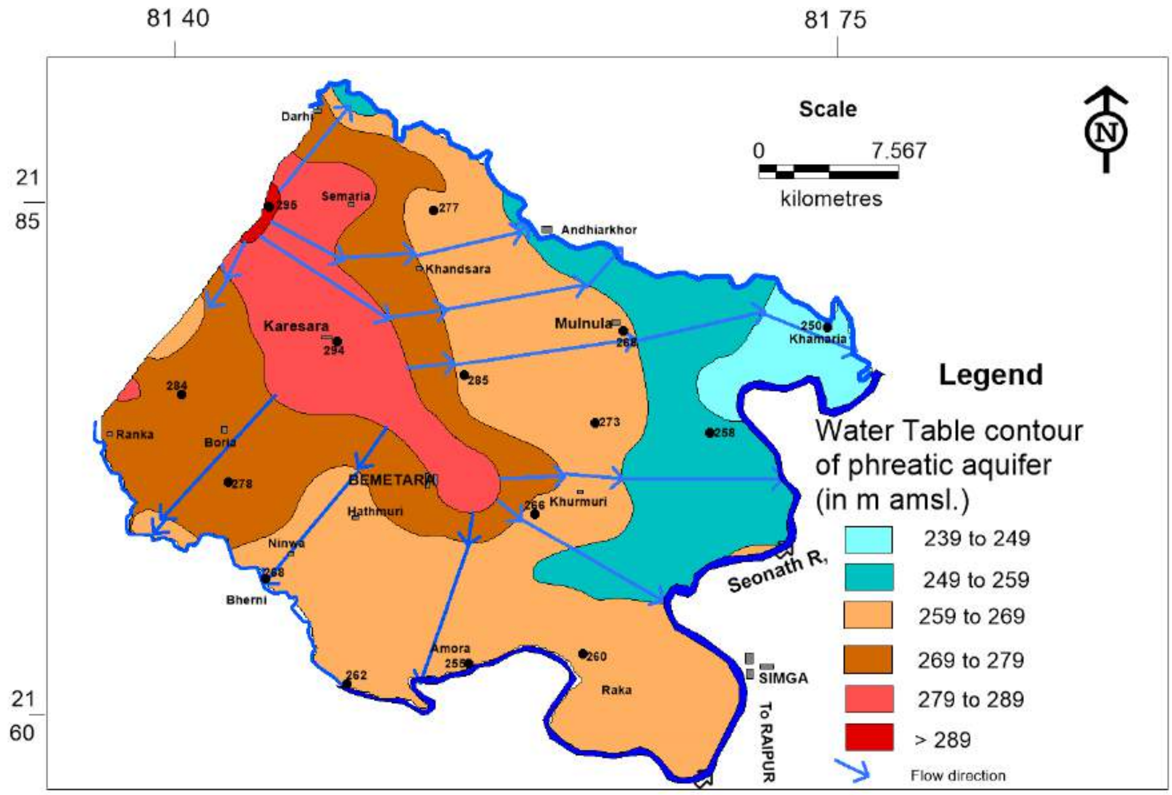


Fig.16 Water table contour of phreatic aquifer (Aquifer- I, Nov -16)

10.3 Deeper aquifer

Exploration was carried in the study area and also adjacent to it by CGWB, NCCR Raipur. Total 18 number of exploratory wells have been drilled around the study area. The details of exploratory wells is given in **Table 5** and T, S values are given in **Table 6**. Histogram plot of casing, depth of fracture, discharge and Transmissivity (T) is depicted in **Fig.17a to 17d**. Depth to water level contour is depicted in **Fig. 18 & 19** and Water Table contour is depicted in **Fig. 20 to 21.**

The depth of bore wells varies from 52.5 to 259.06 m. The depth of casing varies from 6 to 32.8 m which reflects the depth of weathered zone(Fig.17a). One to five fracture zones occurs from depth of 11.9 to 131m. Most of the fractures occur between 20 to 100 m. (Fig.17b).The yield of bore wells varies from 0.77 to 18.97 lps. Medium discharge wells have yield between 2- 8 lps and high discharge area wells have yield between 12-18 lps (Fig.17c). Drawdown of bore wells varies from 0.41 to

35.47 m. Transmissivity (T) varies from 22.15 to 1125.65 m^2/day. Average T of bore wells varies from 100 to 600 m^2/day (Fig.17d). Storativity values varies from 7.9 X 10^{-2} to 5.93 X 10^{-7}.

The analysis of monthly water level of bore wells is given in **Table 7 & 8.** Water level varies from 6.41 to 27.63 mbgl and 8.93 to 42.35 mbgl in June-15 and May-16 respectively. Average water level was 15.7 and 24.23 mbgl in June-15 and May-16 respectively. Similarly in water level varies from 4.33 to 21.65 mbgl and 5.82 to 23.1mbgl in Nov-15 and Nov-16 respectively. Average water level was 11.95 and 12.55 mbgl in Nov-15 and Nov-16 respectively. So it shows that in both Pre- and Post-monsoon there is decline in water level which is due to low uneven rainfall and high draft. From Table 7 also it is clear that in June -15, 54.55% of bore wells was having water level between 10-20 mbgl but in May-16, 58 .3 % of bore wells are having water level between 20-30 mbgl.

Water Table (WT) contour of May-16 and Nov-16 is plotted which is shown in **Fig.20 to 21.**In May-16 WT contour varies from 231 to 267 m amsl and ground water flow direction is from NW to SE towards the Seonath river. In Nov-16 WT contour varies from 245 to 281 m amsl and ground water flow direction is from NW to SE towards Seonath river .

Table 5 Details of exploratory wells

Sl No	Location	Depth Drilled (in m.)	Casing (in m.)	Zone Tapped (in m.)	SWL (mbgl)	Discharge (in lps)	Drawdown (in m.)
1	Amora(EW)	92.2	12	34-37,70-76, 83-86	7.07	16.4	2.08
	Amora(OW)	92.2	12	74-77,80-83,86-89	6.87	16	0.89
2	Barga(EW)	52.5	22.5	34-37,46-49	9.1	18.97	7.18
3	Barga(OW)	55.6	22.5	34-37,46.5-49.5	8.76	18	7
4	Tipni (EW)	202	24	40-43.	18.5	6	4.01
	Tipni (OW)	202	24	40-43	18.25	6	1.15

Table 5 Details of exploratory wells (contd.)

Sl No	Location	Depth Drilled (in m.)	Casing (in m.)	Zone Tapped (in m.)	SWL (mbgl)	Discharge (in lps)	Drawdown (in m.)
5	Dhara (EW)	112.6	12	18.00-21.10, 54.60-57.70	11.11	12.02	2.46
	Dhara(OW)	112.6	6	18.00-21.10, 51.60-54.60	10.99	17.68	2.32
6	Khurusbod(EW)	204.1	8.5	24.10-27.20, 48.50-51.60	21.43	4.364	1.93
	Khurusbod(OW)	204.1	12	21.10-24.10, 36.30-39.40	20.67	4.364	NA
7	Jhal(EW)	204	12	11.90-15.00, 63.80-66.80, 100.40-103.40	1.69	6.189	NA
	Jhal(OW)	204	6.1	11.90-15.00, 60.70-63.80, 88.20-91.20	1.73	7.8	1.34
8	Dadhi(EW)	204	32.8	27.20-30.20, 57.70-60.70	10.5	4.364	1.13
	Dadhi(OW)	204	30.5	27.20-31.20, 57.70-60.70	8.41	2.5	0.41
9	Birsinghi(EW)	69.9	20.5	18.00-21.10, 36.30-39.40, 45.50-48.50	2.47	16.511	1.47
	Birsinghi(OW)	69.9	23.5	24.10-27.10, 36.30-39.30, 45.50-48.50	2.19	16.511	1.52
10	Musawadih(EW)	202	17	25-28	2.8	1.2	32.5
11	Beltara(EW)	73.9	19.5	22-25, 34-37	8.63	18.97	11.15
	Beltara(OW)	73.9	19.5	22-25, 34-37	9.3	18.97	11
12	Piparia(EW)	134	10.3	64.7-67.8,86-89, 128-131	24.45	3	12.38
	Piparia(OW)	147	10.3	64.7-67.8,86-89, 128-131	24.4	3	NA
13	Ninwa(EW)	106.5	18.5	79-82.10	13.77	2.54	1.13
	Ninwa(OW)	106.5	18.5	76.0-79.20, 94.30-97.30	13.67	0.77	5.3
14	Andhyiarkhor OW	84.22	9.9	23.4-76.7	11.66	18	0.838
15	Bemetera OW	106.2	16	15.5 -19.1, 27.1-57.5, 80.3-106.1	NA	18	NA
16	Birampur	259.02	9	19.4-23.4, 31-33, 72.6-74.6, 84.2-85	273	16	35.47
17	Chorbhati	148.57	7.4	56-60, 61-68, 76-87, 128-131	13.06	3.5	19.8
18	Nawagarh	259.06	8.9	34.6-53.8, 76.6-87.8	4.96	7.86	10.17

Table 6 Transmissivity (T) and Storativity (S) of bore wells

Sl No	Location	T (m^2/day) Theis method	S (Theis method)	Lithology
1	Amora	299.07	5.29 X 10^{-4}	Hirri Dolomite
2	Barga	275.16	5.714 X 10^{-4}	Maniyari Shale
3	Beltara	745.9	7.9 X 10^{-2}	Maniyari Shale
4	Birsinghi	347.38	1.68 X 10^{-4}	Maniyari Shale
5	Dadhi	42.02	5.93 X 10^{-7}	Maniyari Shale
6	Jhal	299.24	7.016 X 10^{-5}	Maniyari Shale
7	Ninwa	24.2	1.47 X 10^{-5}	Maniyari Shale
8	Tipni	220.76	1.59 X 10^{-3}	Maniyari Shale
9	Birampur	422.2		Maniyari Shale
10	Khati	1114.5		Maniyari Shale
11	Andhiarkhor	1125.6		Maniyari Shale
12	Bemetera	513.94	3.1 X10^{-5}	Maniayari shale and Hirri Dolomite
13	Chorbhatti	22.15		Hirri Dolomite Hirri Dolomite

10.4 Filling of pond by bore well water

In the study area it is a common practice to fill the pond from bore well water. Sometimes backin a drought year most of the surface water bodies were dried. So Govt. of Chhattisgarh started the programme Gaon Ganga Yojna. The main purpose is for drinking water supply to domestic animals and use by village people. But as the Maniari shale is high yielding that practice is widely followed now a days also when the village ponds have sufficient water. In the study area also agriculture is intensively practiced such as kharif, rabi and at some places summer crops area also taken. Sugarcane is also cultivated in the region which needs huge amount of water.As a result there is decline in water level and at many places hand pumps are replaced by submersible pumps. Different field photographs are given in Annexure-III.

Table 7 Analysis of depth to water level of bore well

Month	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16
Minimum WL (in m)	6.41	5.42	6.02	5.22	3.72	4.33	6.13	6.79	9.22	6.83	8.18	8.93
Maximum WL (in m)	27.63	29.08	26.25	23.35	21.86	21.65	26.6	29.35	46.65	47.63	44.63	42.35
Average WL (in m)	15.70	14.46	13.58	10.24	12.33	11.95	16.27	18.42	25.77	26.34	26.61	24.23
Standard Deviation	6.1	6.4	6.1	5.0	6.0	5.4	6.8	6.4	11.5	11.7	11.4	9.4
Month	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	
Minimum WL (in m)	7.13	9.55	11.53	9.13	2.93	5.82	7.58	8.37	10.72	9.28	12.32	
Maximum WL (in m)	42.35	34.85	40.75	37.6	22.5	23.1	31.05	35.77	44.01	66.53	59.63	
Average WL (in m)	21.69	21.07	22.13	18.42	11.04	12.55	17.60	20.80	24.24	27.34	26.23	
Standard Deviation	9.4	7.2	9.0	8.0	5.2	4.9	7.0	8.4	10.9	15.5	13.5	

Table 8 Analysis of depth to water level of bore well

Sl No	Water level (in m)	Jun-15	Nov-15	May-16	Nov-16	Apr-17	% in June - 15	% in Nov -15	% in May - 16	% in Nov -16	% in April -17
1	0-10	2	4	1	3		18.2	33.3	8.3	30.0	0.0
2	10-20	6	6	2	6	3	54.5	50.0	16.7	60.0	27.3
3	20-30	3	2	7	1	5	27.3	16.7	58.3	10.0	45.5
4	30-40			1		1			8.3		9.1
5	40-50			1		1			8.3		9.1
6	50-60					1					9.1
	Total	11	12	12	10	11					

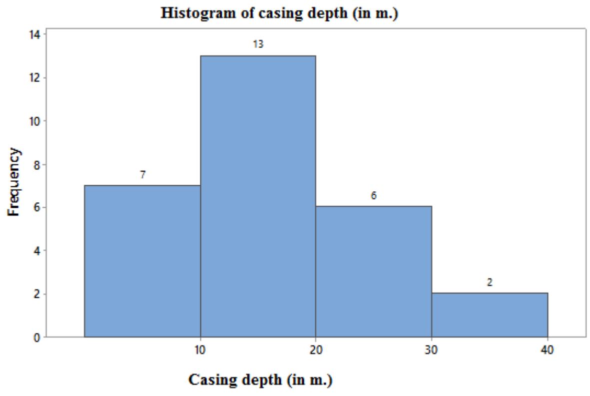


Fig.17a Histogram of casing depth of bore wells

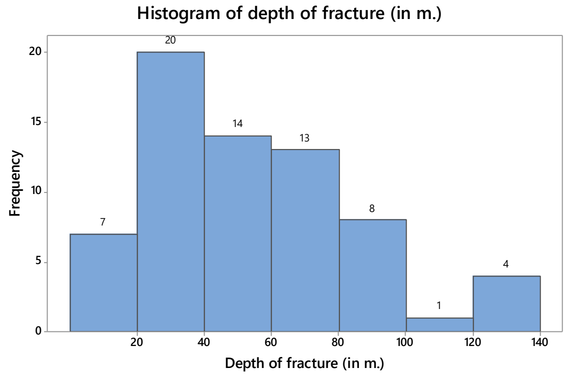


Fig.17b Histogram of depth of fractures of bore wells

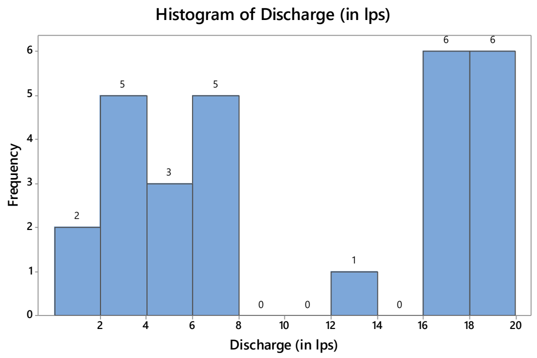


Fig.17c Histogram of discharge of bore wells

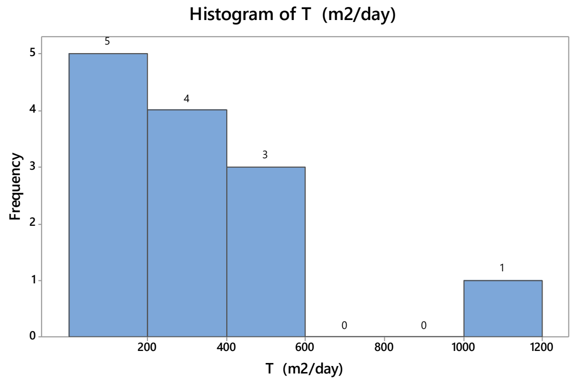


Fig.17d Histogram of Transmissivity T of bore wells

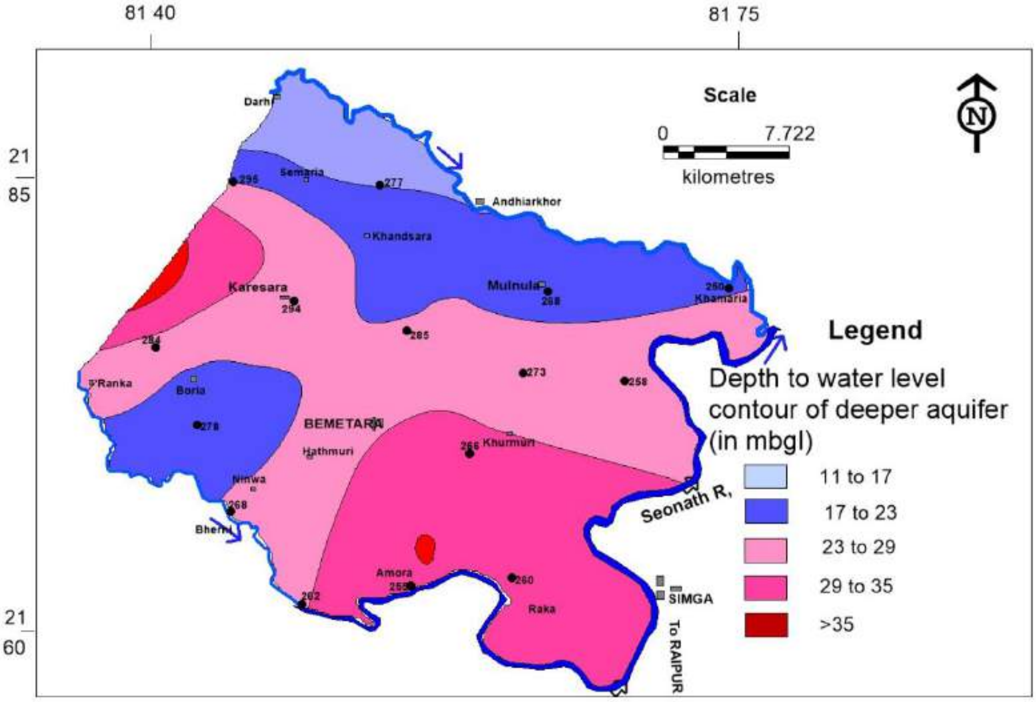


Fig.18 Depth to water level contour of deeper aquifer (Aquifer- II, May -16)

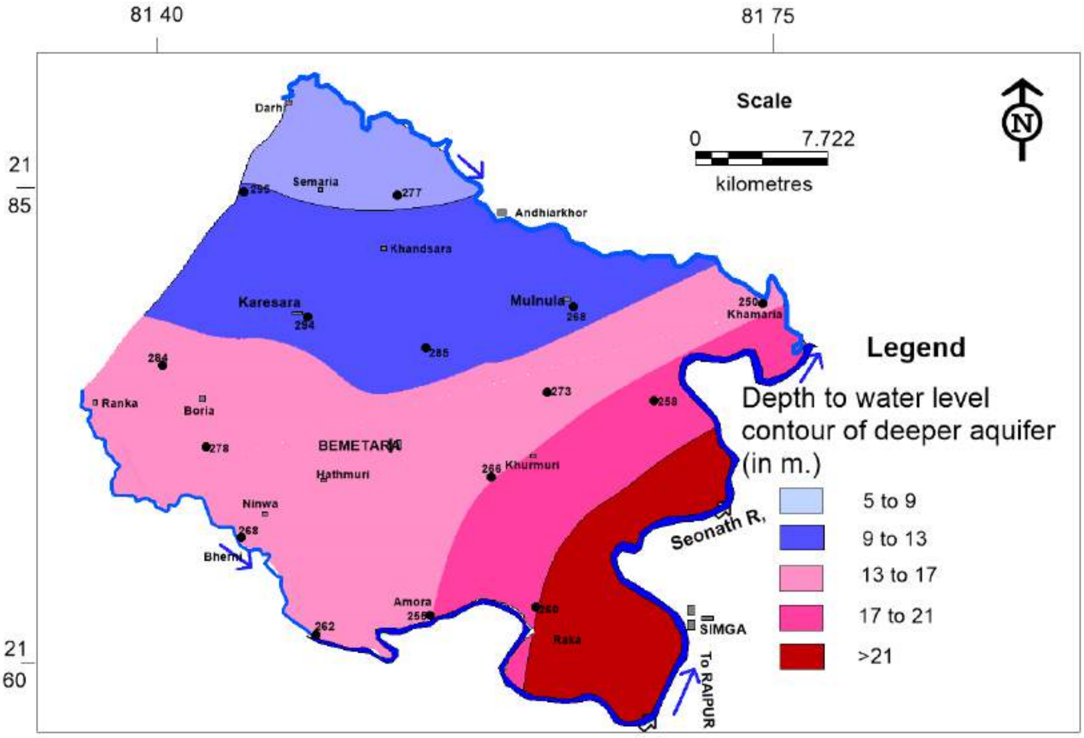


Fig.19 Depth to water level contour of deeper aquifer (Aquifer- II, May -16)

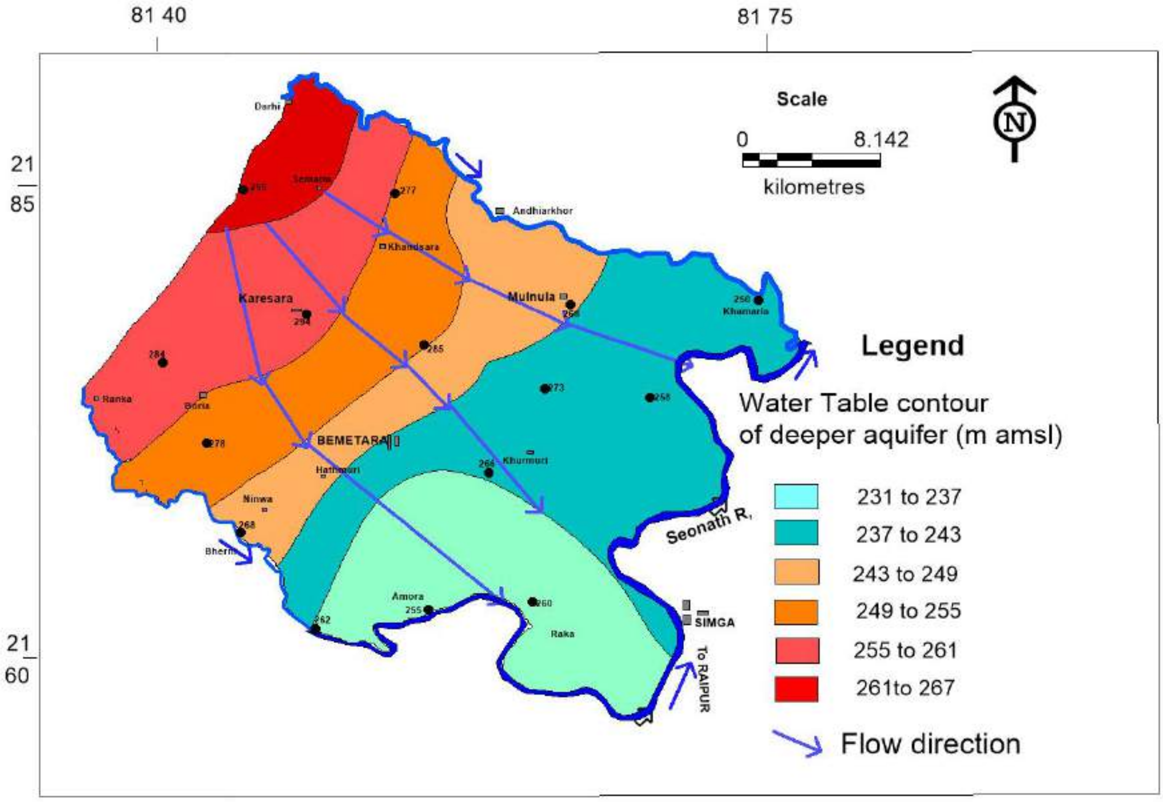


Fig.20 Water Table contour of deeper aquifer (Aquifer- II, May -16)

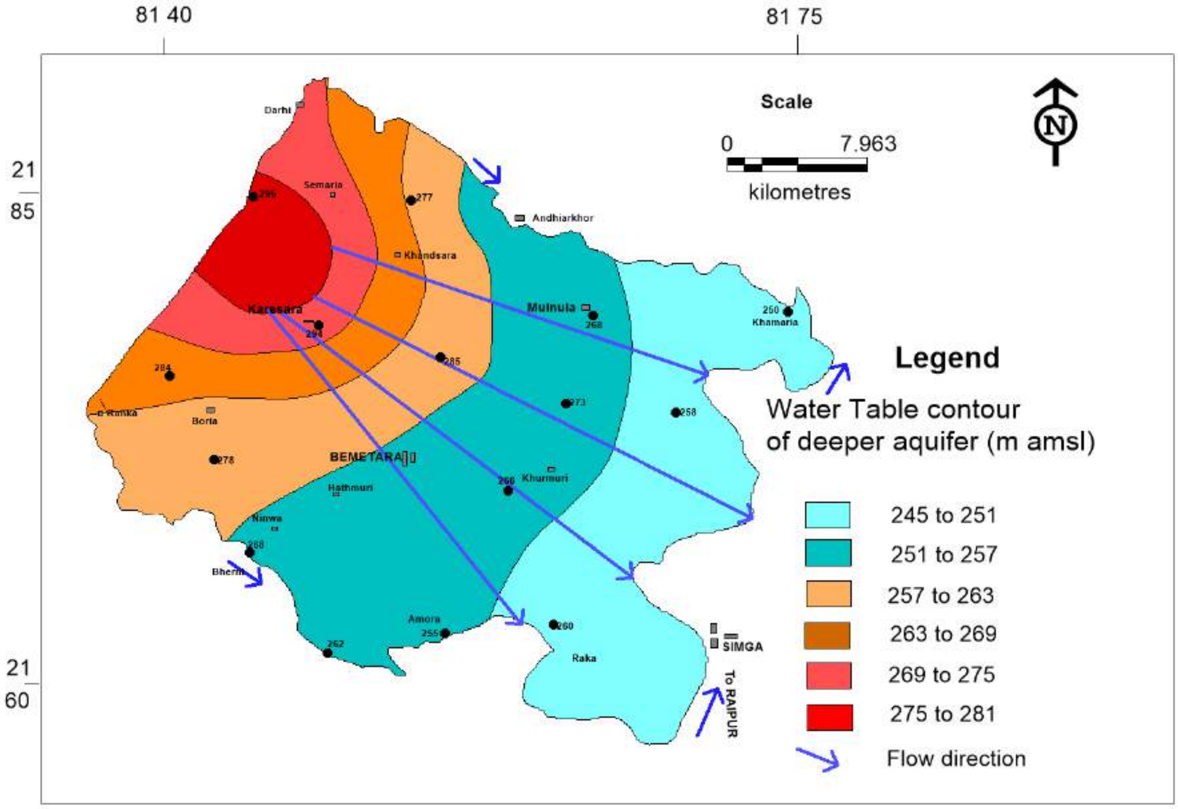


Fig.21 Water Table contour of deeper aquifer (Aquifer- II, Nov -16)

11. Chemical quality

Total 31 samples were collected from deeper aquifer during drilling from bore wells in different times. In situ measurement of electrical conductivity and pH and temperature of both dug well and bore well were also made with the help of potable kit. This is helpful in delineation of different salinity hazard zones. Water samples were collected from wells, which are used regularly for domestic and irrigational purposes covering the whole area. The bottles were cleaned with distilled water, dried and closed prior to their use in the field. Before collecting the representative water samples, each bottle was first rinsed with the water from the respective well and then completely filled with the well water. After filling, the bottles were tightly closed and all particulars were written in the field and tagged to the sample bottles. All the ground water samples were analysed in Central Ground Water Board laboratory at NCCR, Raipur. Chemical analysis of ground water samples of exploratory wells of CGWB is given in Table 9.

11.1 Chemical analysis

Different parameters were analysed by standard methods (APHA.1992). Cations such as sodium and potassium were determined by flame photometer. Calcium and magnesium were determined by ETDA titration methods. Anions like carbonate and bicarbonate were calculated monographically by acidimetric method. Chloride was determined by argentometric titration method and sulphate by turbid metric method using a spectrophotometer having light path 2.5 cm. Fluoride was determined by SPADNS spectrophotometric method. Hardness was analysed by EDTA titrimetric method.

After analysis of the water samples for major ions, validation tests in terms of cation-anion balance was conducted for each sample.

The principle of electro-neutrality requires that the sum of the positive ions (cations) must equal the sum of the negative ions (anions) Thus, the error in a cation-anion balance can be derived from:

Balance error % = $\frac{\sum cations - \sum anions}{\sum cations \ + \sum anions}$ * 100

(Where the ions are expressed in milli equivalents per litre meq/l).

The results obtained were checked for the ionic balance and necessary re – analysis has been done where ever the error exceeded 10%.The result of chemical analysis of water samples of exploratory wells are given in Table- 9.

Table—9 Chemical analysis of ground water samples of exploratory wells of CGWB

Sl No	Location	Source	pH	EC (in µS/cm)	F^-	Cl^-	SO_4^{2-}	HCO_3^-	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+
1	**Amora-1**	EW	7.9	532	0.6	21	76	189	215	40	28	21	1.2
2	**Amora-2**	EW	8	581	0.5	25	58	244	255	56	28	15	0.9
3	**Amora-3**	EW	8	547	0.6	21	56	220	225	44	28	15	0.9
4	**Amora-4**	EW	8.2	613	0.6	25	64	250	275	52	35	17	1
5	**Amora-5**	EW	7.7	1763	1.2	21	1029	183	1155	368	56	94	2.3
6	**Amora-6**	EW	7.6	1958	1.3	43	1163	250	1345	430	65	66	57.5
7	**Dhara**	EW	8	828	0.7	14	262	165	330	40	55	56	1.7
8	**Khurusbod**	EW 2nd Aquifer	7.7	1364	0.9	25	721	128	820	264	38	48	2
9	**Dadhi-1**	EW 1st Aquifer	7.8	1048	0.7	57	271	214	355	64	47	85	14
10	**Dadhi-2**	EW 2nd Aquifer	7.9	990	0.8	46	262	177	330	68	38	87	8.7
11	**Dadhi-3**	OW 2nd Aquifer	7.8	1017	0.8	46	301	195	345	76	37	86	8.3
12	**Birsinghi-1**	EW	8	1241	0.7	21	598	165	610	114	78	73	2.2
13	**Birsinghi-2**	OW	7.8	1385	0.8	21	660	238	680	96	106	79	2.3
14	**Tipni-1**	EW	7.8	599	0.7	18	95	226	225	44	28	34	1.1
15	**Tipni-2**	OW	7.9	598	0.7	25	84	220	220	44	26	33	1.3
16	**Muswadih**	EW	7.9	590	0.5	60	21	244	265	44	37	10	1.1
17	**Jhal-1**	EW	7.8	609	0.9	11	154	159	245	70	17	18	1.4
18	**Jhal-2**	OW	7.7	607	1	14	143	177	255	72	18	16	1.2
19	**Sahaspur-1**	EW	7.9	619	0.8	25	98	207	225	54	22	29	1.6
20	**Sahaspur-2**	OW	7.8	1042	0.9	71	239	214	305	68	32	98	3
21	**Barga-1**	EW	8	488	0.6	7	31	220	220	44	26	9	0.8
22	**Barga-2**	OW	8.2	555	0.6	36	44	244	255	48	32	12	0.9
23	**Tipni-1**	EW	7.7	700	0.8	25	109	238	255	58	26	29	1.1
24	**Tipni-2**	EW	7.8	603	0.7	21	138	214	250	42	35	39	1.3
25	**Tipni-3**	EW	8.2	549	0.7	28	106	159	200	38	25	30	1.2
26	**Tipni-4**	EW	7.7	733	0.7	18	111	268	270	50	35	31	1.2
27	**Beltara-1**	EW	7.8	509	0.5	14	21	262	185	22	31	28	1.5
28	**Beltara-2**	OW	8	495	0.6	11	12	256	165	24	25	28	1.2
29	**Piparia**	EW	7.8	905	0.9	107	66	317	310	36	53	52	17.8
30	**Andhiyarkhor**	EW	8.21	2193	1.3	39	930	110	850	316	14.97	104	0.9
31	**Bemetera**	EW	8.35	631	0.39	35	47	128	190	22	32.85	57	0.4

l

*Parameters in mg/l.

11. 2 Chemical quality of phreatic aquifer (Aquifer-I)

During field work, electrical conductivity of 40 dug wells were analysed. Electrical Conductivity (EC) varies from 220 to 3220 µS/cm. Thirty two % of the samples have EC from 500 to 1000 µS/cm followed by 27% in the range 1000 to 1500 µS/cm. The pH of dug wells varies from 7.09 to 8.15.Frequency plot of electrical conductivity of dug wells is given in Fig. 22 and Pie diagram in Fig. 23. Frequency plot of pH of dug wells is given in Fig. 24.

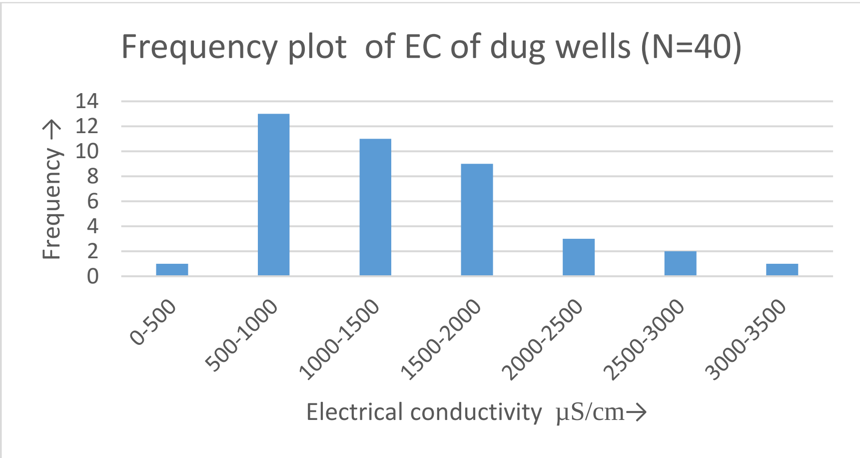


Fig. 22 Frequency plot of electrical conductivity of dug wells

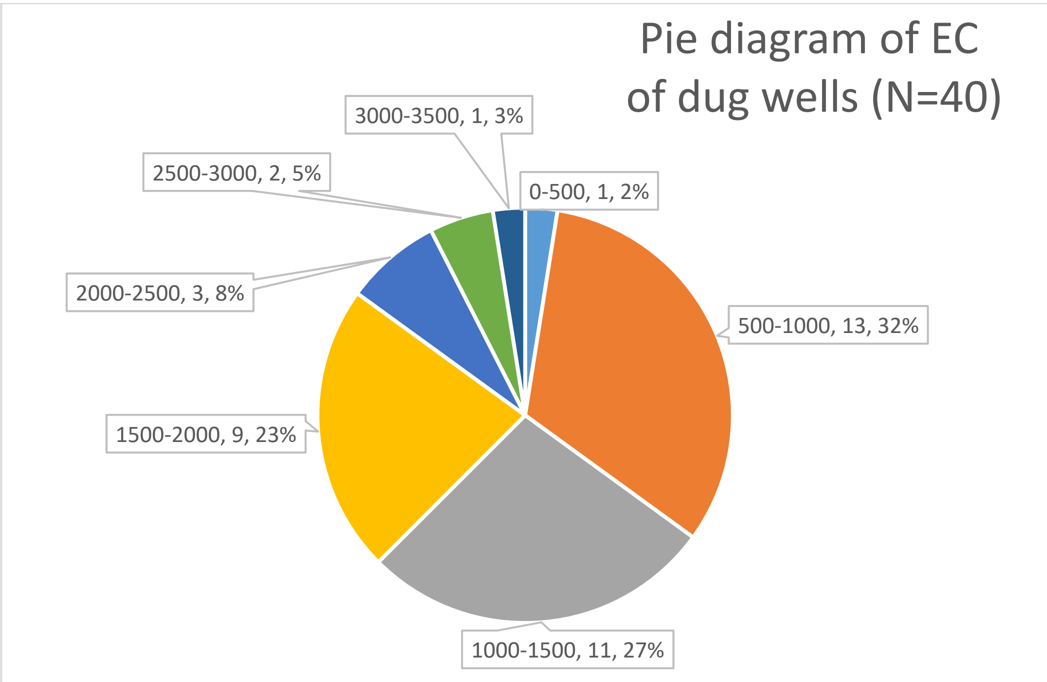


Fig. 23 Pie diagram of EC of dug wells

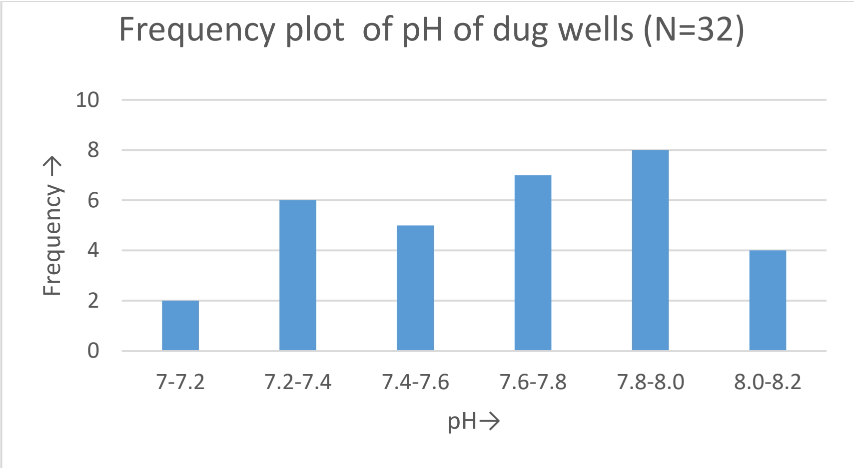


Fig. 24 Frequency plot of pH of dug wells

11.3 Chemical quality of deeper aquifer (Aquifer-II)

Electrical Conductivity (EC) varies from 273 to 3180 µS/cm. Thirty seven % of the samples have EC from 500 to 1000 µS/cm followed by 31% in the range 1500 to 2000 µS/cm. The pH of bore wells varies from 6.79 to 8.06. Aerial distribution of EC of bore wells (Aquifer-II) is given in Fig.25. Frequency plot of electrical conductivity of bore wells is given in Fig.26 and Pie diagram in Fig.27. Frequency plot of pH of bore wells is given in Fig.28.

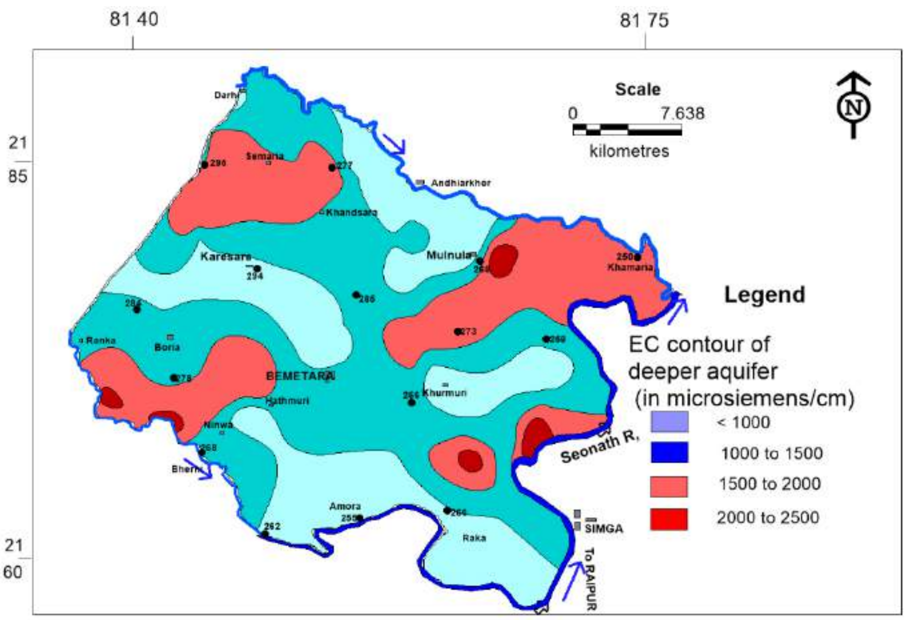


Fig. 25 Aerial distribution of EC of bore wells (Aquifer-II)

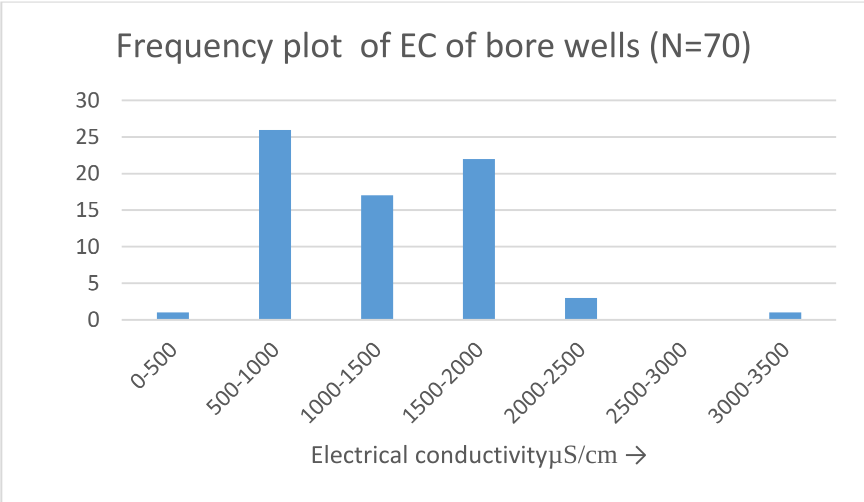


Fig. 26 Frequency plot of electrical conductivity of bore wells

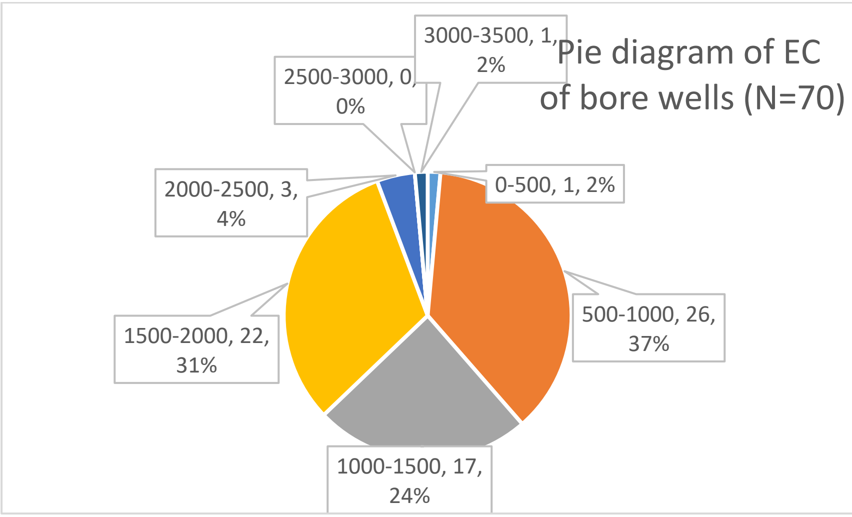


Fig. 27. Pie diagram of EC of bore wells

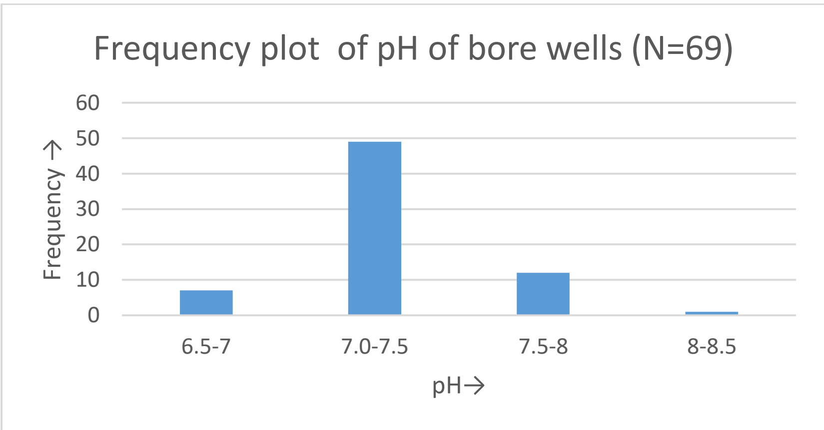


Fig. 28. Frequency plot of pH of bore wells

11.4 Chemical quality of ground water samples collected from exploratory wells of CGWB (Aquifer-II)

Total 31 water samples were collected from 15 exploratory wells and different parameters were analysed. The chemical data are given in Table 9 . The an analysis of data is given below: analysis of data is given below:

Sl No	Parameter	pH	EC (in µS/cm)	* F^-	Cl^-	SO_4^{2-}	HCO_3^-	TH	Ca_2^+	Mg_2^+	Na^+	K^+
1	Minimum	7.6	488	0.39	7	12	110	165	22	14.97	9	0.4
2	Maximum	8.4	2193.0	1.3	107.0	1163.0	317.0	1345.0	430.0	106.0	104.0	57.5
3	Average	7.9	867.5	0.8	30.7	257.1	209.1	381.6	90.6	37.3	45.1	4.6

*All parameters are in mg/l except pH and E.C.

pH of exploratory wells varies from 7.6 to 8.4and EC between 488 to 2193 µS/cm. Sulphate reaches as high as 1163 mg/l. Total hardness of water varies from 165 to 1345 mg/l and magnesium from 14.97 to 106 mg/l. Histogram plots of different parameters are depicted from Fig.29a. to 29f.

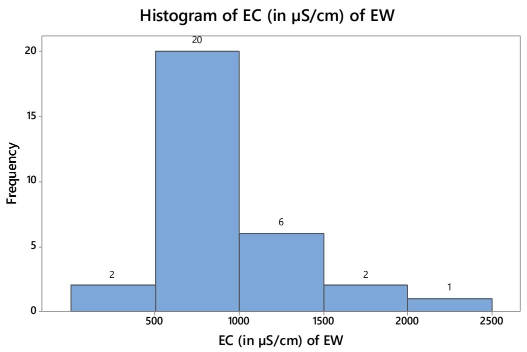


Fig.29a. Histogram of EC of exploratory wells

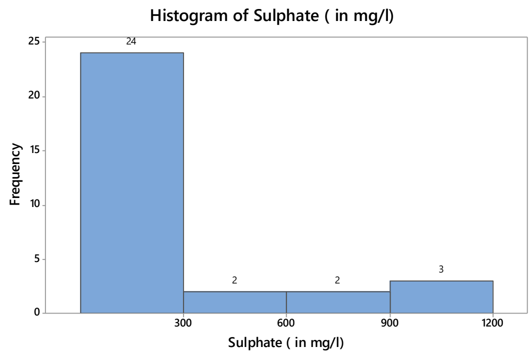


Fig.29b. Histogram of sulphate of exploratory wells

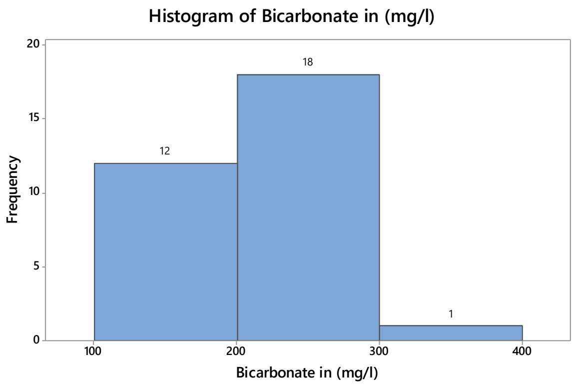


Fig.29c. Histogram of bicarbonate of exploratory wells

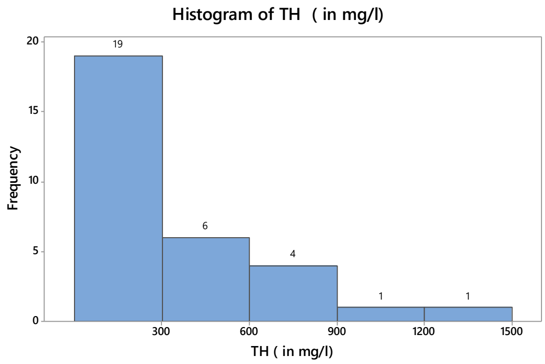


Fig.29d. Histogram of TH of exploratory wells

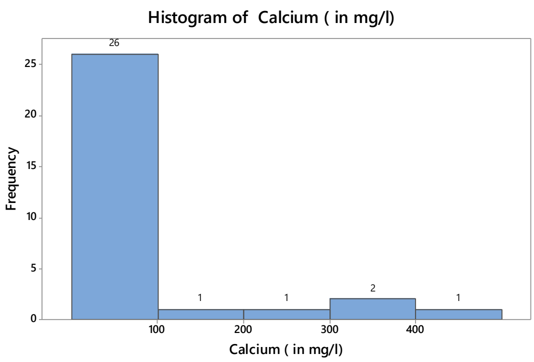


Fig.29e. Histogram of calcium of exploratory wells

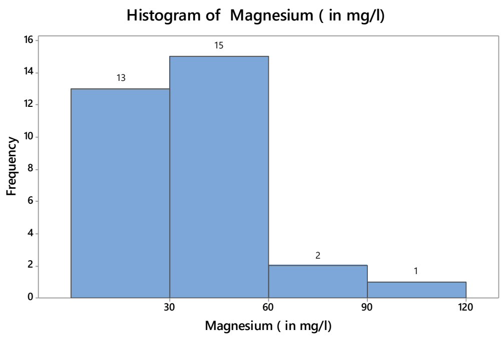


Fig.29f Histogram of magnesium of exploratory wells

11.4.1 Piper Diagram

Piper trilinear diagrams is used for plotting of hydro-chemical data. It is first developed by Hill (1940) and also developed independently by Piper (1944) which shows the relative concentrations of major cations and anions. This diagram consists of two triangles (one for cations and one for anions) and central diamond field. In this method Na and K, CO_3 and HCO_3 and Cl and $NO_3$are combined (Garg, 1978). In both the triangular fields, each vertex represents 100% of reacting values. Here cations, expressed as percentages of total cations in meq/l, plot as a single point on the left triangle, while anions similarly plot on the right angle. These two points are then projected on to the central diamond shaped area. This single point is thus uniquely related to the total ionic distribution and overall /characteristics of the water is represented. Piper diagram is given in below in Fig.30.

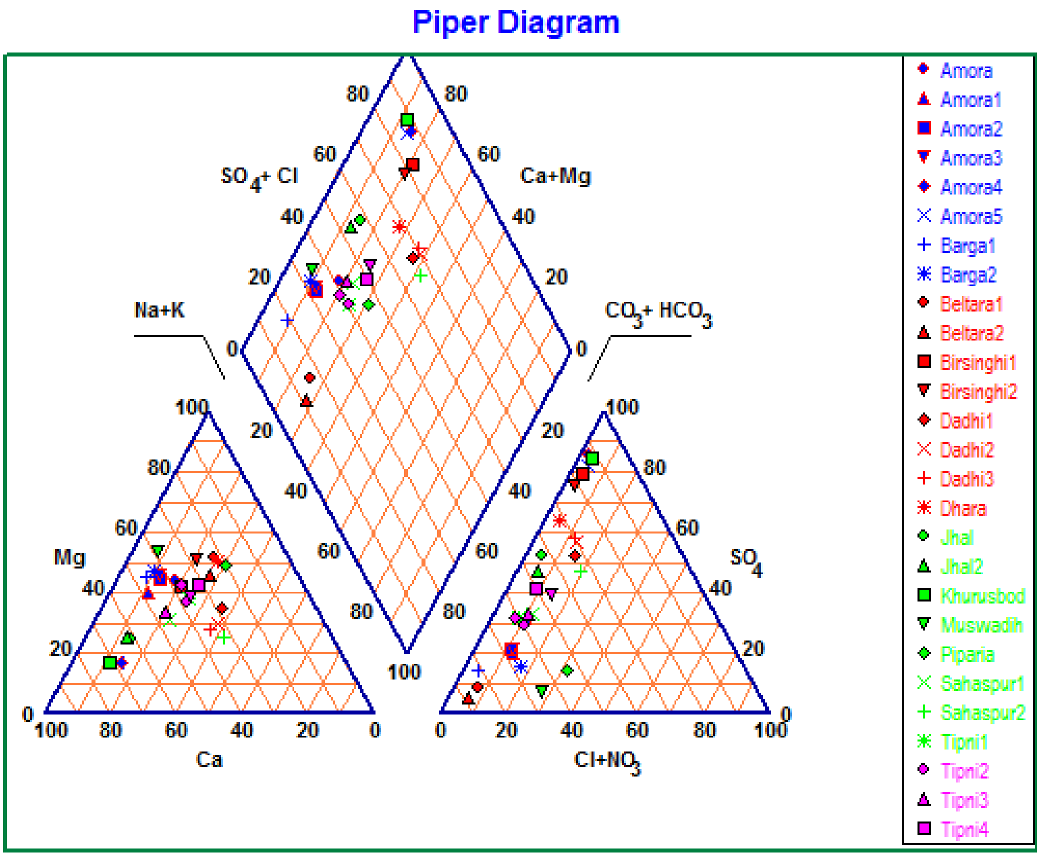


Fig.30 Piper trilinear diagram of exploratory wells

11.4.2 U. S. Salinity Diagram

United States Regional Laboratory in 1954 published a classification diagram for irrigation waters describing 16 classes. In this classification, the total dissolved solids measured in terms of electrical conductivity, and given salinity hazard of irrigation water. Sodium Adsorption Ratio (SAR) has taken as the index for sodium hazard.

$$SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}}$$

(All values are expressed in meq/l).

The US Salinity diagram for both shallow and deep aquifers are given in **Fig. 31.**

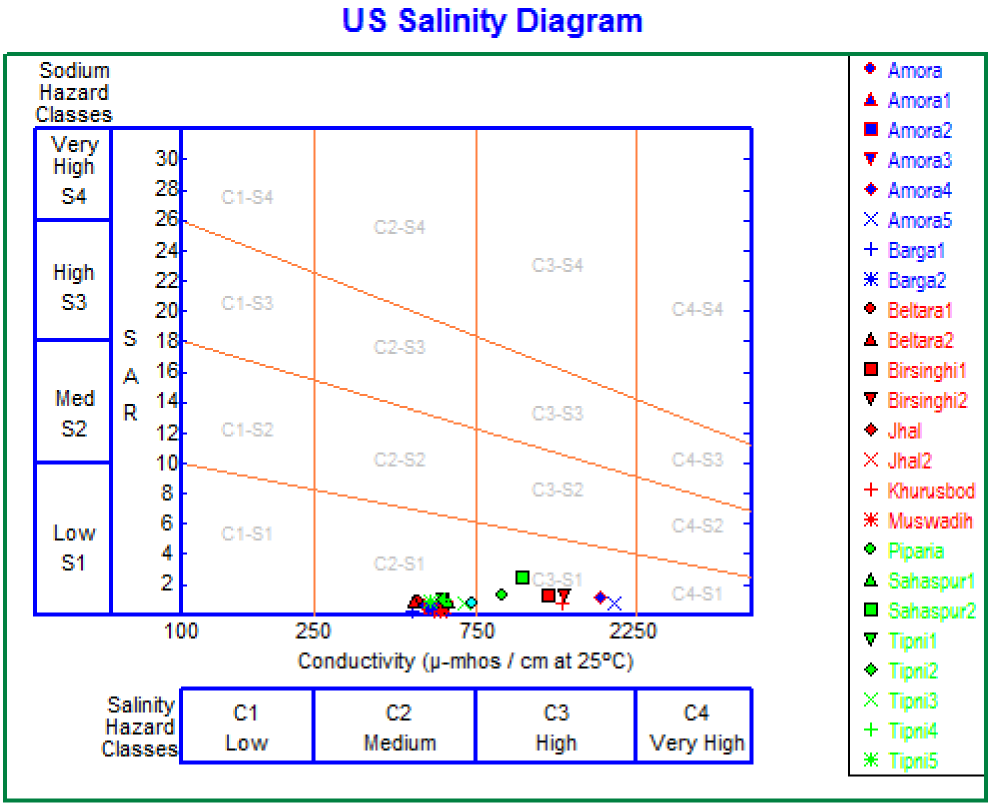


Fig.31 USSL diagram of exploratory wells

11.4.2 Wilcox diagram

Wilcox (1948) defined a sodium-percentage terms of meq/l of the major cations. The relative proportion of Na and K to other cations in water is usually expressed as percentage of sodium among the major cations. The relation can be given as:

$$Na\ \% = \frac{Na+K}{Ca+Mg+Na+K} * 100$$

Wilcox proposed a diagram in which sodium percentage is plotted against electrical conductivity or total concentration for determining the suitability of water for irrigation.

It uses percent-sodium ratio (vertical axis) and conductance (horizontal axis).The Wilcox diagram is given in Fig.32.

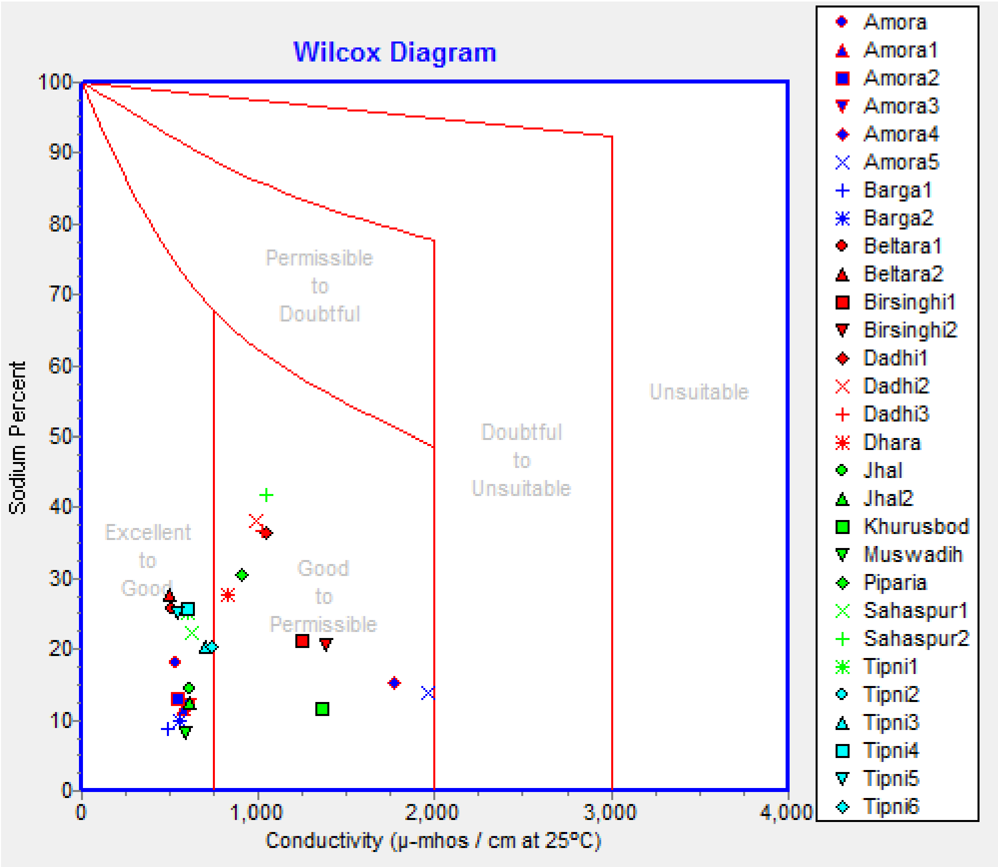


Fig.32 Wilcox diagram of exploratory wells

The quality of water of exploratory wells is interpreted in Table 10 and its analysis is given in Table 11.

From Piper Trilinear diagram it is interpreted that 37.9% of the water samples are Mixed-HCO_3 type and 20.7% are Mg-HCO_3 type. Also 17.2 % of samples Ca-SO_4type,13.8 % of samples are Mixed -SO_4type and rest10.3% of samples are Mg -SO_4 type.

From US Salinity (USSL) diagram it is interpreted that 62.1 % of samples are in C2S1 class and rest 37.9% are in C3S1 class. From Wilcox diagram it is interpreted that 41.4 % of samples are in Excellent to Good category and rest 58.6% are in Good to Permissible category.

Table 10 Interpretation from Piper Trilinear, USSL Salinity and Wilcox diagram

Sl No	Name of EW	Facies (From Piper diagram)	Suitability for irrigation (From USSL)	Suitability for irrigation (From Wilcox)
1	Amora	Mixed-HCO_3	Excellent to Good	C2S1
2	Amora1	Mixed-HCO_3	Excellent to Good	C2S1
3	Amora2	Mixed-HCO_3	Excellent to Good	C2S1
4	Amora3	Mixed-HCO_3	Excellent to Good	C3S1
5	Amora4	Ca-SO_4	Good to permissible	C3S1
6	Amora5	Ca-SO_4	Good to permissible	C2S1
7	Barga	Mg-HCO_3	Excellent to Good	C2S1
8	Barga2	Mg-HCO_3	Excellent to Good	C2S1
9	Beltara1	Mg-HCO_3	Excellent to Good	C2S1
10	Beltara2	Mg-HCO_3	Excellent to Good	C2S1
11	Birsinghi1	Mg-SO_4	Good to permissible	C3S1
12	Birsinghi2	Mg-SO_4	Good to permissible	C3S1
13	Jhal	Ca-SO_4	Excellent to Good	C2S1
14	Jhal2	Ca-SO_4	Excellent to Good	C2S1
15	Khurusbod	Ca-SO_4	Good to permissible	C3S1
16	Piparia	Mg-HCO_3	Good to permissible	C3S1
17	Muswadih	Mg-HCO_3	Excellent to Good	C2S1
18	Dadhi1	Mixed-SO_4	Good to permissible	C3S1
19	Dadhi2	Mixed-SO_4	Good to permissible	C3S1
20	Dadhi3	Mixed-SO_4	Good to permissible	C3S1
21	Dhara	Mg-SO_4	Good to permissible	C3S1
22	Sahaspur1	Mixed-HCO_3	Excellent to Good	C2S1
23	Sahaspur2	Mixed-SO_4	Good to permissible	C3S1
24	Tipni1	Mixed-HCO_3	Good to permissible	C2S1
25	Tipni2	Mixed-HCO_3	Good to permissible	C2S1
26	Tipni3	Mixed-HCO_3	Good to permissible	C2S1
27	Tipni4	Mixed-HCO_3	Good to permissible	C2S1
28	Tipni5	Mixed-HCO_3	Good to permissible	C2S1
29	Tipni6	Mixed-HCO_3	Good to permissible	C2S1

Table 11 Analysis of Piper Trilinear, USSL Salinity and Wilcox diagram

Piper Trilinear diagram			
Sl No	**Facies**	**No. of samples**	**% of samples**
1	Ca-SO4	5	17.2
2	Mg-SO4	1	10.3
3	Mg-HCO3	6	20.7
4	Mixed-HCO3	11	37.9
5	Mixed-SO4	4	13.8
USSL diagram			
Sl No	**Type**	**No. of samples**	**% of samples**
1	C2S1	18	62.1
2	C3S1	11	37.9
WILCOX diagram			
Sl No	**Type**	**No. of samples**	**% of samples**
1	Excellent to Good	12	41.4
2	Good to permissible	17	58.6

11.5 Quality problem in study area

Both phreatic and deeper aquifer of the study area is affected with high electrical conductivity. In phreatic aquifer EC varies from 220 to 3220 µS/cm and in deeper aquifer varies from 273 to 3180 µS/cm. High EC is mainly due to occurrence of SO_4 in ground and the source is gypsum occurring in Maniari Formation. Sulphate varies from 12 to 1163 mg/l.

The occurrence of gypsum in Maniari Formation is not homogenous. The heterogeneity in gypsum occurrence causes ground water at few pockets totally brackish and not suitable for drinking purpose. Govt. of Chhattisgarh has installed RO plant in the villages having quality problems.

11.6 Temperature of Ground water

In situ measurement of temperature of both dug wells and bore wells water were carried out during field study.

11.6.1 Temperature of ground water in phreatic aquifer (Aquifer-I)

Temperature of 40 dug wells water were tested in situ in February-2016.Temperature varies from 20.4 to 29.1^{0}C. About 50 % of the water samples has temperature ranging from 24-26 ^{0}C followed by 22-24 ^{0}C shown in **Fig. 33 & 34..**

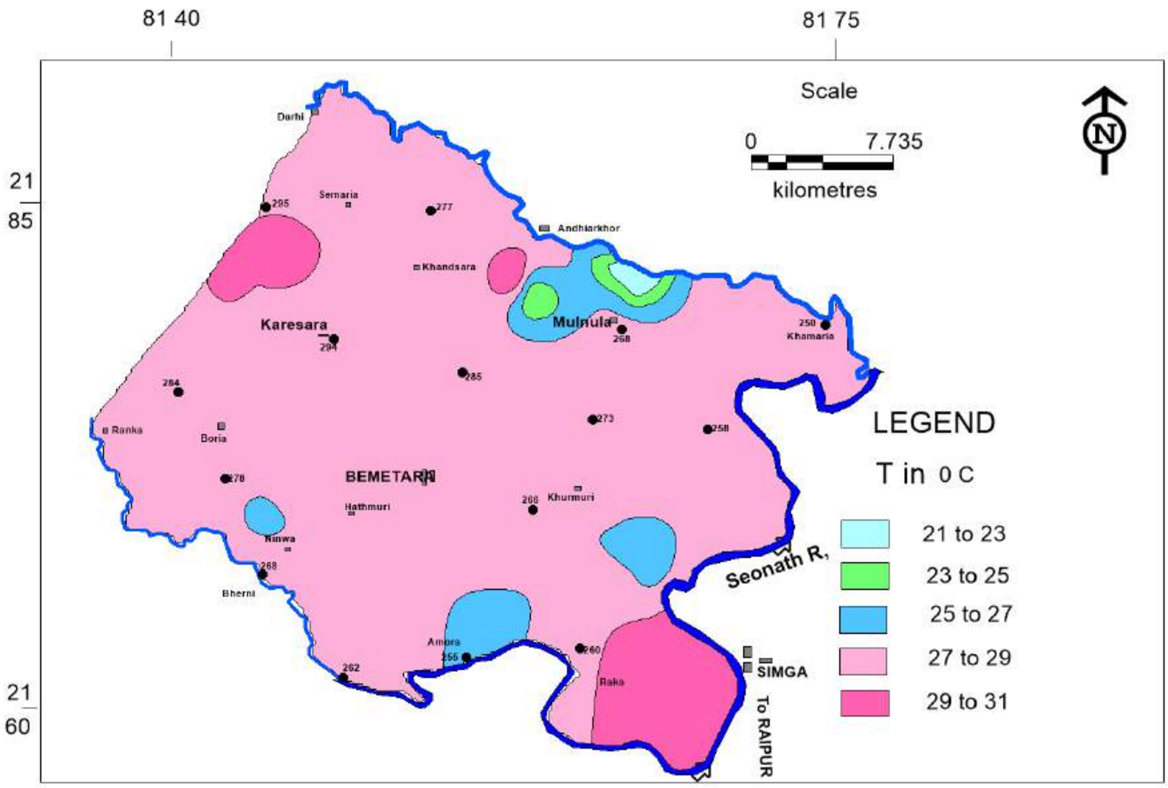


Fig.33 Aerial distribution of Temperature of bore wells (Aquifer-II)

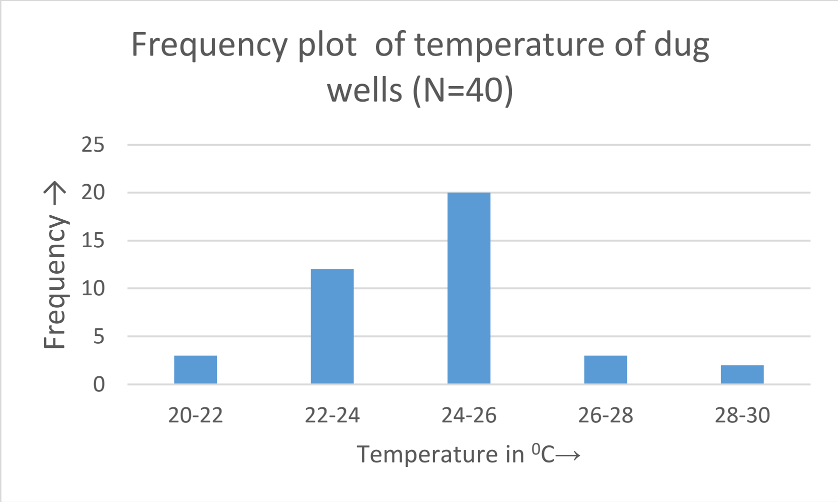


Fig. 34 Frequency plot of temperature of dug wells

11.6.2 Temperature of ground water in deeper aquifer (Aquifer-II)

Temperature of 69bore wells/ hand pump water were tested in situ in February - 2016. The maximum depth of bore wells are up to 100m.Temperature varies from 21.1 to 31.1 ^{0}C. About 50% of the water samples have temperature ranging from 28-30 ^{0}C followed by 26-28^{0}C. Frequency plot of temperature of bore wells is shown in **Fig. 35.**

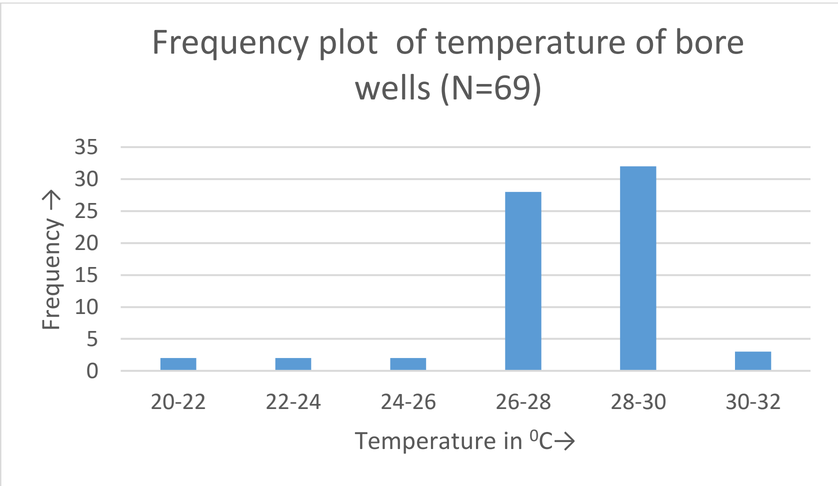


Fig. 35 Frequency plot of temperature bore wells

12. Ground Water Modeling Studies

12.1 Objectives

The Ground Water Modelling studies in the Bemetera area, Chhattisgarh State were carried out with following aims.

I. To depict the existing ground water flow regime.
II. To study the present ground water development scenario including existing extraction pattern for various uses and its effect on ground water regime.
III. To study the future ground water scenario which is possible due to various stresses on the ground water reservoir.

12.2 Hydrogeologic characterization

The study area is a part of Chhattisgarh basin underlain by Chandi limestone, Tarenga shale, Hirri dolomite and Maniari shale. Maniyari shale is gypsiferous and having solution cavities which is high yielding in nature. The aquifer can be divided into two zones shallow and deeper aquifers. Depth of shallow aquifer is upto 20 m and that of deeper aquifer is up to 100m. The youngest member Maniyari Shale is gypsiferous in nature and having solution cavities. It is high yielding in nature and yield varies upto 18 lps.

12.3 Model Conceptualization

The area is underlain by Maniyari Formation, Hirri Dolomite, Tarenga Shale, Chandi Limestone. The area has rivers on three sides and the other side receives ground water inflow. The major recharge is from rainfall and the ground water is extracted by various extraction structures especially for domestic and irrigation purposes. The area receives recharge from rainfall during monsoon season.

12.4 Modelling Software Selection

For simulating ground water flow model, USGS Modular three-dimensional finite difference model MODFLOW is used. The commercial Software Visual Modflow 2011 was utilised for simulating the flow model.

12.5 Model Design

12.5.1Discretisation in space

The area was conceptualised to have two layers one unconfined aquifer and another semi-confined aquifer. The area is discretised into 44 columns and 39 rows making a grid size of 1000m in X- direction and 1000m in Y- direction. To accommodate the flow direction parallel to the cell faces the grid was rotated to 52°. Hence, the major flow will be through the faces of the cells of the Finite difference grid. The finite difference grid is shown as Fig 36. The general information regarding the discretization of the area is presented as Table 12.

Table 12. General Information regarding discretization of Bemetera area

Y DIRECTION	
TOP	2423000
BOTTOM	2384000
DIFERENCE	39000
ROWS	39
CELL HEIGHT	1000m
X DIRECTION	
LEFT	536000
RIGHT	580000
WIDTH	44000
COLUMNS	44
CELL WIDTH	1000m
Z DIRECTION	
NUMBER OF LAYERS	2

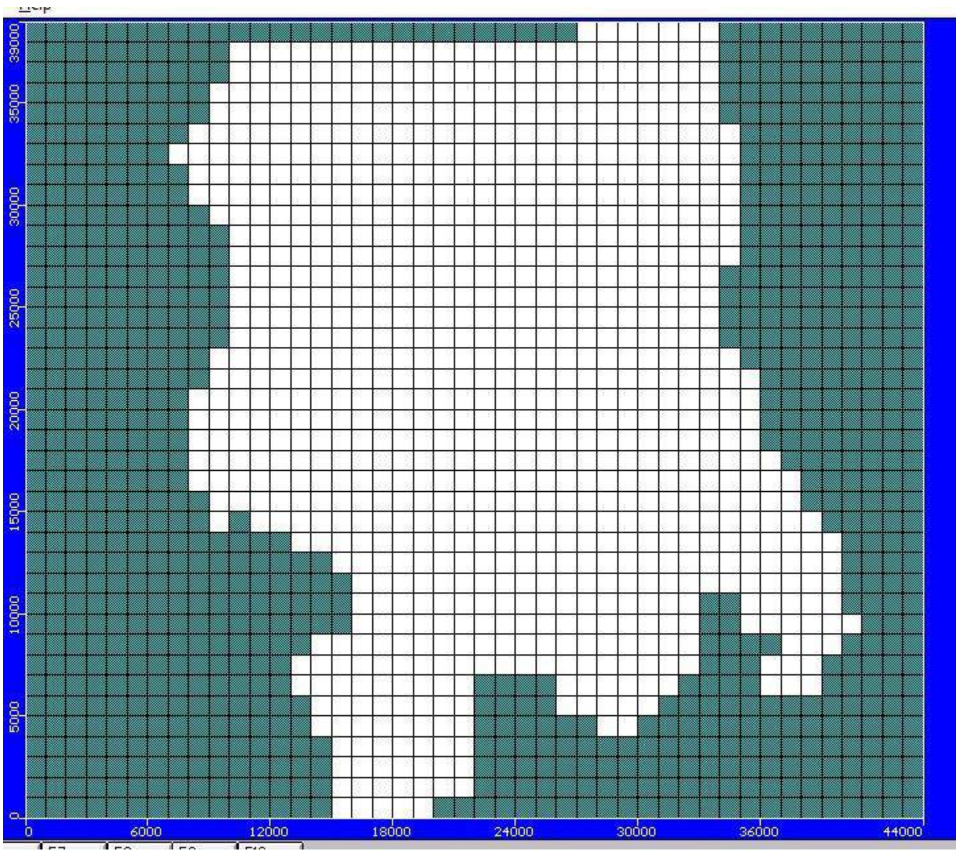


Fig.36 Finite difference grid of the Bemetera Area

12.5.2 Elevations

SRTM data downloaded and used as the ground surface. Whereas bottom of first layer was taken from the ground water exploration data. The bottom of the second layer was taken as 100m below the ground surface. Final Elevations of one column is presented as Fig.37.

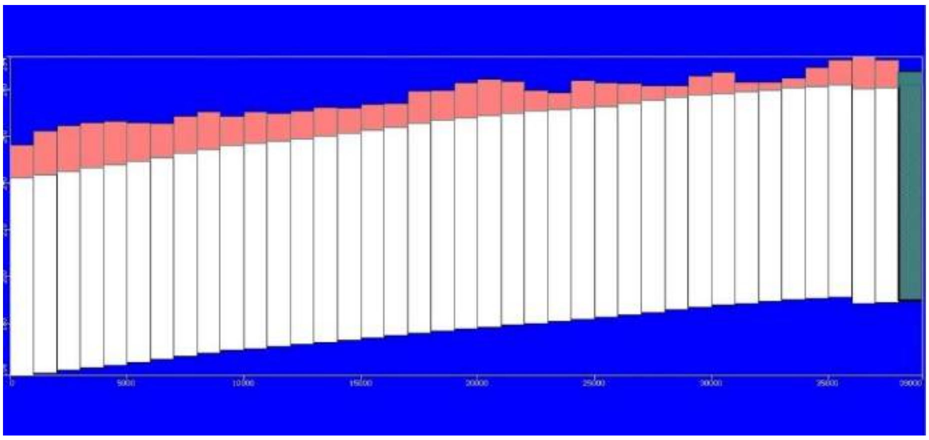


Fig. 37 Elevations of all the layers of Bemetara Area

12.5.3 Boundary conditions

The Area has rivers in three directions which are simulated using Constant Head Boundary and in the fourth side, there is a continuous inflow into the system. Hence this side has the constant flux boundary, which was simulated using Recharge Wells. Constant head boundaries are shown as Fig. 38.

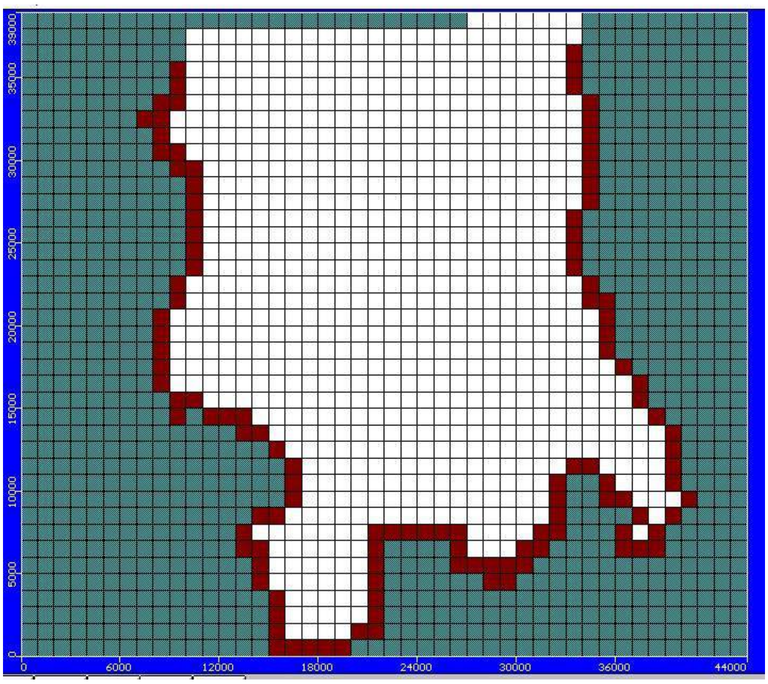


Fig. 38 Constant Head Boundaries simulated in the Bemetara Area

12.5.4 Parameters

The zonation of the conductivity is based on the lithology of the area and is presented as **Fig. 39**. The hydraulic conductivity in all the three directions were shown in the **Fig 40.** The Storage Values of the various zones of the area are presented in **Fig 41.**

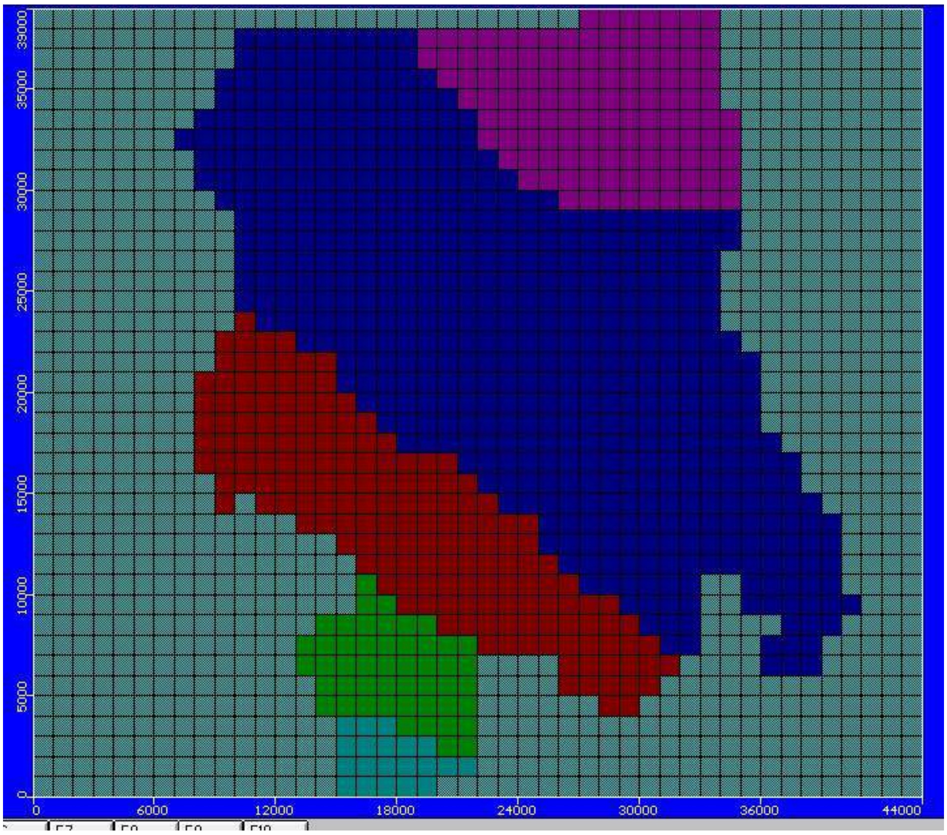
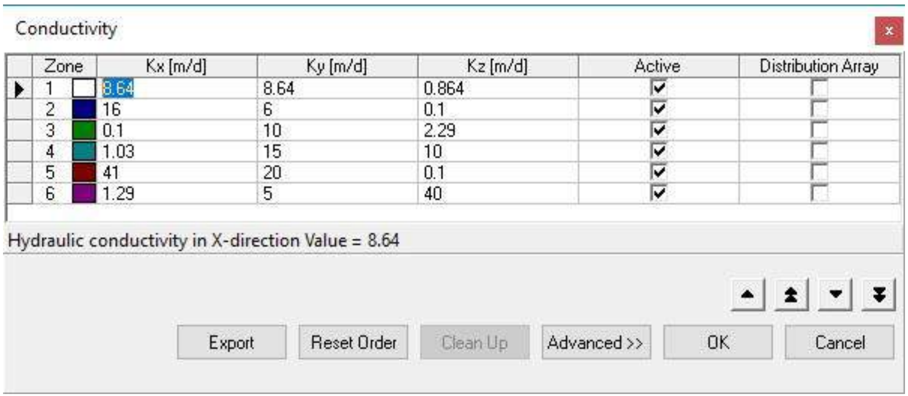


Fig.39. Conductivity zonation of the Bemetara Area



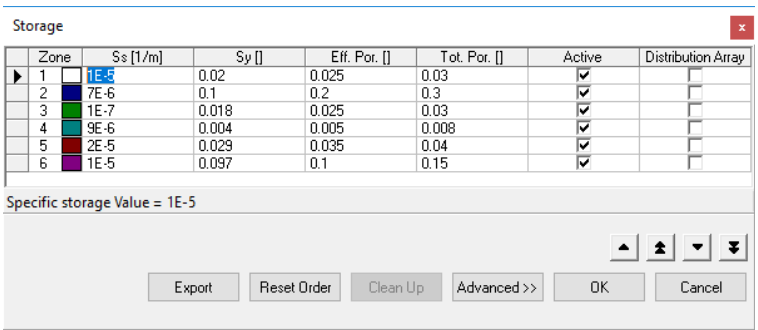
Conductivity

Zone		Kx [m/d]	Ky [m/d]	Kz [m/d]	Active	Distribution Array
1		8.64	8.64	0.864	☑	☐
2		16	6	0.1	☑	☐
3		0.1	10	2.29	☑	☐
4		1.03	15	10	☑	☐
5		41	20	0.1	☑	☐
6		1.29	5	40	☑	☐

Hydraulic conductivity in X-direction Value = 8.64

Export | Reset Order | Clean Up | Advanced >> | OK | Cancel

Fig.40. Conductivity Values of Various Zones in Bemetera Area



Storage

Zone		Ss [1/m]	Sy []	Eff. Por. []	Tot. Por. []	Active	Distribution Array
1		1E-5	0.02	0.025	0.03	☑	☐
2		7E-6	0.1	0.2	0.3	☑	☐
3		1E-7	0.018	0.025	0.03	☑	☐
4		9E-6	0.004	0.005	0.008	☑	☐
5		2E-5	0.029	0.035	0.04	☑	☐
6		1E-5	0.097	0.1	0.15	☑	☐

Specific storage Value = 1E-5

Export | Reset Order | Clean Up | Advanced >> | OK | Cancel

Fig.41. Storage Values of Various Zones in Bemetera Area

12.5.5 Sources and sinks

The major source of ground water in the area is recharge due to rainfall. This is computed from the rainfall amount in the season and multiplying with the infiltration factor. The various recharge zones are presented as **Fig.42.**

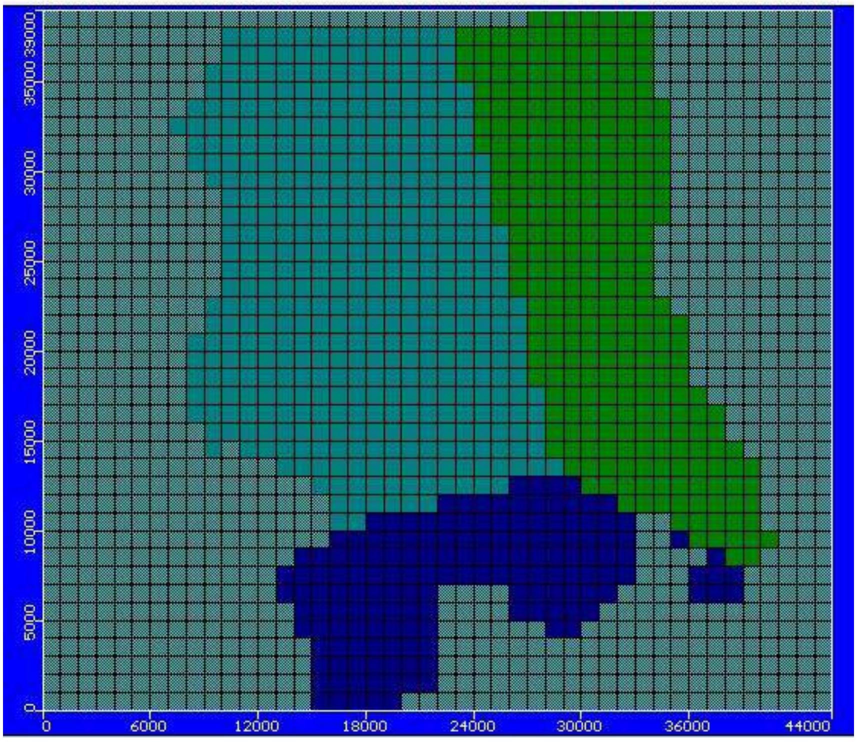


Fig.42. Recharge from Rainfall in Various Zones in Bemetera Area

The only Sink in the modelled area is ground water extraction by way of pumping of borewells. The total extraction was estimated from the village wise well census and using the unit draft figures. The domestic extraction was estimated village wise population and percapita requirement. The total extraction thus calculated for each village is apportioned to each cell and simulated using Pumping Wells. The simulated Wells in the Bemetara Area are presented as **Fig.43**.

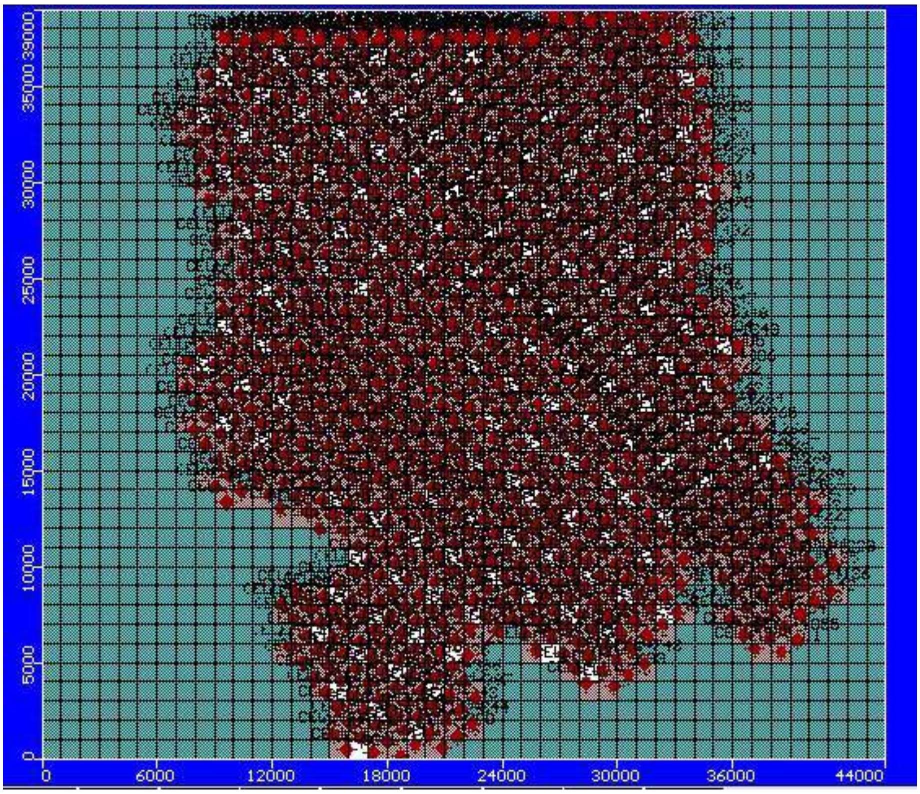


Fig.44. Simulated Pumping Wells in Bemetera Area

12.6 Model simulation in steady state

The model was simulated in steady state condition and observed the ground water flow pattern and adjusted the hydraulic conductivity to match the ground water flow as observed in the field.

12.7 Model simulation in transient state

After running the model in steady state, the model was run in transient state. The prerequisite data requirement for running the model in transient state initial heads and stress periods.

12.7.1 Initial heads

The initial heads were given as the interpolated data using the water table measured from the field observation wells during May 2015. The initial heads computed from the Observed Field data during May 2015 are presented as **Fig. 45 and Fig. 46.**

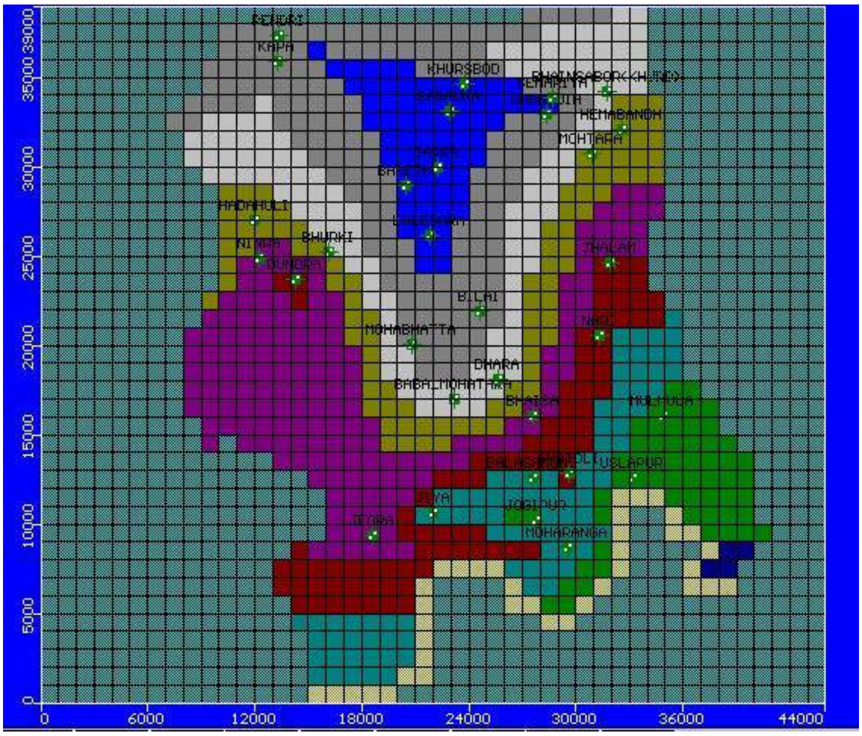


Fig.45. Initial Heads of the First Layer as Simulated from the Observed field data

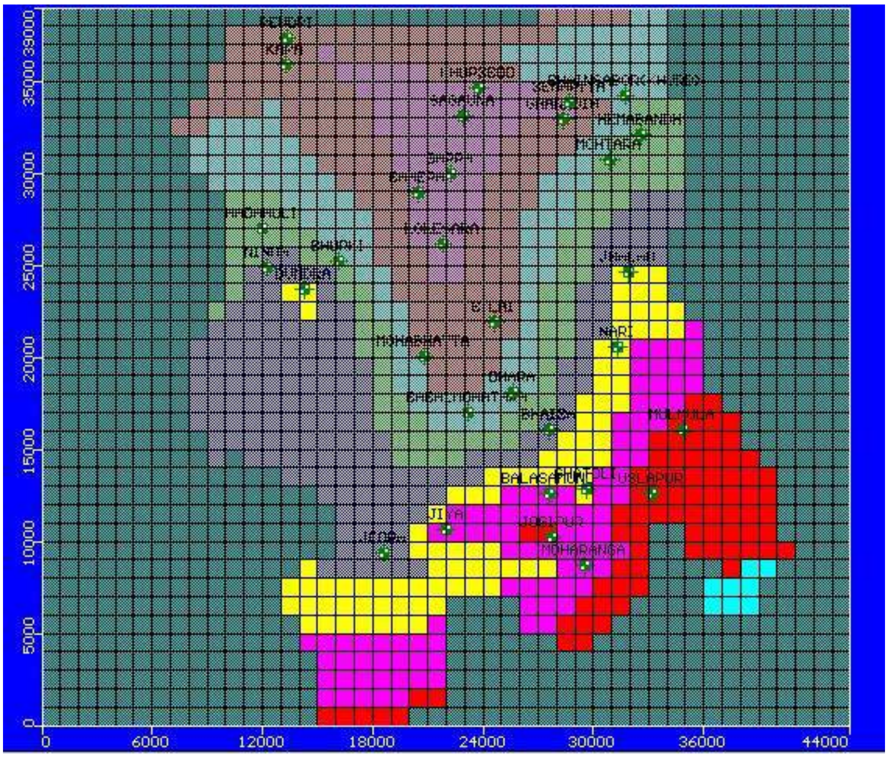


Fig. 46. Initial Heads of the Second Layer as Simulated from the Observed field data.

12.7.2 Stress periods

The year is divided into two stress periods viz monsoon season and non-monsoon seasons. The monsoon stress period is divided into four-time steps and the non-monsoon stress period is divided into eight-time steps.

12.7.3 Simulation

After providing the required data, the model was simulated in Transient State and the heads were compared with the observed ground water heads. For the Purpose of Calibration the field data from the Observation Wells were used which are shown in **Fig, 47.**

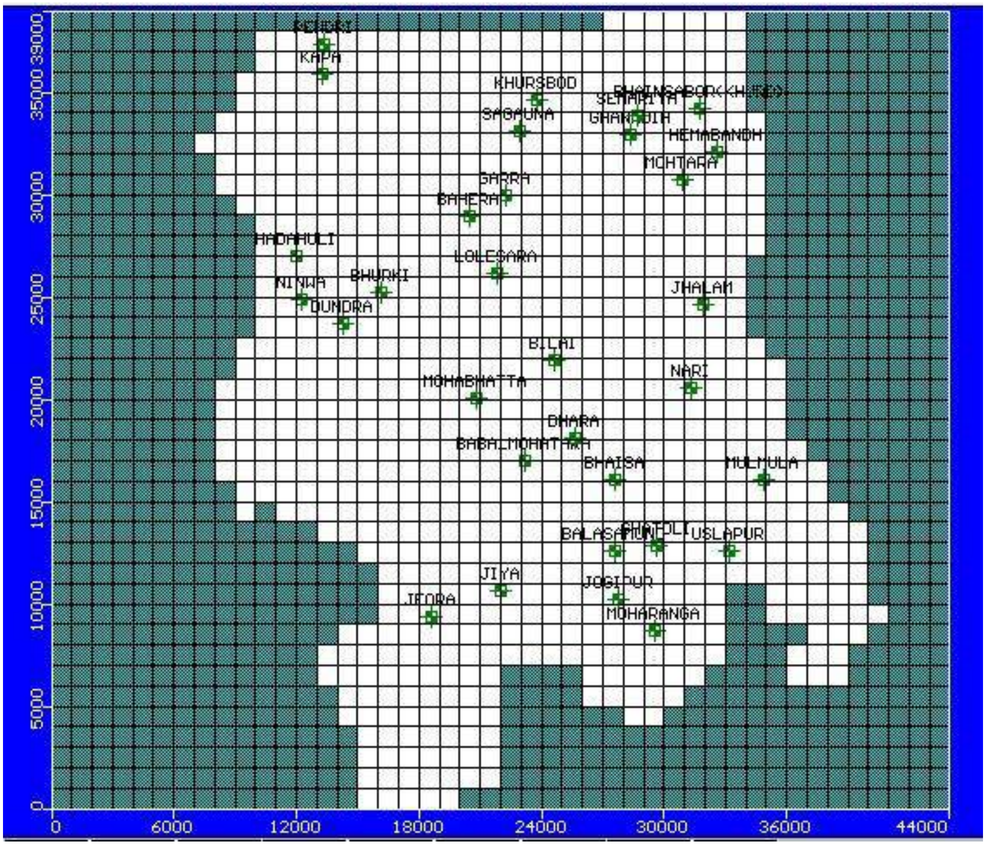


Fig.47 Location of Observation Wells used for the Calibration

12.8 Calibration

The target of the Calibration is to achieve the ground water heads as observed in the ground water observation wells monitored monthly for two years. The Lime stone terrain has made the calibration very difficult as it has the possibility of variable specific yield enhanced by karstification. With the limited data on the karstification, it could be achieved only with the RMS error of 3.44 m. The Calibration Plot of Observed head versus Computed head is presented as **Fig.48**. The hydrographs with Observed and Computed ground water heads of a few observation wells are shown as **Fig. 49a to Fig.49l.**

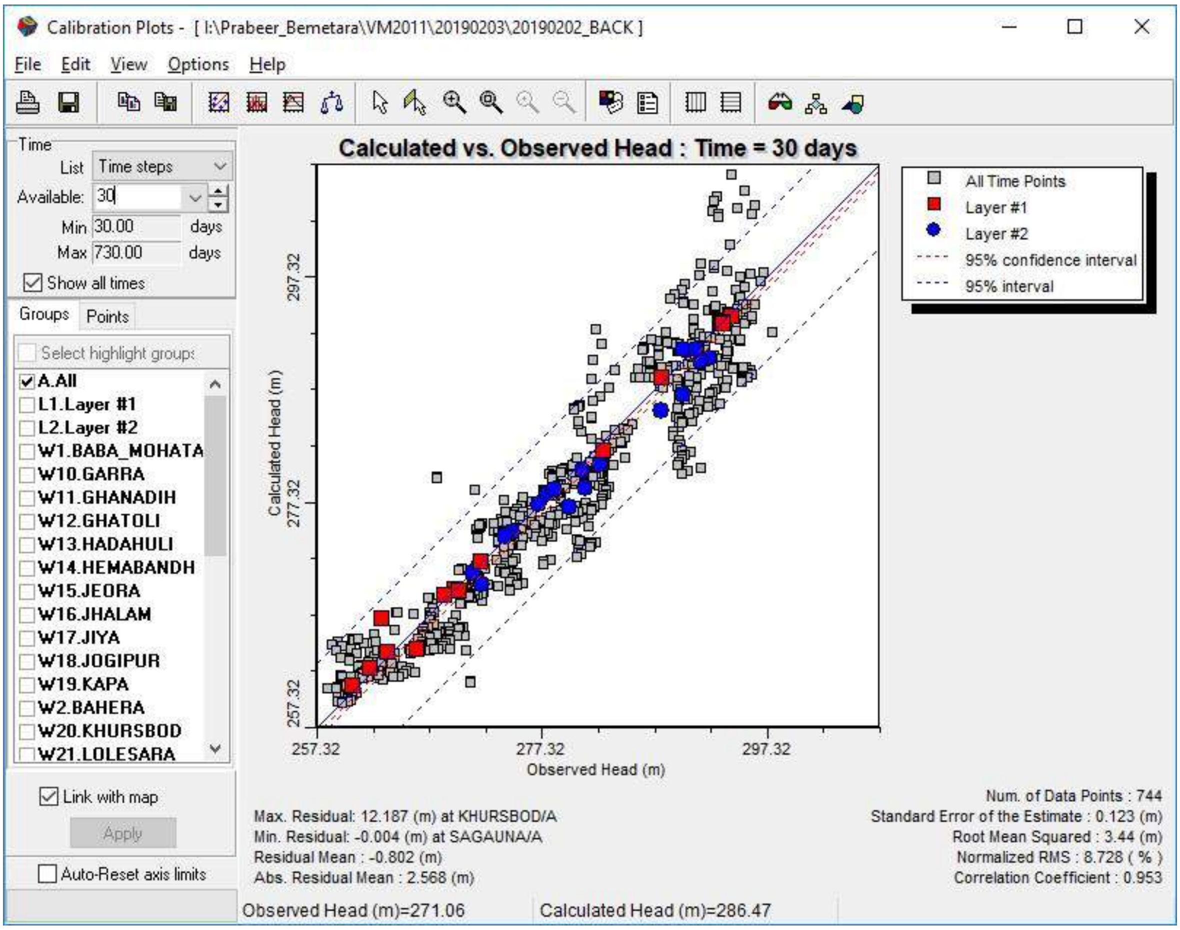


Fig.48. Calibration Plot of Observed head versus Computed head

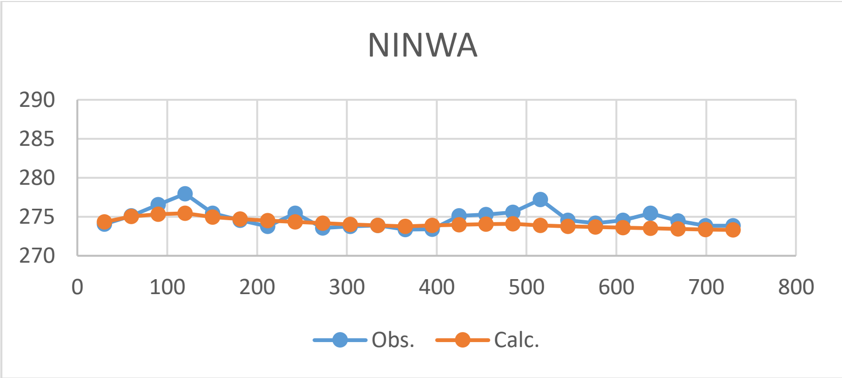


Fig.49a. Hydrograph of Ninwa with Observed head and Calculated head

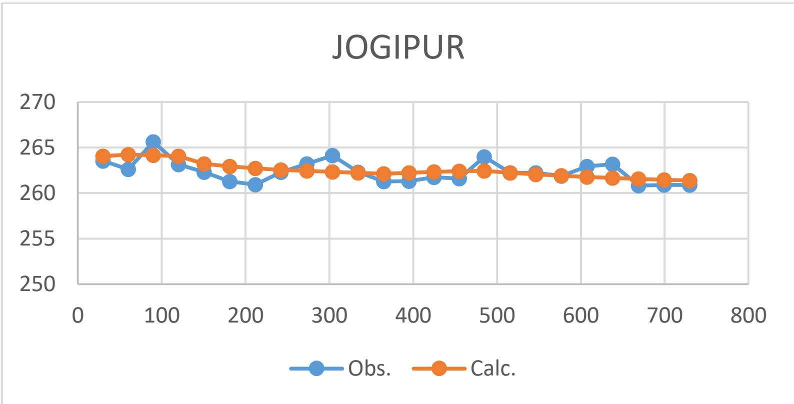


Fig.49b. Hydrograph of Jogipur with Observed head and Calculated head

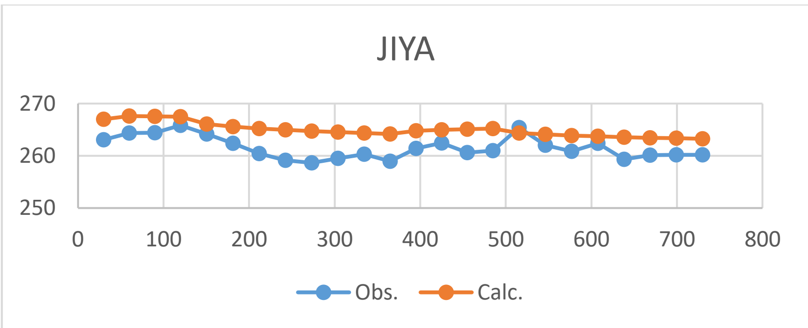


Fig.49c. Hydrograph of Jiya with Observed head and Calculated head

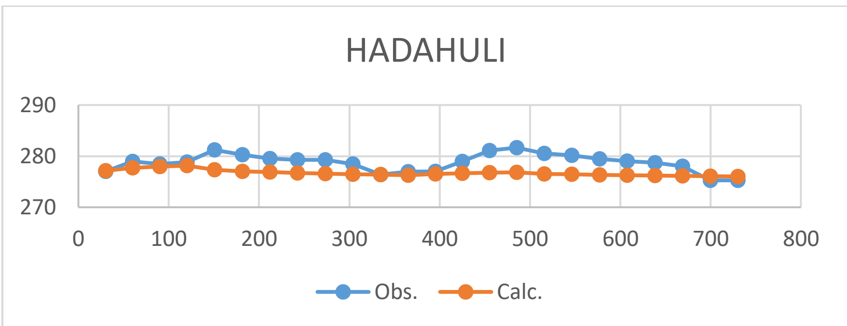


Fig.49d. Hydrograph of Hadahuli with Observed head and Calculated head

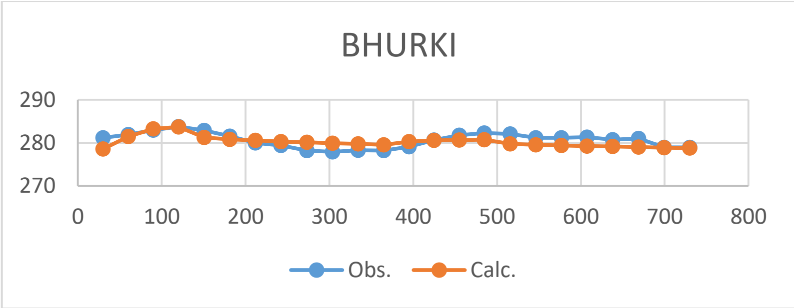


Fig.49e. Hydrograph of Bhurki with Observed head and Calculated head

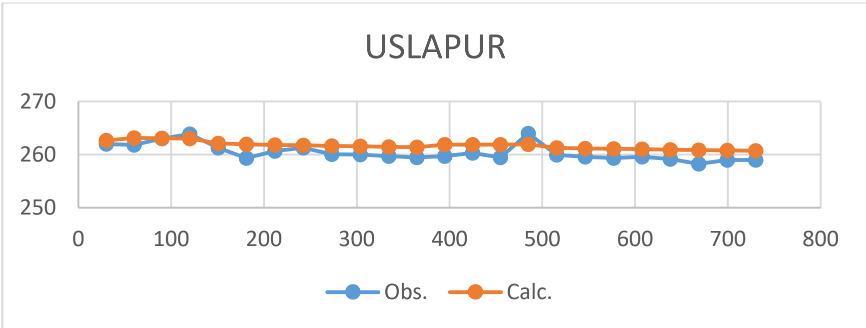


Fig.49f. Hydrograph of Uslapur with Observed head and Calculated head

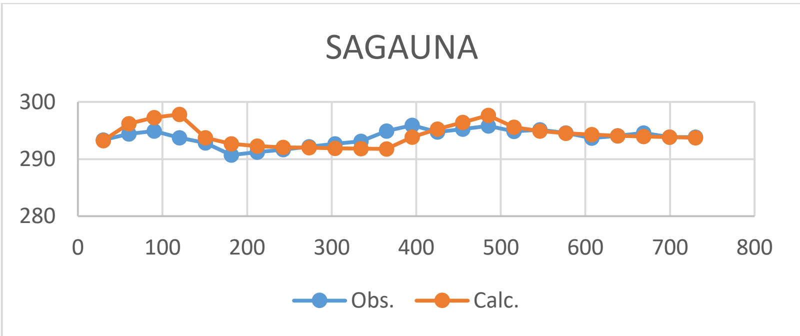


Fig. 49g. Hydrograph of Sagauna with Observed head and Calculated head

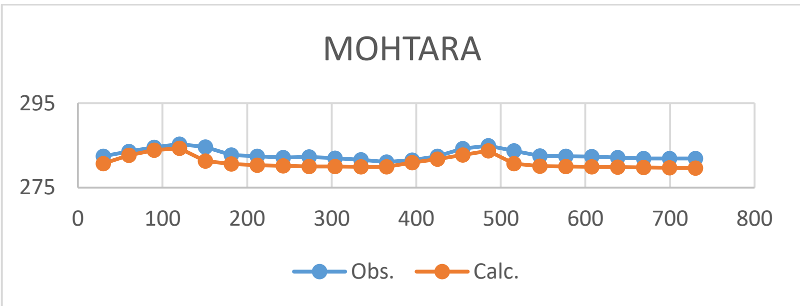


Fig.49h Hydrograph of Mohtara with Observed head and Calculated head

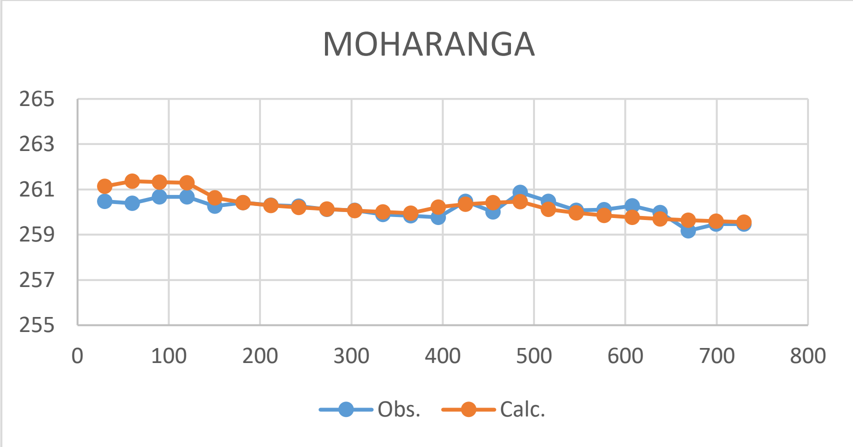


Fig.49i. Hydrograph of Moharanga with Observed head and Calculated head

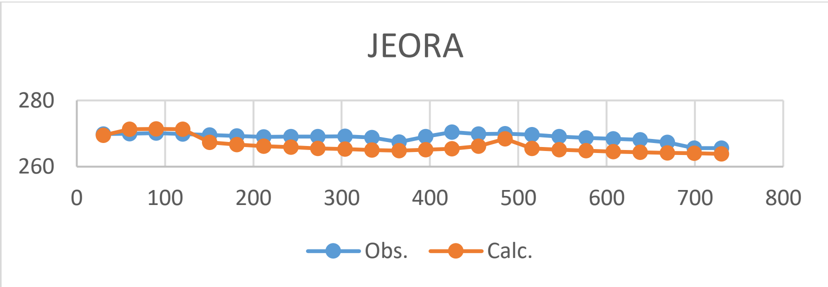


Fig 49j. Hydrograph of Jeora with Observed head and Calculated head

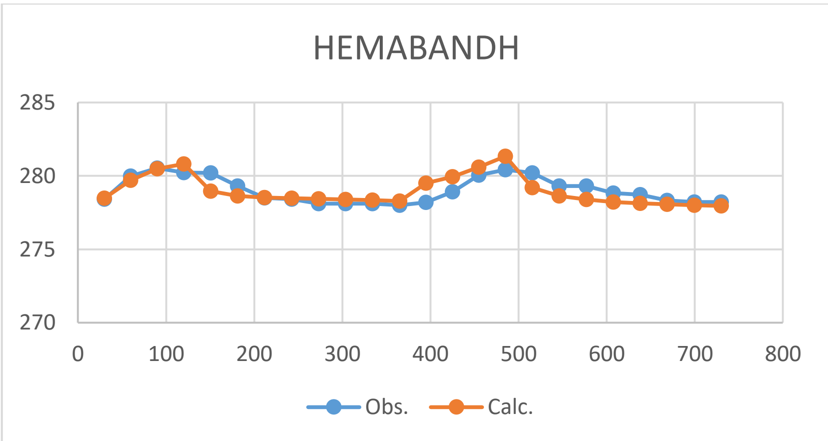


Fig 49k. Hydrograph of Hemabandh with Observed head and Calculated head

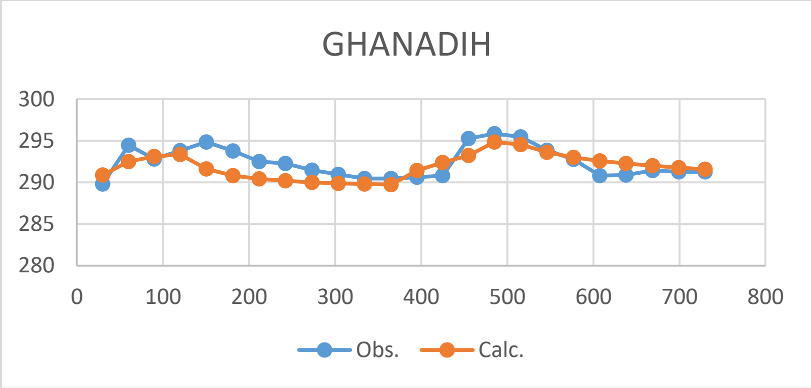


Fig.49l. Hydrograph of Ganadih with Observed head and Calculated head

Contours were developed from the Simulated and observed heads and displayed in the same map for the purpose of comparison. The computed and observed heads during Post monsoon, 2015 were presented as **Fig.50.** The heads during Pre-monsoon 2016 were presented as **Fig.51.** Post monsoon heads during the year 2016 were presented as **Fig.52** and the heads during Pre- monsoon 2017 were presented as **Fig.53**.

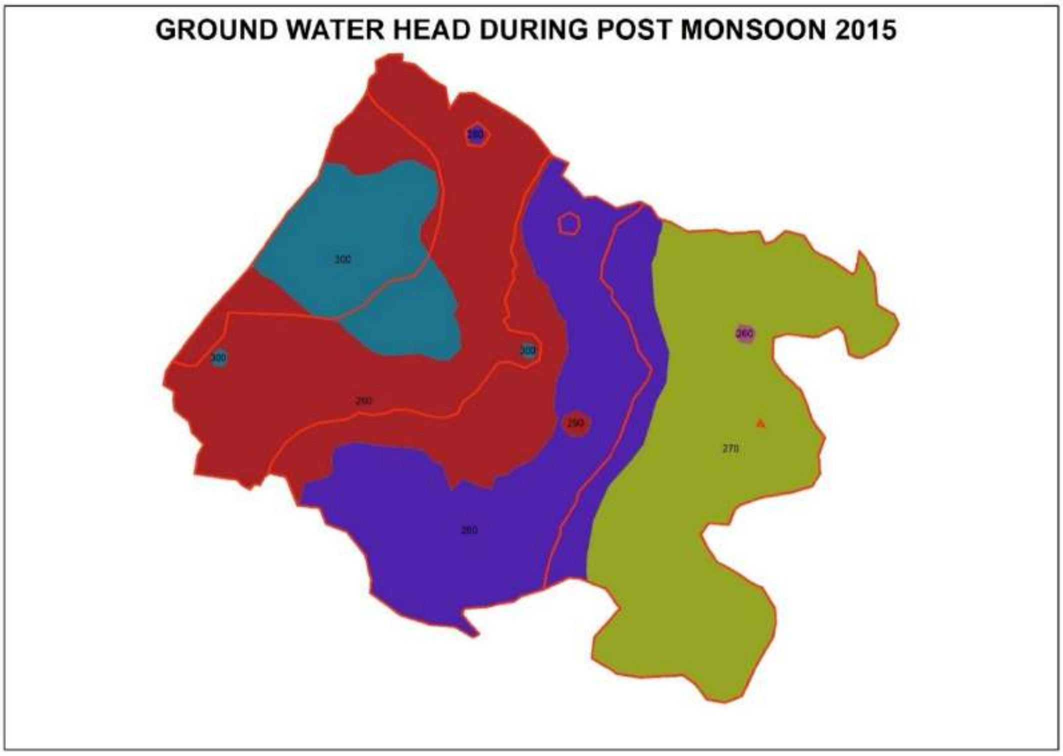


Fig.50. Ground Water Heads during Post - Monsoon 2015.

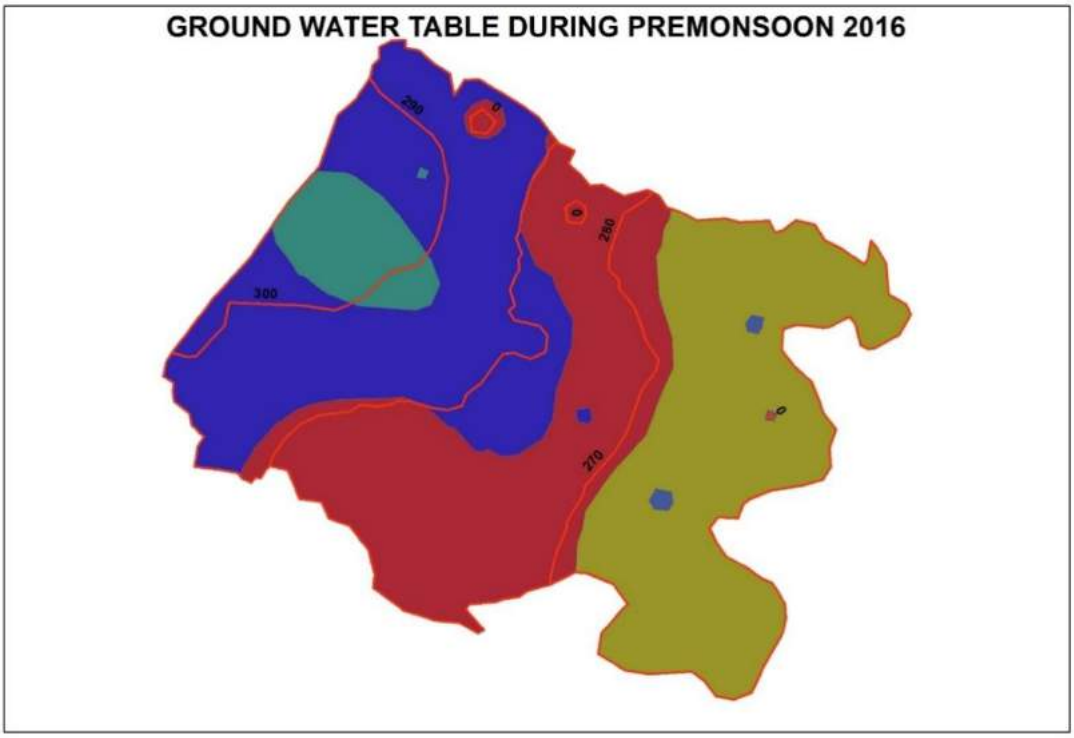


Fig.51. Ground Water Heads during Pre-Monsoon 2016.

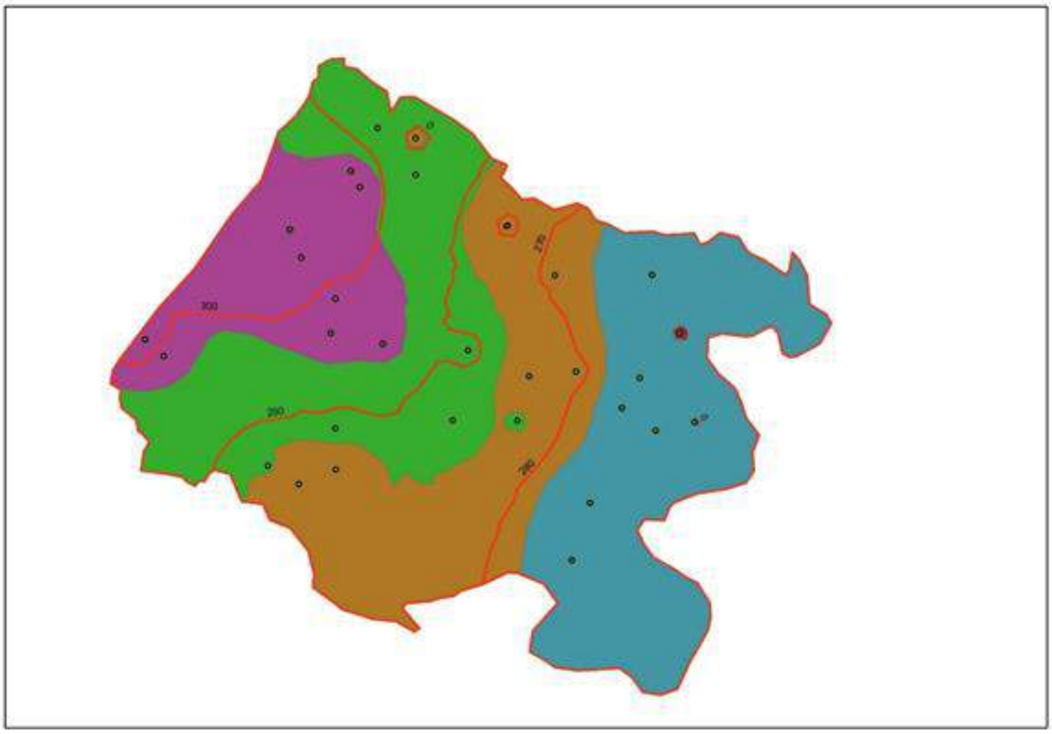


Fig.52. Ground Water Heads during Post- Monsoon 2016

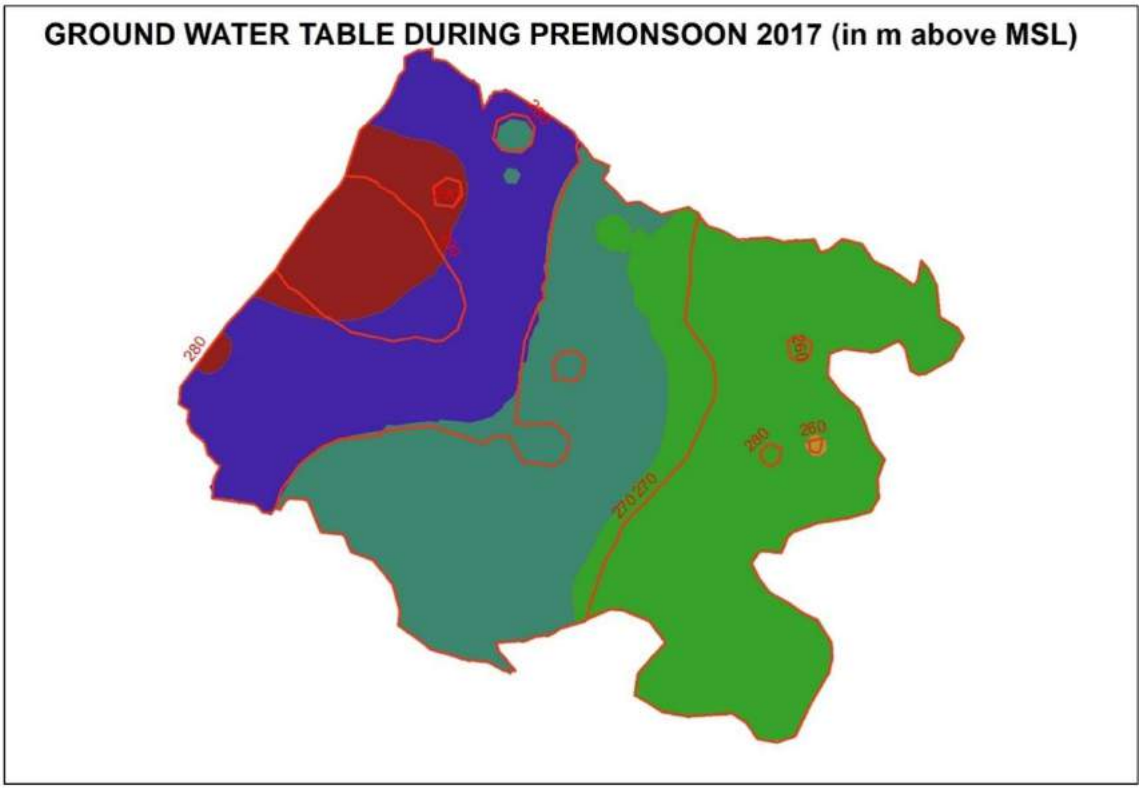


Fig.53. Ground Water Heads during Pre- Monsoon 2017

12.9 Ground water draft in the study area

Mathematical modelling study reveals that monsoon and non-monsoon ground water draft in the study area is 59101.5 m^3/day and 97933.5 m^3/day respectively.

12.10 Ground water recharge in the study area

Recharge calculation in Simga, Andhiarkhor and Bemetera area is given below in Table-13:

Table-13 Recharge calculation in Simga, Andhiarkhor and Bemetera area

Simga		
I	Monsoon 2015 in Simga	(149/365) * 120 = 48.9863 mm
II	Non-monsoon 2015 in Simga	(21/365) * 245 = 14.095 mm
III	Monsoon 2016 in Simga	(141/365) * 120 = 46.35616 mm
IV	Non-monsoon 2016 in Simga	(10/365) * 245 = 6.712329 mm

V	Average monsoon recharge	(48.9863 + 46.35616) /2 = 47.67123 mm
VI	Average non-monsoon recharge	(14.09598 + 6.71232) /2 = 10.40411 mm
Andhiarkhor		
I	Monsoon 2015 in Andhiarkhor	(135/365) * 120 = 44.38456 mm
II	Non-monsoon 2015 in Andhiarkhor	(50/365) * 245 = 33.5616 mm
III	Monsoon 2016 in Andhiarkhor	(125/365) * 120 = 41.0959 mm
IV	Non-monsoon 2016 in Andhiarkhor	(27/365) * 245 = 18.123 mm
V	Average monsoon recharge	(44.38456 + 41.0959) /2 = 42.73973 mm
VI	Average non-monsoon recharge	(33.5616 + 18.123) /2 = 25.8423 mm
Bemetera		
I	Monsoon 2015 in Bemetera	(197/365) * 120 = 64.7671 mm
II	Non-monsoon 2015 in Bemetera	(36/365) * 245 = 24.1643 mm
III	Monsoon 2016 in Bemetera	(137/365) * 120 = 91.9589 mm
IV	Non-monsoon 2016 in Bemetera	(47/365) * 245 = 31.5479mm
V	Average monsoon recharge	(64.7671 + 91.9589) /2 = 78.363 mm
VI	Average non-monsoon recharge	(24.1643 + 31.5479) /2 = 27.8561 mm

12.11 Predictive simulations

After calibration, only three predictive simulations were made. The scenarios developed were given below:

I. If same amount of recharge and extraction continues what will be the effect on Ground Water heads as on 2021.

II. If the Extraction was doubled either by way of increasing the irrigation land or by increasing the water intensive crops what will be the effect on the ground water heads as on 2021.

III. If by any chance of climate change the rainfall recharge was reduced to half as of 2016, what will be the effect on ground water reservoir as on 2021 even though the extraction remains same.

12.12 Scenario I: Same amount of recharge and extraction

This scenario is developed to know what will be the effect on ground water reservoir if the same amount of stresses continues to exist. The rainfall recharge is considered as the average of the recharge during the years where the data is used for calibration. The extraction is considered as same as the years of calibration.

After simulating, contours were made with the pre-monsoon ground water head during the year 2021 and was presented as **Fig.54**. This map gives an idea that the ground water heads slightly reduced in most of the area. The fluctuation map generated from the ground water heads during pre-monsoon 2017 and 2021 and is presented as **Fig. 55.** Even though some area shows a rise in water level, most of the area shows a decline in water levels. It is suggestive of even though there is no increase in the existing extraction, the ground water head decreases indicating a misbalance between recharge and extraction. Hence it is recommended to have some artificial recharge measures to improve the situation.

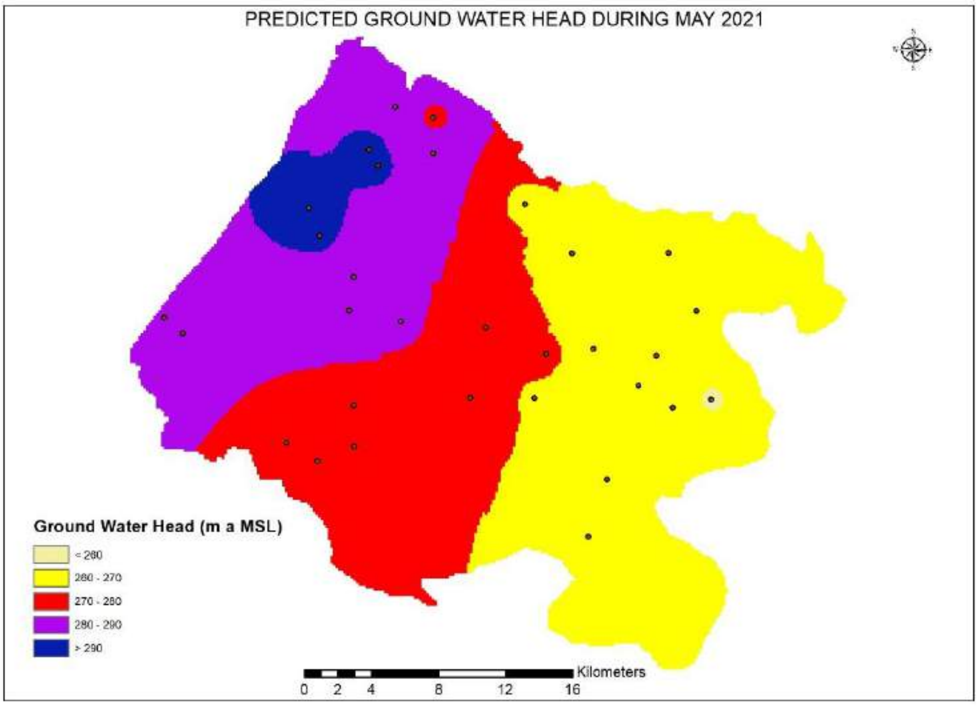


Fig.54. Ground Water Heads during Pre- Monsoon 2021 due to Scenario I

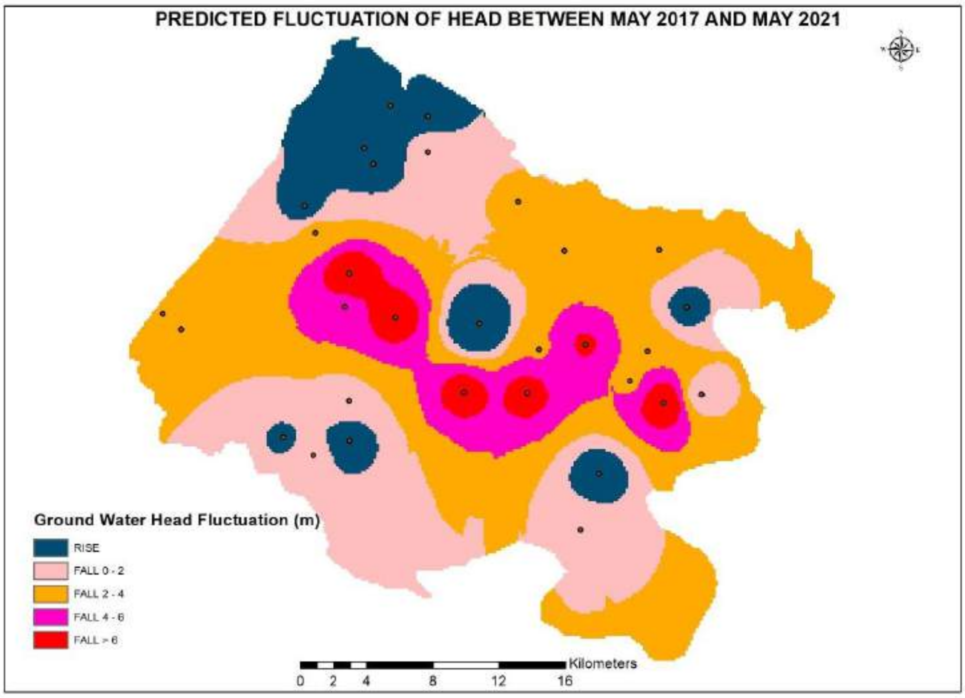


Fig.55. Fluctuation between Ground Water Heads during Pre Monsoon 2017 and 2021due to Scenario I.

12.13 Scenario II: Same amount of recharge and extraction is doubled

This scenario is developed to know what will be the effect on ground water reservoir if the recharge is maintained same but the extraction has become doubled due to either increase in the irrigated area or change in cropping pattern which requires more water.

The rainfall recharge is considered as the average of the recharge during the years where the data is used for calibration. The extraction is considered double the extraction during the years of calibration.

After simulating, contours were made with the pre-monsoon ground water head during the year 2021 and was presented as **Fig.56.** This map gives an idea that the ground water heads reduced in most of the area. The fluctuation map generated from the ground water heads during pre-monsoon 2017 and 2021 and is presented as **Fig.57.** Only very small area shows a rise in water level, but most of the area shows a decline in water levels. It is suggestive that the ground water head decreases indicating a considerable misbalance between recharge and extraction. Hence it is recommended to have some artificial recharge measures to improve the situation without which it will lead to a devastating situation within no time.

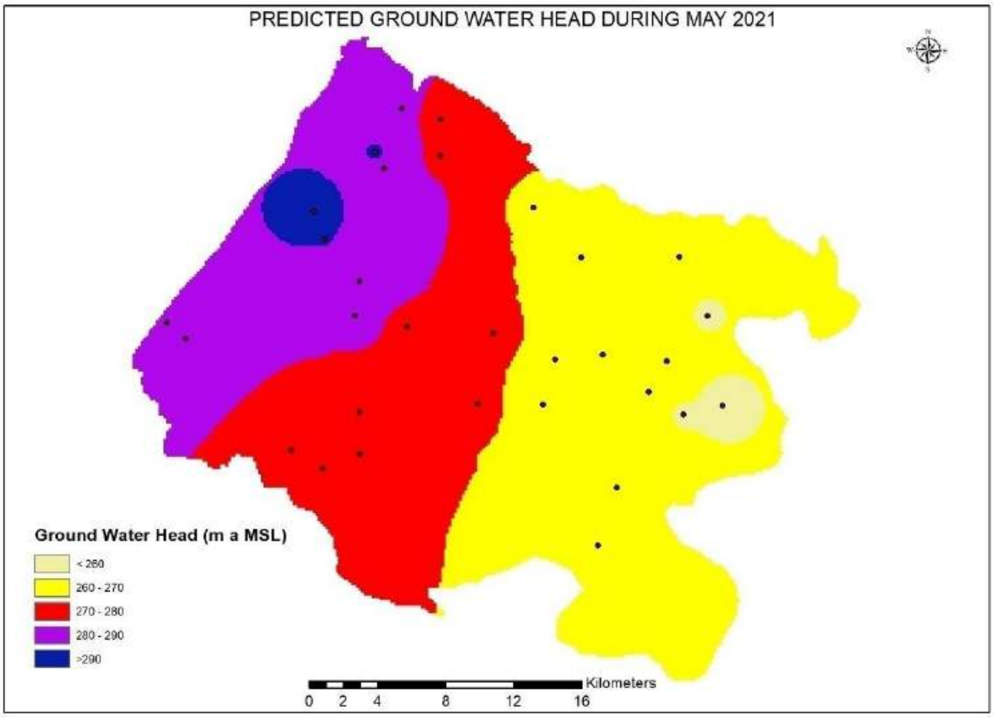


Fig.56. Ground Water Heads during Pre-Monsoon 2021due to Scenario II

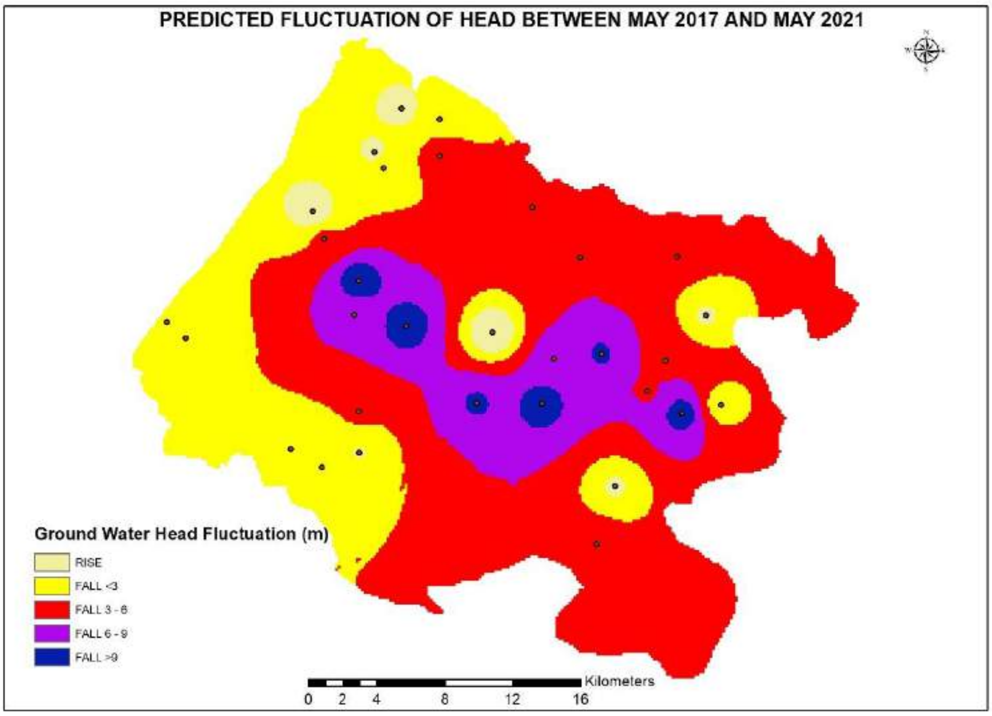


Fig 57. Fluctuation between Ground Water Heads during Pre-Monsoon 2017 and 2021due to Scenario II.

12.18 Scenario III: Recharge is half and extraction is same

This scenario is developed to know what will be the effect on ground water reservoir if the recharge is reduced to half may be due to climate change or any other reasons but the extraction is maintained same.

The rainfall recharge is considered as half of the average of the recharge during the years where the data is used for calibration. The extraction is considered as same extraction during the years of calibration.

After simulating, contours were made with the pre-monsoon ground water head during the year 2021 and was presented as **Fig.58.**This map gives an idea that the ground water heads reduced in most of the area is in between 260 – 290m above MSL. The fluctuation map generated from the ground water heads during pre-monsoon 2017 and 2021 and is presented as **Fig.59.**The area in the Central Region is a decline of 4m whereas the rest of the area is less than 4m decline. It is suggestive that the impact of reduction of recharge to fifty percent has a significant effect on the ground water regime.

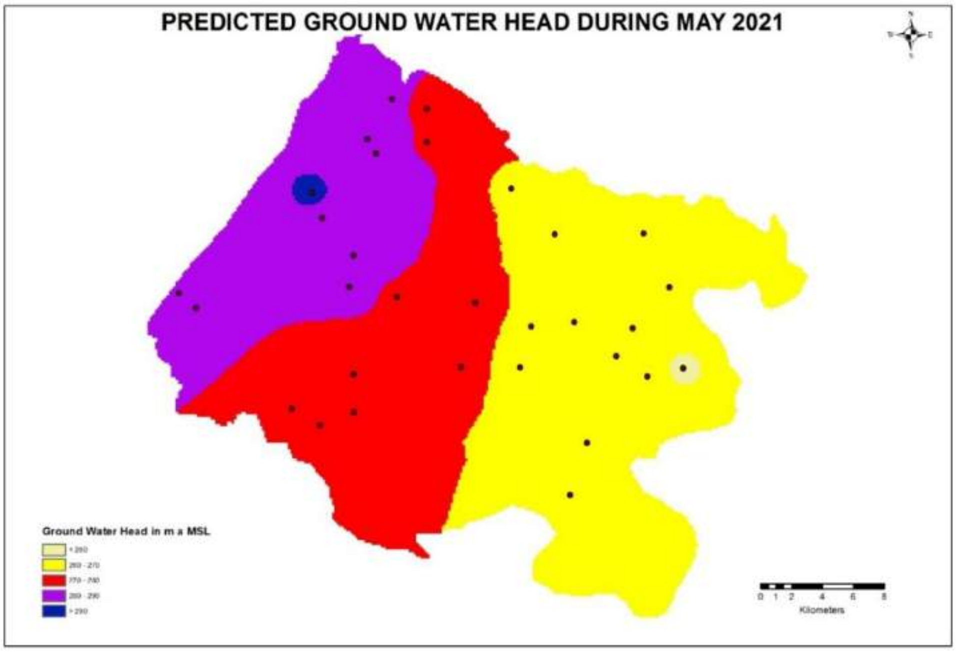


Fig.58. Ground Water Heads during Pre-Monsoon 2021due to Scenario III

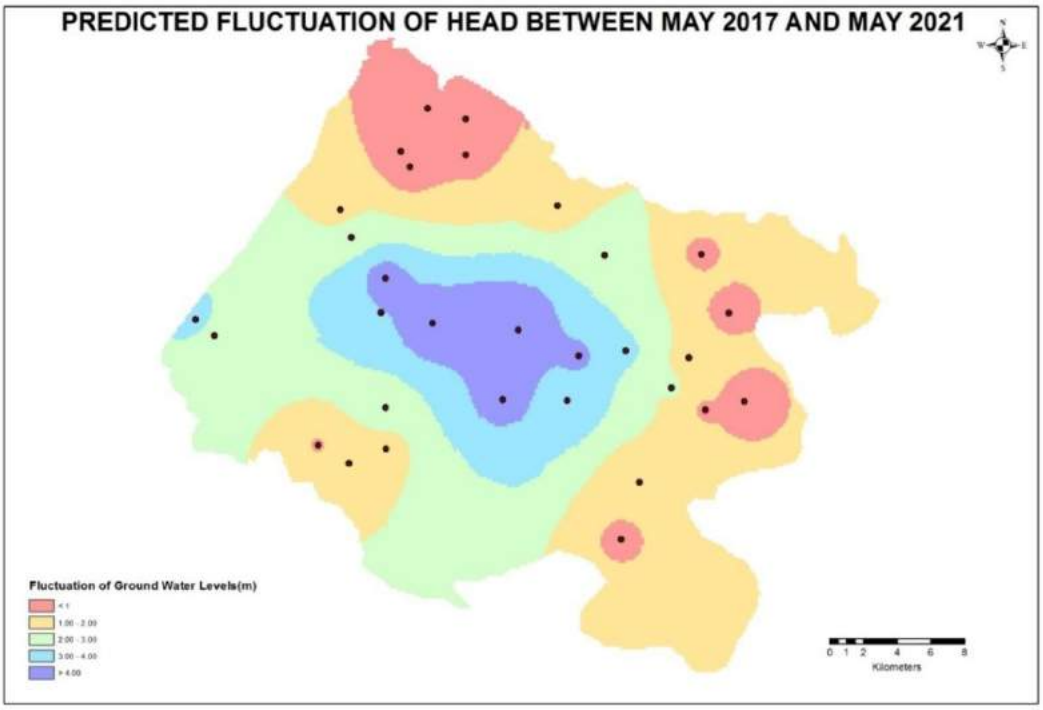


Fig.59. Fluctuation between Ground Water Heads during Pre-Monsoon 2017 and 2021 due to Scenario III

13. Output and Outcome

i. The study area is a part of Bemetera district in Chhattisgarh state having total area of 857 sq. km which is bounded by the Seonath River in the south, Hanp River in the east, Dotu River in the west. It is a part of the Mahanadi River basin.

ii. It is a part of Chhattisgarh Supergroup of Precambrian age underlain by Maniari Shale, HIrri Dolomite, Tarenga Shale and Chandi Limestone..

iii. Maniyari shale is the youngest formation of Chhattisgarh basin and the thickness exceeds 300m.It is gypsiferous and solution cavities are present as a result, it forms prolific aquifers.

iv. The average annual rainfall of Bemetera district is 1159.14 mm which is highly variable in 4 blocks of Bemetera district.

v. Agriculture is intensively practiced in the region. Two crops such as Kharif, Rabi are common in the area and at some places summer crop is also harvested. Different crops in the area are paddy, wheat, sugarcane, soyabean, pulses, blackgram, banana, papaya and seasonal vegetables. In the study area there is no major or medium irrigation projects. Agriculture is mainly dependent on bore well irrigation.

vi. Solution cavities present in Maniyari shale forms prolific aquifers and yield of bore wells go as high as 18.97 lps

vii. Transmissivity (T) of bore wells varies from 22.15 to 1125.65 m^2/day and average T varies from 100 to 600 m^2/day.

viii. Storativity (S) of bore wells varies from 7.9 X 10^{-2} to 5.93 X 10^{-7}. The aquifers are in semi-confined to confined conditions.

ix. Monthly monitoring of both dug wells and bore wells were carried out 24 times from May-2015 to April-2017.

x. Water level varies from 1 to 14.9 mbgl and 1.3 to 15 mbgl in May-15 and May-16 respectively. Similarly water level varies from from 1 to 12.9 mbgl and 1.3 to 11.5 mbgl in Nov.-15 and Nov.-16 respectively. The average water level was 7.83 m and 7.33 m respectively in May.-15 and in May.-16. The average water level was 5.93 m and 5.71 m respectively in Nov.-15 and in Nov.-16.

xi. In phreatic aquifer, EC varies 220 to 3220 μS/cm and in deeper aquifer it varies from 273 to 3180 μS/cm. Higher EC is mainly due to occurrence of SO_4 in ground water and the source is gypsum occurring in Maniari Formation. Sulphate varies from 12 to 1163 mg/l in Maniari Formation.

xii. Ca and Mg are the dominant cations and SO_4 and HCO_3 are the dominant anions. Due to high EC at some places, water is not suitable for drinking and Govt. of Chhattisgarh has installed RO plant for supply of potable drinking water.

xiii. As per USSL and WILCOX diagram, water is suitable for irrigation purpose.

xiv. Temperature of dug well water varies from 20.4 to 29.1 ^{0}C and that of bore well from 21.1 to 31.1 ^{0}C

xv. In the study area, it is a common practice to fill up village ponds from bore wells. There is indiscriminate exploitation of deeper aquifer and decline of water level. People in the area should be made aware regarding the impact on ground water and must be stopped immediately.

xvi. Ground water modelling study reveals that monsoon draft in the study area is 59101.5 m^3/day and non-monsoon draft is 97933.5 m^3/day.

xvii. In Simga area average monsoon recharge is 47.67123 mm and average non-monsoon recharge is 10.40411 mm. In Andhiarkhor area average monsoon and non-monsoon recharge are 42.73973 mm and 25.8423 mm respectively. In Bemetera area average monsoon and non-monsoon recharge are 78.363 mm and 27.8561 mm respectively.

xviii. In Mathematical modelling studies, a scenario was simulated with the same amount of recharge and extraction as of present day. Even in this situation, most of the area shows a decline in water levels. It suggests that even though there is no increase in the existing extraction, the ground water head decreases indicating a misbalance between recharge and extraction. Hence it is recommended to have some artificial recharge measures to improve the situation.

xix. According to another scenario when there is the same amount of recharge but the extraction is doubled, most of the area shows declining water levels. It is suggestive that the ground water head decreases indicating a considerable imbalance between recharge and extraction. Hence, it is recommended to have artificial recharge measures to improve the situation without which it will lead to a devastating situation within no time.

xx. The other scenario simulated with the half of the present day recharge and extraction is same as of now. In this scenario, most of the area shows decline in water levels to an extent of 30m even. It is suggestive that the impact of reduction of recharge to fifty percent has a considerable effect on the ground water regime.

xxi. High water intensive crops like sugarcane must be stopped cultivating in the area. Paddy must be stopped cultivation in the area by exploiting deeper aquifer in Rabi season. Farmers in the area should be made aware regarding advantage of crop rotation.

xxii. Different demand side measures like drip and sprinkler irrigation should be encouraged by government in a wider scale.

xxiii. Different artificial recharge measures have to be implemented in the study area to enhance recharge. Roof Top Rain Water Harvesting (RTRWH) should be made mandatory in the area where ever feasible to face the future challenges in the scenario of decreasing recharge & increasing extraction.

xxiv. In the study area all-out effort should be made to conserve rain water and recharge the aquifer by making gully plugs, nallah bunds and check dams. Percolation tanks are also suitable recharge structures that can be implemented. Every village having tanks which are generally silted which can be de-silted to enhance recharge. Recharge shaft of 10-15 m. can be made at the bottom of the tank.

xxv. As water is extracted from bore well for irrigation purpose injection wells/ recharge wells are the most suitable recharge structures in eastern and western part of the study area. The depth of recharge bore well should be from 40 t0 60 m. Filtered rainwater can be recharged through the bore well.

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ANNEXURES

		Annexure-I Monthly water level monitoring data of dug wells in the study area												
SlNo	Village	Y	X	RL GL (amsl)	Dia (in m.)	Depth (in m.)	M.P. (magl.)	WL-May15 (mbgl)	WL-June15 (mbgl)	WL-July15 (mbgl)	WL-Aug.15 (mbgl)	WL-Sept.15 (mbgl)	WL-Oct.15 (mbgl)	WL-Nov.15 (mbgl)
1	Bemetera NHS	21.70421	81.53089	282.45	3.5	13	0.9	8.9	7.2	1.2	1.2	1.5	3.27	8.63
2	Jeora	21.64066	81.62001	265.155	2.3	12.5	0.45	1.89	1.75	1.63	1.45	1.75	2.02	2.3
3	Kathiya	21.61361	81.64444	266.155	3	13.4	0.4	1	0.7	0.38	0.8	1.2	1.12	1.02
4	Simga NHS	21.628	81.707	268.425	1.9	12.5	0.6	2.58	0.37	0.91	0.5	1.2	0.74	1.1
5	Arjuni	21.67807	81.66091	256.995	2	12.88	0.3	9.03	8.2	0.99	6.1	1.1	2.15	2.36
6	Jiya	21.67131	81.63065	262.255	1.75	14	0	7.55		5	4.9	3.5	5.17	6.96
7	Talla	21.67371	81.59508	265.935	2.1	12	0.4	5.88	10.8	3.67	7.7	7.1	2.93	6.28
8	Nari	21.79315	81.6111	272.92	2.25	14.5	0.5	10.38	9.65	10.02	8.3	6.9	10.11	10.24
9	Mulmula	21.79333	81.66667	268.14	2.7	14.6	0	12.3	10.5		7.5	6.1	12.52	12.9
10	Muthpuri	21.79718	81.72819	253.83	2.2	14.5	0.7	13.9	11.7	11.45	9.45	8.6	10.49	10.92
11	Mau	21.7675	81.7375	250.11	2.1	13.6	0.4	11.3	10.7	9.39	9.1	10.7	7.41	11.2
12	Tuma	21.765	81.70644	250.79	4	10.3	0.45	8.83	9.05	8.82	8.15	8.35	8.31	8.45
13	Bitkuli	21.77453	81.66797	258.89	2.75	9.67	0.4	9.5	8.8	7.38	6.4	8.1	9.27	9.12
14	Birampur	21.76926	81.66179	256.125	2	8.3	0.45	6.66	5.15	6.41	3.05	3.85	7.44	7.31
15	Uslapur	21.76191	81.68257	254.33	1.3	10	0	6.5	5.1	5.26	4.1	3.2	5.81	7.76
16	Amora	21.64901	81.55359	263.895	1.9	11.7	0.5	8.3	7.3	1.23	1.3	1.9	2.13	5.5
17	Jeori	21.6415	81.53922	264.76	2.95	15.7	0.5	14.9	10.1	4.47	1.7	2	1.97	4
18	Bijabhata	21.65885	81.55344	269.03	2.6	13.9	0.65	9.05	3.75	2.03	2.15	2.25	3.35	7.7
19	Farri	21.66714	81.54254	268.245	3.4	15.2	0.5	13	9.8	2.34	1.8	2.6	2.04	3.21
20	Mohabhatta	21.71583	81.55222	284.95	1.5	8	0.4	1.4	1.2	0.8	0.7	1	1.3	1.5
21	Baba Mohatara	21.71532	81.58923	274.64	4.1	11.5	0.6	6.3	3.6	1.54	1.4	1.8	1.9	2.43

		Annexure-I Monthly water level monitoring data of dug wells in the study area												
SlNo	Village	Y	X	RL GL (amsl)	Dia (in m.)	Depth (in m.)	M.P. (magl.)	WL-May15 (mbgl)	WL-June15 (mbgl)	WL-July15 (mbgl)	WL-Aug.15 (mbgl)	WL-Sept.15 (mbgl)	WL-Oct.15 (mbgl)	WL-Nov.15 (mbgl)
22	Bhaisa	21.74178	81.62307	273.38	2.65	15	0.7	10.7	9.9	11.59	6.8	9.7	9.71	10.3
23	Gadwa	21.69111	81.38028	274.01	2.55	12	0.4	9	7.75	8.44	6.5	4.9	7.92	6.65
24	Ninwa	21.68186	81.46407	270.9	2.7	11.5	0.45	9.85	8.85	7.79	6.35	4.95	7.46	8.35
25	Dundra	21.68963	81.48531	271.1	2.4	13.7	0.25	12.45	12.15	6.97	10.15	8.45	8.47	8.46
26	Moharanga	21.71439	81.69097	256.015	2.35	14.5	0.45	2.45	0.95	1.03	0.75	0.75	1.16	1
27	Jogipur	21.70991	81.66863	260.4	3.2	11	0	9.5	6.5	7.4	4.4	6.9	7.73	8.76
28	Balasamund	21.72195	81.64912	266.13	2.9	11.5	0.6	11	8.9	8.64	6.2	9.1	11.02	10.76
29	Ghatoli	21.73807	81.65945	267.51	2.3	10	0.4	9	7.75	9.1	4.3	6.1	8.63	8.88
30	Nawagaon (Karanjia)	21.77639	81.65749	259.32	2.85	6.5	0.2	5.6	5.5	5.2	6.3	5.1		
31	Piparbhata	21.70214	81.59492	269.085	2.1	14	0.5	9.2	8	0.95	0.6	0.9	1.18	1.85
32	Kusmi	21.69807	81.62232	267.675	3.2	9.3	0.8	9.7	9.2	4.05	1	0.9	1.63	5.24
33	Khurmuri(NHS)	21.71228	81.61395	271.35	1.7	14.8	0.3	10	9.5	3.22	1.9	2.5	4.21	4.44
34	Pendri	21.7594	81.3761	285.8	2.65	8.5	0.5	10	9.1	6.63	4	2.7	1.77	9.1
35	Kapa	21.7508	81.3869	282.21	2.1	10.5	0	8.9	7.6	4.55	6.1	4.1	5	5.2
36	Kestara	21.6886	81.3617	284.425	3.5	8.18	0.6	6.6	6.8	6.9	5.3	5.3	5.52	5.7
37	Bija	21.67	81.4025	275.11	2.65	13.3	0.4	12.2	11.7	12.9	10.2	10.8	12.97	
38	Dhanagaon (Dhaneli)	21.83349	81.57639	271.2	1.5	11.3	0	10.2	9.6	9.6	9.1	8.7	9.11	9.52
39	Bilai	21.75329	81.56133	277	1.75	13.6	1.4	10.6	10.5	10.04	7.85	11		9.68
40	Jhalam	21.81987	81.58405	268.36	1.6	7.2	0	6.3	6.7	6.5	5.8	5.6	6.31	6.2
41	Lolesara	21.75694	81.51228	285.29	1.6	11	0	4.9	3.8	2.38	2.9	2.8	4.51	4.2
42	Hemabandh	21.86666	81.53152	274.27	3.25	6.6	0	4.9	4.6	3.04	2.5	2.8	2.82	3.71

		Annexure-I Monthly water level monitoring data of dug wells in the study area												
SlNo	Village	Y	X	RL GL (amsl)	Dia (in m.)	Depth (in m.)	M.P. (magl.)	WL-May15 (mbgl)	WL-June15 (mbgl)	WL-July15 (mbgl)	WL-Aug.15 (mbgl)	WL-Sept.15 (mbgl)	WL-Oct.15 (mbgl)	WL-Nov.15 (mbgl)
43	Mohtara	21.84723	81.53148	271.76	2.17	13	0.4	6.2	4.9	3.74	2.8	2	2.72	4.64
44	Bhainsabor/ Khurd	21.87243	81.50976	277.525	1.5	7.4	0.45	6.9	5.9	4.87	2.4	2.1	3.22	4.35
45	Semariya	21.84933	81.49435	289.6	2.4	11.8	0	4.7	2.4	1.56	2.1	2.1	2.1	3.17
46	Dadhi (NHS)	21.89392	81.4728	281.16	1.6	9.1	0	6.4	5.6	4.32	3.4	2.7		5.1
47	Newaspur	21.88569	81.52168	276.125	1.7	13.9	0.25	11.35	10.15	9.54	8.65	7.35	8.99	9.75
48	Bahera	21.76282	81.48264	284.95	1.85	8.8	0	6.22	3.1	1.66	1.3	3	3.05	4.03
49	Betar	21.85403	81.43816	297.25	1.6	10	0.2	2.2	1.4	1.16	1.2	1.7		1.61
50	Chilphi	21.87573	81.46651	284.1	2.95	11.2	0.45	6.65	6.05	4.04	3.75	3.95	3.62	6.35
51	Ghanadih	21.84081	81.49956	277.675	2.2	8	0.6	7.2	6.55	1.92	3.55	2.55	1.52	2.59
52	Garra	21.7811	81.4853	292.86	2.25	15.3	0.5	10.3	10.1	8.53	8.3	8.8	6.51	10.58
53	Sagauna	21.8033	81.4658	290.65	2.15	8.76	0.6	7.5	5	3.89	3.4	4.6	5.51	7.6
54	Khursbod	21.8181	81.4594	290.89	4.1	9.6	0	6.4	6.6	5.02	3.1	2.8	3.57	6.63
55	Bhurki	21.71179	81.48505	272.745	2.8	9.9	0.6	6.2	5.7	4.93	3.9	3.1	4.03	5.36
56	Umariya	21.85646	81.44711	291.795	2.2	11	0.4	5.4	4.4	0.7	3.4	1	1.21	1.75
57	Hadahuli	21.6917	81.4464	273.06	2.15	11	0.4	5.8	5	3.07	3.6	3.2	0.85	1.78
58	Dhara	21.73926	81.59605	269.05	1.3	9	0.2	2.3	1	1.14	1.4	1.2	2.41	3.31
59	Motisura	21.68056	81.425	272.9	1.6	10.7	0.2			3.98	3	2.2		3.61
60	Hadahuli	21.7642	81.3422	282.43	2.6	9.7	0.3			7.36	7.3	6	6.05	5.72
61	Bharampuri	21.7583	81.3458	284.61	1.4	10.35	0.4			8.22	8	6.4	6.62	6.57
62	Andhiarkhor	21.83833	81.5975	266.865	2.5	13.5	0.4			11.75	8.5	11.7	11.51	11.9
63	Damiadih	21.90715	81.49227	261.78	2.6	13.4	0.65			9.5	7.75	6.85	9.75	8.85
64	Karamtara	21.91813	81.47597	275.35	2,4	11.5	0			7.41	7.15	6.3	8.2	9.23

		Annexure-I Monthly water level monitoring data of dug wells in the study area												
SlNo	Village	Y	X	RL GL (amsl)	Dia (in m.)	Depth (in m.)	M.P. (magl.)	WL-May15 (mbgl)	WL-June15 (mbgl)	WL-July15 (mbgl)	WL-Aug.15 (mbgl)	WL-Sept.15 (mbgl)	WL-Oct.15 (mbgl)	WL-Nov.15 (mbgl)
65	Gidwa	21.89983	81.45984	283.835	3.6	6.8	0.8			1.53	1.4	2	2.09	2.65
66	Kodwa	21.89988	81.44437	286.925	2.5	6	0.2			1.61	1.4	2.3	4.21	2.88
67	Pendri	21.89142	81.44262	290.865	4	11.6	0.55			4	3.1	2.9	4.93	3.65
68	Janta	21.87798	81.43751	292.43	2.9	5.6	0.15			1.03	1.95	1.05	3.56	2.6
69	Jewra	21.79306	81.38972	265.83	1.8	7.8	0.3			2.3	1.8	2.1	2.11	3
70	Khati	21.77833	81.435	284.29	1.65	6.7	0.4			2.18	1.6	2.3	4.72	6.13
71	Chorbhatti	21.74556	81.53472	284.59	1.7	9.5	0			3.79	3.50			4.8

		Annexure-I Monthly water level monitoring data of dug wells in the study area																
Sl No	Village	WL-Dec.15 (mbgl)	WL-Jan.16 (mbgl)	WL-Feb.16 (mbgl)	WL-Mar.16 (mbgl)	WL-April16 (mbgl)	WL-May16 (mbgl)	WL-June16 (mbgl)	WL-July16 (mbgl)	WL-Aug.16 (mbgl)	WL-Sept.16 (mbgl)	WL-Oct.16 (mbgl)	WL-Nov.16 (mbgl)	WL-Dec.16 (mbgl)	WL-Jan.17 (mbgl)	WL-Feb.17 (mbgl)	WL-Mar.17 (mbgl)	WL-April 17 (mbgl)
1	Bemetera NHS	11.94	11.5			11.99		3.9	1.2	1.65	1.3	1.5	6.4	11.7	8.19	8.5	11.6	10.3
2	Jeora	2.68	2.55	2.55	2.45	2.81	4.2	2.55	1.23	1.74	1.65	1.92	2.55	2.96	3.17	3.52	4.32	6.05
3	Kathiya	1.45	1.5	1.32	1.05	1.45	1.3	8.2	7.75		0.55	0.69		0.94	1.1	1.23	1.38	
4	Simga NHS	2.48	2.6	2.17	2.5	3.13	2.89	2.1	2.3	0.6	0.52	0.62	2.1	2.27	2.15	2.08	2.59	2.8
5	Arjuni	2.71	3.2	3.53	3.7	3.9	5.3	6.1	6.3	2.5	0.12	0.24	3.2	2.93	3.12	2.5	3.34	7.8
6	Jiya	8.88	10.2	10.7	9.85	9.05	10.37	7.9	6.85	8.7	8.34	3.9	7.3	8.47	6.96	9.98	9.18	9.15
7	Talla	6.95	7.2	7.47	5.5	5.17	7.55	11	7.2	4.39	3.45	1.85	7.2	4.65	4.24	3.93	4.1	11.1
8	Nari		10.11	10.5	10.35	10.43	10.38	9.9	10.2	9.95	9.6	9.1	10.2	10.44	10.21	10.81	10.55	10.8
9	Mulmula	12.92	12.52	13.1	13	13.1	13	11.15	12.7	12.6	11.9	12.6	11.5	12.92	10.73	11.7	13.92	12.1
10	Muthpuri		10.49			13.6		12.1				12.62			10.05			
11	Mau	11.02	7.41		12.45	12.3	12.1	11.1	10.4	12.02	11.1	10.8	10.7	11.03	9.2	11.48	12.51	11.1
12	Tuma	8.83	8.31	9.75	9.35	9.48	9.8	10.65	9.45	9.3	8.65	8.05	8.05	8.29	7.04	8.76	9.17	9.35
13	Bitkuli		9.27								6.6	7.56						
14	Birampur		7.44									6.45						
15	Uslapur	6.4	5.81	7	7.1	7.4	7.6	7.4	6.8	7.6	3.1	7.12	7.5	7.76	7.51	7.93	8.82	8.1
16	Amora	7.8	2.13	9.2	7.5	8.53	9.45	2.7	1.2	2.86	1.48	1.69	2.15	4.6	7.9	11.7		10.7
17	Jeori	10.8	1.97	14.9	14.5	14.9	15	14.8	7.8	13.33	10.4	2.38	3.2	9.44	14.01	14.48	14.4	14
18	Bijabhata	8.58	3.35	11.05	10.8	11.53	12	9.15	2.15	3.04	2.57	2.75	6.15	8.05	9.15	10.18	11.65	12.15
19	Farri	7.9	2.04	13.55	14.35			14.6	10.1	4.85	4.21	1.8	5.2	5.2	6.4	12.27	14.3	14.5
20	Mohabhatta	1.59	1.3	1.57	1.5	1.53	1.58	1.3	0.7	1.21	1	1	1.3	1.32	1.4	1.32	2	2.3
21	Baba Mohatara	3.04	1.9	3.86	5.5	5.14	2.96	2.7	1.3	1.78	1.68	1.76	2.8	2.79	2.61	2.93	5.3	6

		Annexure-I Monthly water level monitoring data of dug wells in the study area																
Sl No	Village	WL-Dec.15 (mbgl)	WL-Jan.16 (mbgl)	WL-Feb.16 (mbgl)	WL-Mar.16 (mbgl)	WL-April16 (mbgl)	WL-May16 (mbgl)	WL-June16 (mbgl)	WL-July16 (mbgl)	WL-Aug.16 (mbgl)	WL-Sept.16 (mbgl)	WL-Oct.16 (mbgl)	WL-Nov.16 (mbgl)	WL-Dec.16 (mbgl)	WL-Jan.17 (mbgl)	WL-Feb.17 (mbgl)	WL-Mar.17 (mbgl)	WL-April 17 (mbgl)
22	Bhaisa	10.73	9.71	10.6	10.7	11	11.14	10.7	10.1	9.5	10.51	9.6	9.9	10.19	9.01	9.53	11.16	10.2
23	Gadwa	8.31	7.92	10.3	10.3	9.53	9.08	7.9	7.2	8.52	8	5.1	6	7.72	8.33	8.98	9.58	7.45
24	Ninwa	9.15	7.46	9.34	9.15	9	9.53	9.5	7.8	7.63	7.35	5.71	8.35	8.73	8.38	7.44	8.45	9.05
25	Dundra	10.41	8.47	12.13	12.25	12.35	12.64	12.42	11.05	10.3	9.95	7.33	8.85	10.73	8.12	9.99	12.47	12.55
26	Moharanga	1.12	1.16	2.3	1.35	1.53	1.59	1.65	0.95	1.42	0.55	0.95	1.35	1.32	1.15	1.44	2.25	1.95
27	Jogipur	9.11	7.73		5.9	7.72	8.75	8.7	8.3	8.43	6.05	7.8	7.8	8.14	7.1	6.87	9.2	9.4
28	Balasamund	10.81	11.02	10.9	10.9			10.8	8.1	10.01	8.3	9.4	9.6	9.65	9.1	9.33	9.9	10.8
29	Ghatoli	8.96	8.63	9.08	9.55	9.69		9.55	8.3	9.45		9.02	10.1	9.61	9.01	9.8	9.4	9
30	Nawagaon (Karanjia)							5.15										
31	Piparbhata	3.93	1.18	7.76	7.7	8.35	8.97	7.7	0.5	1.24	0.99	1.08	1.9	3.3	5.61	6.12	5.91	8.2
32	Kusmi	7.21	8.7						6.2	4.27	5.2	1.78	5.1	6.73	6.82	8.31		
33	Khurmuri (NHS)	3.33	3.9	9.76	13	5.67	6.82	4.3	2.7	5.51	2.65	2.41	2.9	4.47	4.9	7.28	10.3	10.9
34	Pendri	3.78	10	9.9	10	10.28	10.07	9.3	7.65	7.92		9.32	5.1	10.62			10.67	7.5
35	Kapa	6.14	6.9	8.39	9	9.99	9.6	7.1	6.3	5.13	4.6	5.31	4.9	6.63	7.02	8.63	9.7	7.1
36	Kestara	5.97	6.7	6.86	6.95	7.26	7.47	7.4	6.55	5.9		5.85	5.3	6.2	5.33	5.57	7.2	7.4
37	Bija							12.6	12.4	14.5	12.2	8.73	11	14.55	11.06	13.01	14.5	14.5
38	Dhanagaon (Dhaneli)	10.33	10.41	10.42	10.6	9.7	10.23	10.4	9.6	7.5	8.6	9.28	9.9	9.42	5.38	7.17	10.1	9.9
39	Bilai	10.8	11.3	11.3	10.9	10.69	10.93	10.6	9.8	10.3	10.6	10.6	10.8	10.97	8.9	10	10.62	11
40	Jhalam	6.8	6.5	6.3	6.4	6.7	6.6	6.7	6.4	6.3	6.8	6.4	6.4	6.48	5.84	6.34	6.6	6.8
41	Lolesara	4.88	6	5.68	0	5.3	5.26	4	2.8	3.25	2.2	3.22	4.1	0	4.89	6.07	5.8	5.6

		Annexure-I Monthly water level monitoring data of dug wells in the study area																
Sl No	Village	WL-Dec.15 (mbgl)	WL-Jan.16 (mbgl)	WL-Feb.16 (mbgl)	WL-Mar.16 (mbgl)	WL-April16 (mbgl)	WL-May16 (mbgl)	WL-June16 (mbgl)	WL-July16 (mbgl)	WL-Aug.16 (mbgl)	WL-Sept.16 (mbgl)	WL-Oct.16 (mbgl)	WL-Nov.16 (mbgl)	WL-Dec.16 (mbgl)	WL-Jan.17 (mbgl)	WL-Feb.17 (mbgl)	WL-Mar.17 (mbgl)	WL-April 17 (mbgl)
42	Hemabandh	4.52	4.6	4.9	4.9	4.9	5.01	4.82	4.1	2.97	2.6	2.82	3.7	11.72	4.18	4.3	4.7	4.8
43	Mohtara	4.93	5.2	5.05	5.4	5.78	6.29	5.8	4.9	3.08	2.4	3.65	4.8	4.9	4.98	5.2	5.45	5.9
44	Bhainsabor/ Khurd	5.05	6.05	6.22	6.3	5.15	5.1	5.15	4.95	4.2	4.75	3.05	3.55	4.37	4.98	6.17	6.29	6.65
45	Semariya	3.7	3.9	4.5	4.9	5.88	6.42	2.55	2.6	0.95	0.8	1.89	2.1	3.39	3.63	4.32	4.68	3.55
46	Dadhi (NHS)	5.8	6.4	6.46	6.55	7.1	6.2	5.2	5	4.5	3.8	2.4	4.3	5.8		6.79	6.4	5.4
47	Newaspur	11.65	12.95					12.85	12.75	10.43	8.85	7.8	10	3.93	5.85	7.9		
48	Bahera	4.52	4.2	4.25	5.85	7.53	7.28	5.5	4.2	1.95	1.5	1.67	2.5	0	3.13	4.38	5.75	5.8
49	Betar	1.82	2	2.3	2.3	2.48	2.5	1.72	1.6	1.3	1.6	1.37	2.9	2.15	2.47	2.67	2.9	3.2
50	Chilphi	6.43	6.95	8.03	7.8	6.8	6.35	5.85	5.05	5.17	4.35	4.75	5.95	6.68	6.13	7.08	7.63	6.7
51	Ghanadih	3.86	4.1	4.9		5.9	5.91	5.75	5.55	1.11	0.5	0.9	2.5	3.58	5.57	5.47	4.96	5.1
52	Garra	10.51	10.4	10.5	10.5	10.6	10.68	9.9	9.3	9.9	8.8	9.57	8.4	8.68	8.26	8.73	9.24	9.2
53	Sagauna					5.2	3.42	2.4	3.6	3.05	2.5	3.45	3.2	3.75	4.67	4.24	3.75	4.5
54	Khursbod	7.7	6.6	7.2	7.1	7.1	7.05	7.2	5.8	3.81	5.6	4.54	7	7.25	3.65	5.17	7.3	6.8
55	Bhurki	6.86	7.5	8.7	8.95	8.6	8.7	7.8	6.2	5.11	4.6	4.78	5.7	5.72	5.55	6.12	5.85	7.9
56	Umariya	2.8	2.3			3.42	3.44	1.9	2.3	0.93	1.7	1.14	1.7	2.14		2.31	2.84	3
57	Hadahuli	2.54	2.8	2.8	3.6	5.65	8.09	8	3.1	0.93	0.4	1.5	1.9	2.6	3.03	3.31	4	6.75
58	Dhara	3.7	3.9	4	1.1	3.52	2.6	2.6	0.3	1.37	0.6	1.26	1.7	3.21	2.18	4.11	3.8	3.9
59	Motisura	5.14	6.3	6.3	6.1		6.75	5.6	4.9	3.67	3.1	3.58	3.6	5.55	6.05	6.27	6.44	7.65
60	Hadahuli	6.97	7.8					8.6	8.3	7.85	8.2	6.3	7	9.17	8.31	8.97		
61	Bharampuri	3.34	8.1								8.1	7.76	7.5	7.83				
62	Andhiarkhor	11.9	11.9	11.68	11.8	11.75	11.79	11.9	10.5	11.95	11.8	11.7	11.5	11.77	10.13	10.7	11.75	12.2

		Annexure-I Monthly water level monitoring data of dug wells in the study area																
Sl No	Village	WL-Dec.15 (mbgl)	WL-Jan.16 (mbgl)	WL-Feb.16 (mbgl)	WL-Mar.16 (mbgl)	WL-April16 (mbgl)	WL-May16 (mbgl)	WL-June16 (mbgl)	WL-July16 (mbgl)	WL-Aug.16 (mbgl)	WL-Sept.16 (mbgl)	WL-Oct.16 (mbgl)	WL-Nov.16 (mbgl)	WL-Dec.16 (mbgl)	WL-Jan.17 (mbgl)	WL-Feb.17 (mbgl)	WL-Mar.17 (mbgl)	WL-April 17 (mbgl)
63	Damiadih	10.81	11.45	11.95	12.15	12.65	12.75	8.5	7.95	12.03	7.5	9.41	10.85	11.03	9.97	10.66	12.07	
64	Karamtara	10.22	10.9	11.1	11.3			9.4	9.15	10.6	7.4	10.01	10.2	11.02				
65	Gidwa	2.9	3.1	2.4	3.15	3.1	3.05	2.35	3	2.01	1.5	2.12	2.3	3.16	2.9	4.33	3.1	3.2
66	Kodwa		5.4	3.2		3.6	3.88	2.75	2.95	1.6	2.65	2.19	3.25	2.87	2.83	3.97	3.33	3.95
67	Pendri	4.36	5.15	6.83	6.49	7.03	5.86	6.85	6.3	4.27	2.95	0.92	4.55	2.47	4.15	5.65	3.88	5.7
68	Janta	3.16	3.35	3.77	4.3	4.73	4.9	4	3.8	1	2.7	1.47	2.95	3.09	3.26	4.96	4.58	5.15
69	Jewra		4.2			4.93	4.87	4.8	2.1	1.85	2.8	3.38	3.5	4.82	6.01	7.17		5.55
70	Khati							4.8	3.1	2.75	0.8	4.62	5.9					
71	Chorbhatti			8.2						3.3		4.03	5.1	8.5	7.52	9.02		

Annexure-II Monthly water level monitoring data of bore wells in the study area

Sl N0	Location	Y	X	R.L.	M.P.	Casing (masl)	Depth (masl)	WL-June15 (mbgl)	WL-July15 (mbgl)	WL-Aug.15 (mbgl)	WL-Sep.15 (mbgl)	WL-Oct.15 (mbgl)	WL-Nov.15 (mbgl)	WL-Dec.16 (mbgl)	WL-Jan.16 (mbgl)
1	Dhara	21.74361	81.58917	269.685	0.45	257.685	177.485	17.67	19.94	22.35	14.4	14.27	21.65	24.67	27.45
2	Khurusbod	21.81472	81.46333	289.6	0.5	277.6	85.5	21.05	11	13.2	12.7	21.86	12.6		14.4
3	Dadhi	21.89917	81.47306	275.805	0.58	243.005	71.805	7.54	5.93	6.02	5.22	7.68	6.76	9.07	12.15
4	Birsinghi	21.96722	81.50167	282.38	0.67	261.88	212.48	6.41	5.42	7.53	6.13	3.72	4.33	6.13	6.79
5	Jhal	21.79139	81.55444	273.795	0.45	261.795	69.795	11.49	13.93	11.75	7.25	4.01	7.71	9.45	15.55
6	Ninawa	21.67917	81.45917	269.905	0.35	251.405	163.405	15.05	13.47	12.45	8.05	16.62	10.39	16.2	19.23
7	Amora	21.64861	81.56167	266.25	0.47	254.25	174.05	16.89	14.57	12.63	10.33	15.48	13.53	21.63	19.03
8	Tipni	21.80778	81.35194	302.525	0.55	278.525	100.525	27.63	29.08	26.25	23.35	20.46	21.52	26.6	29.35
9	Barga	21.725	81.43889	274.88	0.25	252.38	219.28	13.31	14.86	13.85	9	12.33	11.25	14.94	19.95
10	Beltara	21.74167	81.26667	283.1	0.4	263.6	209.2	15.7	15.09	15.2	6.3	7.59	10.35	15.85	20.12
11	Simga	21.6283	81.706	268.095	0.4	259.095	-36.325	20	15.755		12.45	15.39	14.8	18.2	18.6
12	Andhiarkhor	21.8384	81.5976	262.42	0.7	252.52	178.2	8.1	7.8	8.1	7.7	8.56	8.45		

Annexure-III Monthly water level monitoring data of bore well

Sl N0	Location	WL-Feb.16 (mbgl)	WL-Mar.16 (mbgl)	WL-April16 (mbgl)	WL-May16 (mbgl)	WL-June16 (mbgl)	WL-July16 (mbgl)	WL-Aug.16 (mbgl)	WL-Sep.16 (mbgl)	WL-Oct.16 (mbgl)	WL-Nov.16 (mbgl)	WL-Dec.16 (mbgl)	WL-Jan.17 (mbgl)	WL-Feb.17 (mbgl)	WL-Mar.17 (mbgl)	WL-April 17 (mbgl)
1	Dhara	46.65	28.1	37.25	27.22	30.05	32.5	37.05	37.6	15.35	13.75	28.05	28.08	36.92	37.95	40.05
2	Khurusbod	20.5	24.4	25.6	29.2	20.7	19.2	24.15		11.1	11.2	19	19.78	17.6	22.9	20.1
3	Dadhi	14.02	12.32	12.02	12.02	10.72	17.12	14.12	9.62	3.37	5.82	8.02	9.53	10.72	10.42	12.32
4	Birsinghi	9.22	6.83	8.18	8.93	7.13	9.55	11.53	9.13	2.93	7.13	7.58	8.37	10.94	9.28	12.43
5	Jhal	20.65	21.75	25.35	22.25	22.35	20.85	16.65	16.75	11.47	11.95	15	18.34	21.52	22.4	23.45
6	Ninawa	27.67	24.25	27.95	23.08	23.25	20.27	25.35	18.25	7	13.35	18.09	20.29	23.97	23.15	23.45
7	Amora		47.63	44.63	35.03	25.73	15.63	15.53	14.93	10.78		17.03	32.23	44.01	66.53	59.63
8	Tipni	42.35	41.95	42.55	42.35	42.35	34.85	40.75	26.05	22.5		31.05	35.77	39.94	38.85	
9	Barga	24.35	22.08	28.11	21.4	21.55	24.25	20.8	18.45	13.45	14.15	17.65	21.38	24.72	22.65	23.25
10	Beltara	24.51	27.75	22.55	22.68	18.9	19	15.2	15.94	10.1	15.7	19.36	22.03	24.72	23.6	23.85
11	Simga	27.79	32.7	30.2	29.9			22.42	14.55	12.7	23.1	19.2	21.3	21.26	34	31
12	Andhiarkhor			14.88	16.7	15.9	18.5	22.05	21.4	11.7	9.3	11.15	12.46	14.55	16.33	19

Annexure-III Field Photographs of the study area.

Maniari Shale exposed in the study area

Solution cavities present in Tarenga Shale.

Solution cavities present in Tarenga Shale

Cavities present in Maniari Shale

Maniari shale exposed in the study area

Bore well water entering the dug well

Dug well water used for drinking purpose

Dry dug well filled with bore well water

Waste water from RO plant entering a dug well

Collection of drinking water from dug well

Collection of drinking water from dug well

Indiscriminate exploitation of GW by bore well

Pond filling from bore well water

Pond filling from bore well water

Pond filling from bore well water

Ponds in the study area

Dry ponds in the study area

Hanp river(eastern boundary of the study area)

Sheonath river(Southern boundary of the study area)

RO plant installed in the study area

Scarcity of drinking water in summer season

Indiscriminate exploitation of GW by bore well

Pond filling from bore well water

Pond filling from bore well water

Pond filling from bore well water

Ponds in the study area

Dry ponds in the study area

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