Government of India
Ministry of Jal Shakti
Dept. of Water Resources, River Development & Ganga Rejuvenation
Central Ground Water Board
Rajiv Gandhi National Ground Water Training & Research Institute

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Stable Isotope Investigations to Study Surface Water - Ground Water Interaction in a Hardrock Terrain in Parts of Durg District, Chhattisgarh

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FOREWORD

Study of environmental isotopes can reveal the interrelationships between surface water and ground water effectively. The study of stable isotope signatures of Deuterium (δD) and Oxygen ($\delta^{18}O$) in water samples is one of the most valuable and advance methodologies available to establish the recharge source of ground water and for establishing the interaction between surface water and ground water in an area. The establishment of the relationship between waters above and below the earth surface plays an important role in managing the water resource of an area. With this in view the study on interaction of surface water and ground water through stable isotope investigation has been taken up in the Pulgaon Nala Watershed in Durg district of Chhattisgarh State.

The R & D study has been carried out by the Rajiv Gandhi National Ground Water Training and Research Institute (RGNGWTRI), Central Ground Water Board in collaboration with the Physical Research Laboratory (PRL), Ahmedabad. Collection of hydrogeological data from the study area along with collection of ground water, surface water and rain water samples from the field were done by RGNGWTRI. The analysis of water samples for δD and $\delta^{18}O$ was carried out by PRL, Ahmedabad. Shri Bikram Kumar Sahoo, Scientist-D (Sr. Hydrogeologist) of RGNGWTRI has carried out the study and has prepared the report in collaboration with the PRL. A thorough investigation of the study area through intensive sampling of both surface and ground water has been carried out to establish the relation between water of two domains. The knowledge of interrelationship and interaction between surface water and ground water in the area will help decide the management strategies for water resources in the area. I am sure that the report will be of immense use to all stakeholders.

K C Naik
Chairman
Central Ground Water Board

ACKNOWLEDGEMENTS

First and foremost, I express my heartfelt gratitude to the Chairman, Central Ground Water Board, Ministry of Jal Shakti, Dept. of Water Resources, River Development & Ganga Rejuvenation, Government of India for his kind permission to carry out the present study.

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I am very much thankful to Shri Sunil Kumar, Regional Director, Rajiv Gandhi National Ground Water Training and Research Institute, Raipur for providing all logistic supports for carrying out this study. His constant guidance, encouragement and motivation have been the source of inspiration in completion of this report.

Dr. Pradeep K Naik, Superintending Hydrogeologist, Rajiv Gandhi National Ground Water Training and Research Institute, Raipur has thoroughly scrutinised the draft report. I thank him for his valuable suggestions, inputs and guidance which helped a lot in bringing the report in the present form.

I would like to express my sincere thanks to Dr. R D Deshpande, Scientist-SG and Chairman, Geosciences Division, Physical Research Laboratory, Ahmedabad for his valuable guidance and suggestions in carrying out the works related to this study. I thank the Regional Director, CGWB, NCCR, Raipur for allowing analysis of water samples for major cations and anions in the Regional Chemical Laboratory. I thank Shri R K Dewangan, Scientist-B, CGWB, NCCR, Raipur for doing the chemical analysis of water samples.

Last but not the least; I thank Dr. Utpal Gogoi, Regional Director, CGWB, SER, Bhubaneswar for extending all the supports in preparation of this report.

Bikram Kumar Sahoo

EXECUTIVE SUMMARY

Study of interaction between ground water and surface water was carried out through investigation of stable isotopes of Deuterium (δD) and Oxygen (δ^{18}O) in water samples in a small watershed in Durg district, Chhattisgarh State. The area is underlain by Proterozoic limestone of Chhattisgarh Supergroup. The ground water in the area occurs under water table and semi-confined conditions. Ground water level varies between 2.03 m bgl and 28 m bgl during pre-monsoon and between 1.4 m bgl and 15.2 m bgl during post-monsoon season in the area. By and large, ground water in the area is potable in nature. Mapping of hydrochemical facies of the area shows that the ground water is calcium-bicarbonate type. A total of 53 ground water samples, 27 surface water samples (from nala, ponds and reservoirs) were collected both during pre- and post-monsoon seasons and were analysed for δD and δ^{18}O. Twelve rainwater samples were also collected and analysed for δD and δ^{18}O. The Local Meteoric Water Line (LMWL) has been constructed with the δD and δ^{18}O of rainfall (r^2=0.995).

Plotting of δD and δ^{18}O values of the surface water bodies and ground water collected during pre-monsoon season shows distinctive enrichment pattern which indicates that both waters are not in interaction. This shows that the surface water bodies, mainly the village ponds are not contributing to the ground water storage during this season. However, the identical isotopic compositions of surface water and ground water collected during post-monsoon season are indicative of active interaction of water of these two domains. The similarity of isotopic composition of ground water samples of both pre- and post-monsoon seasons with that of precipitation shows that the source of recharge of ground water is the same i.e. precipitation for both these seasons.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

Due to ever increasing stresses on ground water resources from different sectors, its augmentation through artificial means has become an inevitable management option for sustainability of this precious resource. The understanding of efficacy of any artificial recharge project depends on understanding of the surface and ground water interaction in that area. The ground water development in Durg (undivided) district, Chhattisgarh, which is underlain entirely by hard rocks has increased manifold. Consequently, few blocks in the district have been categorised as semi-critical to critical from ground water development point of view. Supply side management through augmentation of ground water through managed aquifer recharge by adopting suitable terrain specific methods is one of the measures to check the continuous declining trend of ground water in an area. However, the success or failure of the recharge measures depends upon whether there is any connectivity between the surface and sub-surface aquifers.

Through study of the environmental isotopes in the surface and ground water samples of the area, the source and area of recharge to the ground water can be ascertained. Environmental isotopes of Deuterium (δD) and Oxygen-18 ($\delta^{18}O$) have been widely used to study interaction between surface water and ground water. Variation of isotopic signatures both in surface and ground water samples can be used to understand the interaction and recharge process in hard rock terrain.

Keeping all these facts in view, a study on interaction of surface water and ground water through stable isotope investigations has been taken up in the Pulgaon Nala Watershed in Durg (undivided) district. Keeping in view the expertise of Central Ground Water Board in hydrogeological investigations and the expertise of Physical Research

Laboratory (PRL), a unit of Department of Space, Government of India in carrying out studies on isotopic investigations in hydrology, the study has been taken up jointly by these two organizations. A memorandum of agreement (MoA) was signed between the CGWB and PRL to carry out this research **(Annexure-I)**.

1.2 SCOPE OF THE WORK

In the present study titled "Stable Isotope Investigations to Study Surface Water-Ground Water Interaction in a Hardrock Terrain in Parts of Durg District, Chhattisgarh" the responsibility of RGNGWTRI is to compile available geological, geomorphological, hydrometerological, hydrogeological data and compilation of hydrogeological information of the study area; establish key observation wells and periodic monitoring of ground water levels; collect samples of precipitation, samples from surface water bodies (rivers, tanks and ponds) and samples of ground water for analysis of Deuterium (δD) and Oxygen-18 ($\delta^{18}O$) composition. The responsibility of PRL is utilization of existing hydrogeological data of the study area available with CGWB for planning collection of water samples from surface and ground water monitoring stations. Analysis of water samples for Deuterium (δD) and Oxygen-18 ($\delta^{18}O$) composition is in the scope of PRL, Ahmedabad where the facilities, infrastructure and expertise are available. After completion of the field work and analysis of water samples for isotopic signature, the analysis of the data and preparation of the final report is to be prepared jointly by both the organisations. The study will indicate the level of interaction between surface and ground water in areas underlain by hard rock which will ultimately help the researchers, planners and executing agencies in managing the ground water resources of such areas.

1.3 LOCATION, AREA AND EXTENT

The study area, Pulgaon Nala Watershed (**Fig. 1.1**) is bounded by 81°15'11" to 81°25'25" E longitudes and 20°57'29" to 21°10'54" latitudes and falls in the Survey of India (SOI) toposheets 64G/8 &64H/4. The Pulgaon Nala Watershed has an area of around 242 km^2

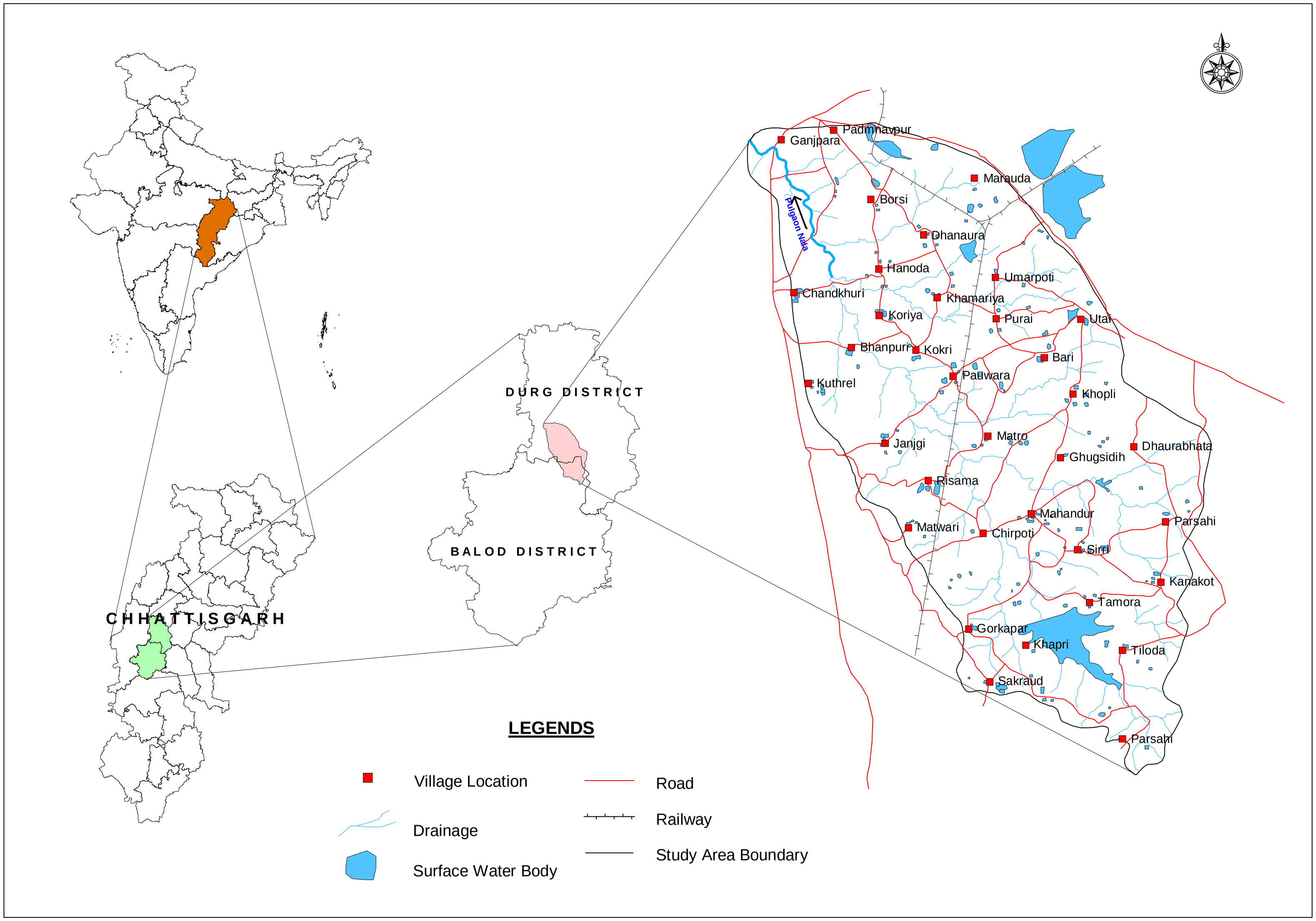


Fig. 1.1: Index map of the study area (Pulgaon Nala watershed) (Not to scale)

and falls in Durg and Balod districts of Chhattisgarh State. The study area is around 70 kms from Raipur, the capital city of Chhattisgarh and is well connected through a good network of roads with NH-6 that connects Mumbai and Kolkata. Durg and Bhilai are two towns near the study area. The index map of the study area is presented in **Fig. 1.1**.

1.4 CLIMATE

The climate of Durg is sub-tropical with three distinct seasons. Temperatures remain moderate for most of the year. Summer season starts with beginning of March and continues till the second week of June. Monsoon commences from middle of June and remains till the early October. Winter season commences from November and lasts till the end of January. The temperature rises to maximum in May, sometimes even touches 46^{o}C and the mean minimum temperature is around 11^{o}C in December (**Table 1.1** and **Fig. 1.2**).

Table 1.1: Mean temperature and relative humidity

Month	Mean Daily Temperature (^{o}C)		Relative humidity (%)	
	Max	Min	At 08:30 IST	At 17:30 IST
Jan	26.6	11.4	87.3	36.7
Feb	30.5	14.7	80.3	32.7
Mar	36.3	18.9	66.0	20.7
Apr	39.6	23.9	56.7	21.0
May	42.2	27.4	49.7	18.7
Jun	37.4	27.1	69.3	46.3
Jul	31.0	24.9	91.0	76.3
Aug	30.2	25.0	93.3	77.7
Sep	30.8	24.6	93.0	71.0
Oct	31.6	21.0	89.7	48.0
Nov	30.1	17.0	90.0	41.0
Dec	27.9	12.6	88.7	36.0
Annual	**32.8**	**20.7**	**79.6**	**43.8**

Station: Lavandi, Indira Gandhi Krishi Vishvavidyalaya, Raipur

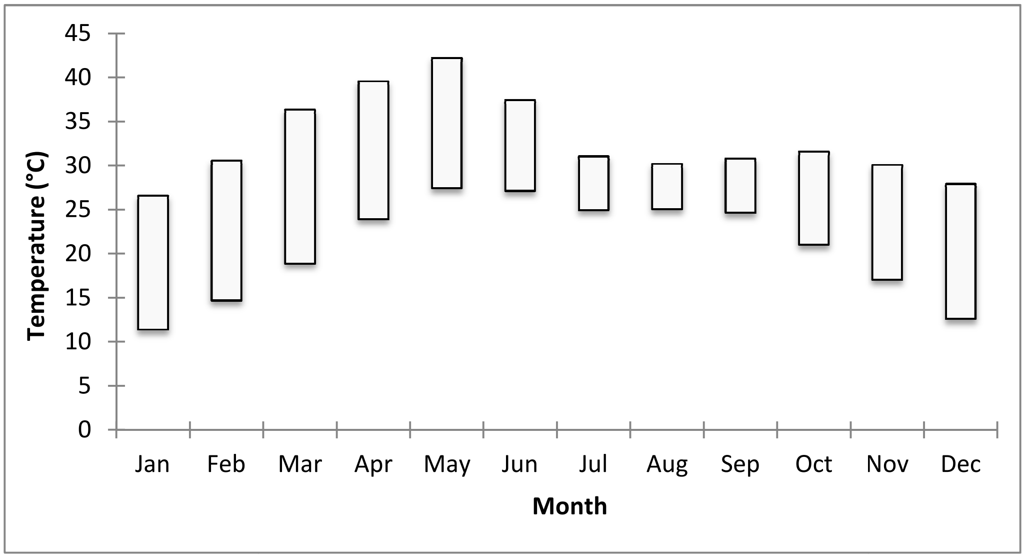


Fig. 1.2: Monthly variation of temperature

May is the hottest month and December is the coldest. Heat is experienced during the months from March to June. The day temperature during these months generally ranges from 36^{o}C to 42^{o}C and during night the temperature ranges from 19^{o}C to 27^{o}C.

The area receives rainfall from south west monsoon which contributes more than 85% of the total rainfall. The annual normal rainfall of the area is 1288.8 mm (**Fig. 1.3**) and on an average there are 63 rainy days in a year.

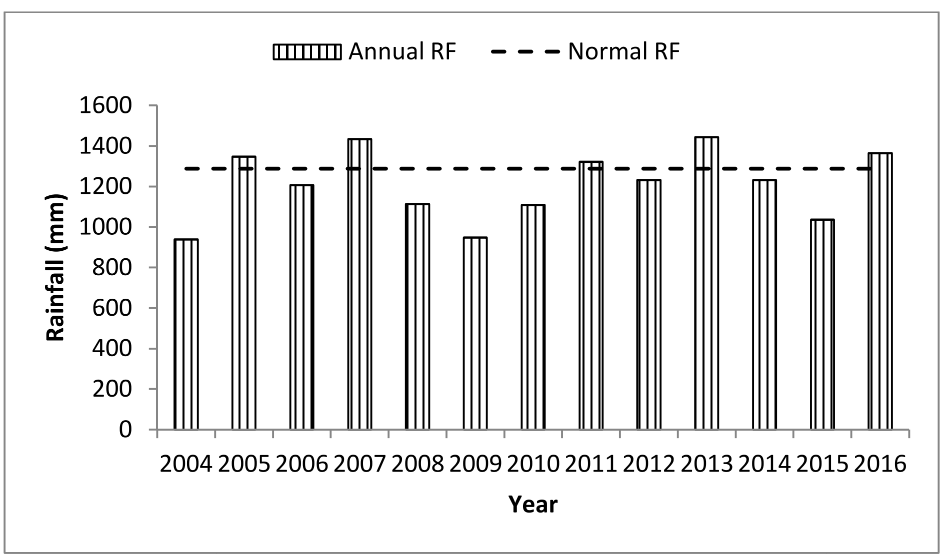


Fig. 1.3: Annual rainfall in the study area

The monsoon sets in the area in the mid-June and withdraws in early October. Rains are predominant during July to September. From June to September is the monsoon season and October to May is the non-monsoon season.

1.5 PHYSIOGRAPHY AND DRAINAGE

Physiographycally the area is a part of the Chhattisgarh Plain which is mostly flat in nature. The area is having gently sloping erosional surface and thin to moderate cover of soil. The highest and lowest elevations in the area are 300 mamsl and 280 mamsl respectively. The general slope of the area is towards the NNW direction.

The area falls in the Mahanadi Basin. The area is drained by Pulgaon Nala which flows towards NNW direction following the general slope of the area. Pulgaon Nala is a tributary of Tandula River which joins the Seonath River. Finally, Seonath River joins the Manahanadi River.

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It may be used as the best available index to describe a particular stream network. It is a measure of how well or how poorly a watershed is drained by stream channels. Drainage density depends upon physical characteristics of the drainage basin. Soil permeability and underlying rock type affect the runoff in a watershed; impermeable ground or exposed bedrock will lead to an increase in surface water runoff and therefore to more frequent streams. Rugged regions or those with high relief will also have a higher drainage density than other drainage basins if the other characteristics of the basin are the same. The drainage density in the area is calculated as 0.75 km/km^2, which is very less. This indicates good infiltration capacity of the soil of the watershed as well as the flat nature of the terrain.

Numerous surface water bodies are present in the area. They are mostly village ponds and surface water reservoirs. The total area of all the water bodies in the watershed is around 8.1 km^2. Largest among them is the Khapri Reservoir at the southern part of the study area which has an area of around 4.1 km^2.

The physiography and drainage map of the study area is presented in the **Fig. 1.4**.

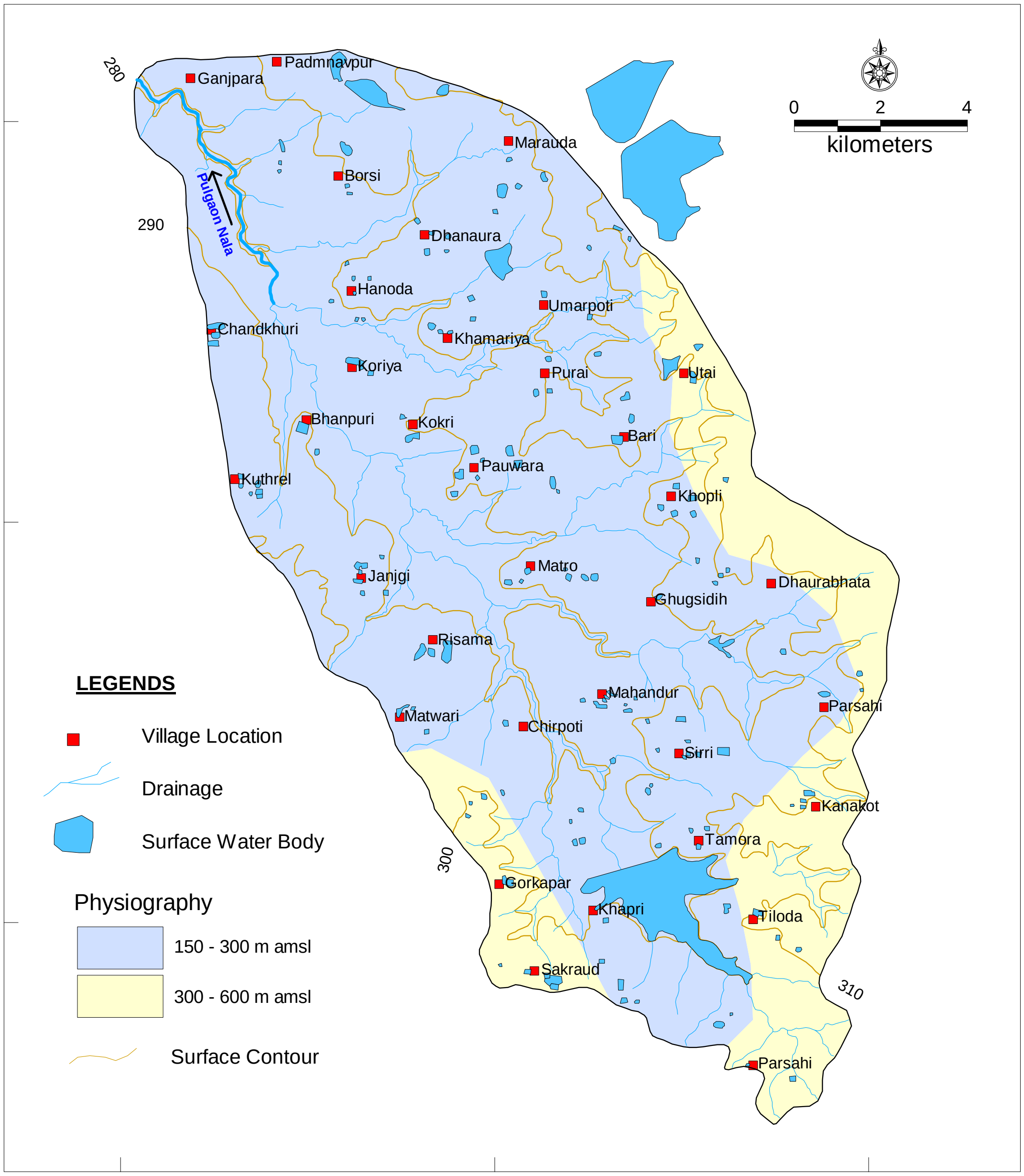


Fig. 1.4: Physiography and drainage map of the study area (Pulgaon Nala watershed)

1.6 SOIL

Generally, soils are classified on the basis of texture, mineral content and presence of salts and alkalies. However, in present context the classification and distribution is adopted as per the soil orders in US soil taxonomy and their Indian equivalents. There are 12 orders in US soil taxonomy but only one order is found in the study area. The soil that covers the study area belongs to the Vertisol order of the US soil taxonomy and its Indian equivalent is Deep Black Soil.

Vertisol is a soil in which the content of clay size particles is 30% or more by mass in all horizons of the upper half-metre of the soil profile. They are characterized by a high content of expanding and shrinking clay known as montmorillonite. They may also be characterized by salinity and well defined layers of calcium carbonate or gypsum. Evidence of strong vertical mixing of the soil particles over many periods of wetting and drying can be observed in this type of soil. Vertisols are found typically on level or mildly sloping topography in climatic zones that have distinct wet and dry seasons. Depending on the parent material and the climate, they can range from grey or red to the more familiar deep black. Vertisols contain high level of plant nutrients, but, owing to their high clay content, they are not well suited to cultivation without painstaking management. Vertisols are especially suitable for rice because they are almost impermeable when saturated. Rainfed farming is very difficult because vetisols can be worked only under a very narrow range of moisture conditions as they become very hard when dry and become very sticky when wet.

1.7 GEOLOGICAL SETUP

The study area is entirely covered by the rocks of Raipur Group which belongs to Chhattisgarh Supergroup of Proterozoic age and comprises of limestone, shale and sandstone. The geological succession of Chhattisgarh Supergroup is presented in the **Table 1.2.** The major rocks in the area are limestone and sandstone of Chandi Formation and shale of Gunderdehi Formation which belong to Raipur Group of Chhattisgarh

Supergroup of rocks. Gunderdehi Formation consists of purple to reddish brown calcareous shale.

Table 1.2: General geological succession of the study area

Age	Stratigraphic Unit		Major Lithology	Description of Lithology
Quaternary	Recent to sub-recent		Top soil	Soil/ Laterite/ Alluvium
			Dolerite Intrusive	
Meso-Neo Proterozoic	Chhattisgarh Supergroup	Raipur Group		
		Chandi Formation (136 m)	Sandstone (0-2 m)	Purple to brown, bedded, ferruginous, glauconite ortho-quartzite, and white thinly bedded sand stone
			Shale-Sandstone Intercalation (0-3m) Shale (0-35 m)	Pale cream, non-calcareous shale with thinly bedded to laminated sandstone. Yellowish to pale, non-calcareous, thinly laminated shale.
			Limestone (35-136 m)	Purple to grey Stromatolitic limestone with occasional shale intercalation.
		Gunderdehi Formation (227 m)	Calcareous Shale	Purple, thinly laminated shale.
		Chamuria Formation	Limestone	Grey, flaggy, laminated limestone.
		Chanderpur Group		
Archaean	Older basement (Rocks of Dongargarh Supergroup, Chilpi Group, Iron ore Group, Amgaon Group)			

Note: The broken line represents unconformity.

This Formation covers a very small portion with an area of around 14 km^2 and is found in the south-western parts of the study area. The rest 228 km^2 is covered by Chandi Formation which consists of grey and purple stromatolitic limestone with arenite/ferruginous sandstone intercalations (Deodongar member). Rocks in the area are, in general, horizontally bedded to gently dipping, structurally non-deformed rocks. The limestone are thickly bedded to massive (**Fig. 1.5**), jointed, karstic in nature showing fractures, solution cavities and sink holes.

Fig. 1.5: Limestone exposure in the quarry face in the study area (Village: Ghugsidih)

The geological map of the Study Area is presented in **Fig. 1.6.**

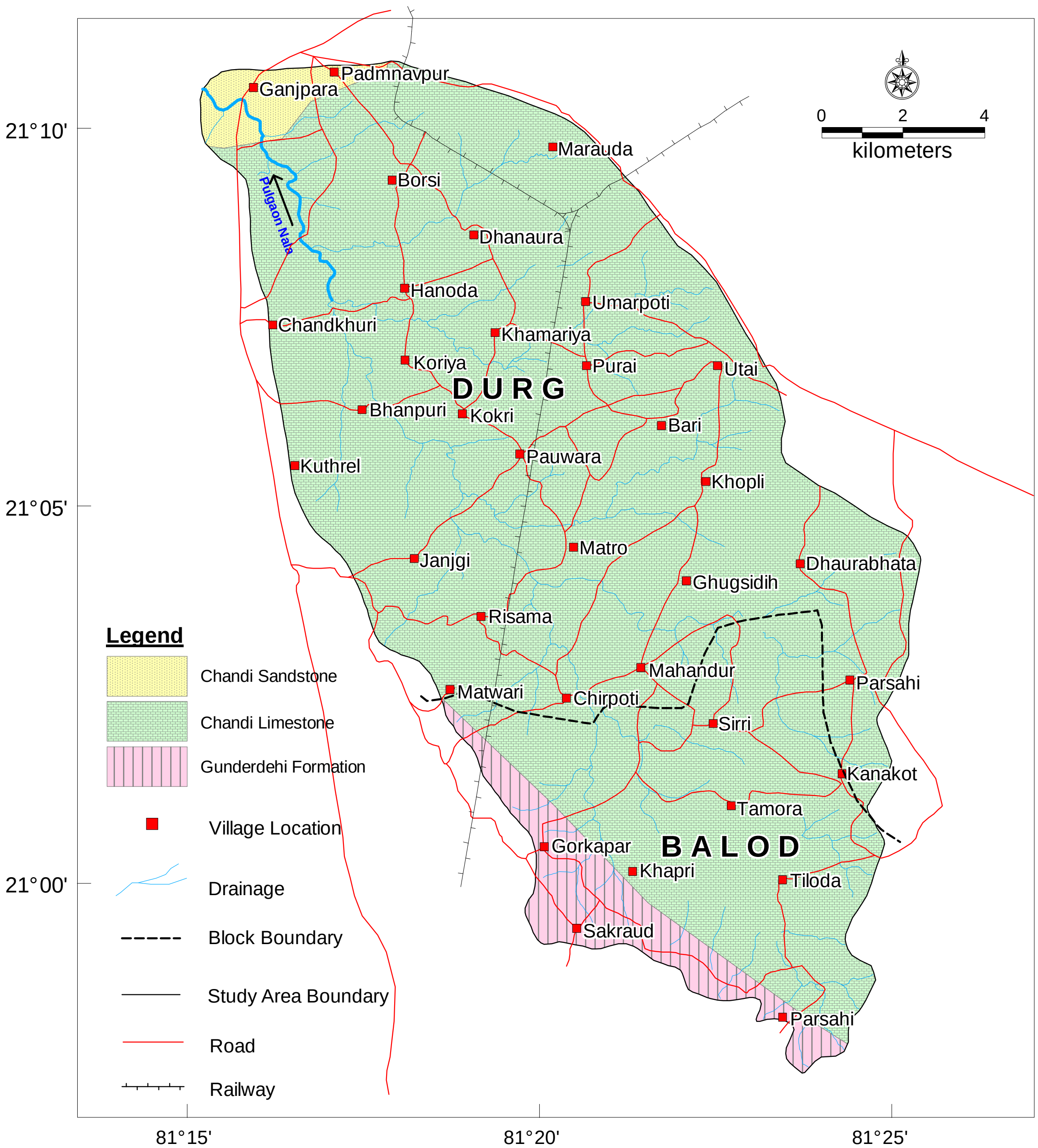


Fig. 1.6: Geological map of the study area (Pulgaon Nala watershed)

Chapter 2

HYDROGEOLOGY

2.1 WATER BEARING FORMATIONS

Hard rocks underlying the area consist mainly of limestone, shale and sandstone of Chandi Formation and belong to Chhattisgarh Supergroup of Proterozoic age. Limestone exposures are found in major parts of the area. The limestone in the area has developed karsts through the action of the carbonic acid solution, which dissolves calcium carbonate in the limestone. The carbonic acid that causes karstic features is formed as rain passes through the atmosphere picking up carbon dioxide (CO_2), which dissolves in the water. Once the rain reaches the ground, it passes through soil that can provide much more CO_2 to form a weak carbonic acid solution, which dissolves calcium carbonate.

The ground water in the area occurs under water table and semi-confined conditions. The weathered and fractured part of the formation constitutes the aquifers in the area. These formations are the most potential in regards to ground water yield. The weathered zone is restricted to upper 30 m depth. Most of the fractures are productive down to 150 m. The yield of exploratory wells drilled by CGWB in this formation varies between 1-12 lps with maximum no. of wells having discharge of around 3 lps. The transmissivity of value for Chandi Formation in the area varies between 7-63 m^2/day.

2.2 BEHAVIOUR OF WATER LEVEL

The water level behavior of the study area was studied by monitoring the water levels in the bore wells (hand pumps). Water levels were measured in 34 bore wells (**Annexure-II**) during the pre-monsoon season (May 2016) and in 38 bore wells (**Annexure-III**) during the post-monsoon season (November 2016). The bore wells tap mainly the semi-confined aquifer that is being used for abstraction of ground water.

The no and percentage of wells with different DTW ranges during pre-monsoon and post-monsoon seasons are presented in **Table 2.1.**

Table 2.1: Wells with different ranges of water levels

DTW Range (m bgl)	Pre-monsoon season		Post-monsoon season	
	No of wells	% of wells	No of wells	% of wells
0 to 3	2	5.88	6	15.79
3 to 5	1	2.94	12	31.58
5 to 10	17	50.00	14	36.84
10 to 15	9	26.47	4	10.53
15 to 20	3	8.82	2	5.26
20 to 30	2	5.88		
Total	34		38	

The water level during the pre-monsoon season varies between 2.03 m bgl and 28 m bgl in the study area. In this season, maximum number of wells i.e. 50% (17 nos. of wells out of 34) show depth to water (DTW) in the range of 5 to 10 m bgl; 26.47% of wells show DTW in the range of 10 to 15 m bgl and another 14.7% show DTW in the range of 15 to 30 m bgl (**Fig. 2.1**). A total of 8.82% of wells have water level less than 5 m bgl. The shallowest water level was observed in the bore well at Ganjpara which is located at the mouth of the Nala and the deepest water level is observed in the bore well at Daurabhata which is located near the eastern boundary of the watershed.

Similarly, the water level during the post-monsoon season varies between 1.4 m bgl and 15.2 m bgl in the study area. In this season, maximum number of wells i.e. 36.84% show depth to water (DTW) in the range of 5 to 10 m bgl; followed by 31.58% of wells with DTW in the range of 3 to 5 m bgl and another 15.79% show DTW less than 3 m bgl (**Fig. 2.2**). Only 5.26% wells have water level more than 15 m bgl. The shallowest water level was observed in the bore well at Parsahi which is located at the south-eastern part of the watershed and the deepest water level is observed in the bore well at Marauda which is located near the north-eastern boundary of the watershed.

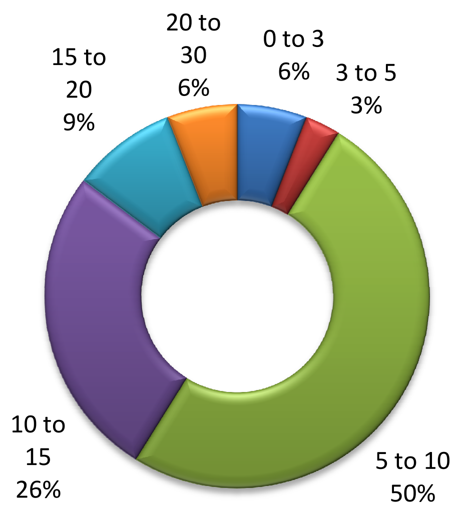


Fig. 2.1: Percentage of wells with different DTW ranges during pre-monsoon season.

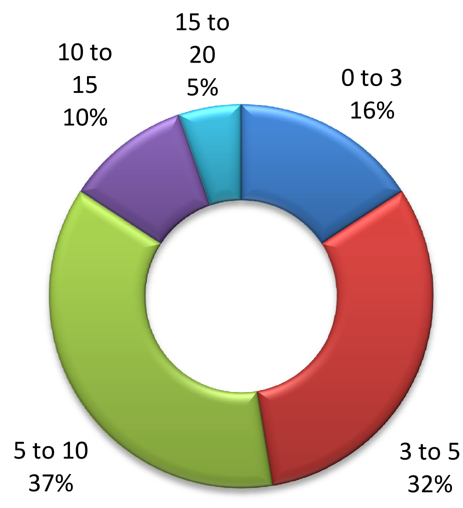


Fig. 2.2: Percentage of wells with different DTW ranges during post-monsoon season.

Ground-water levels are controlled by the balance among recharge to, storage in, and discharge from an aquifer. The no. and percentage of wells with different water level fluctuation ranges is presented in **Table 2.2** and **Fig. 2.3.**

Table 2.2: Wells with different ranges of water level fluctuations

Fluctuation Range (m)	No of wells	% of wells
0 to 3	9	28.125
3 to 5	11	34.375
5 to 10	7	21.875
10 to 15	4	12.5
15 to 20	1	3.125
Total	32	

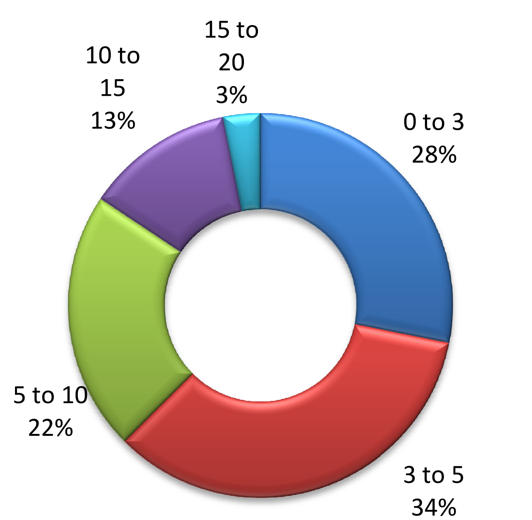


Fig. 2.3: Percentage of wells with different water level fluctuation ranges between pre- and post-monsoon seasons.

From ground water fluctuation figures it is evident that all the wells monitored in the study area have shown a rise in water level during the month of November as compared to the month of May. The maximum fluctuation is recorded as 16.38 m at Daurabhata and the minimum is 0.98 m at Parsahi.

The depth to water level maps of the study area during pre-monsoon and post-monsoon seasons and ground water level fluctuation maps between pre- and post monsoon seasons are presented in **Fig. 2.4, Fig. 2.5** & **Fig. 2.6**, respectively.

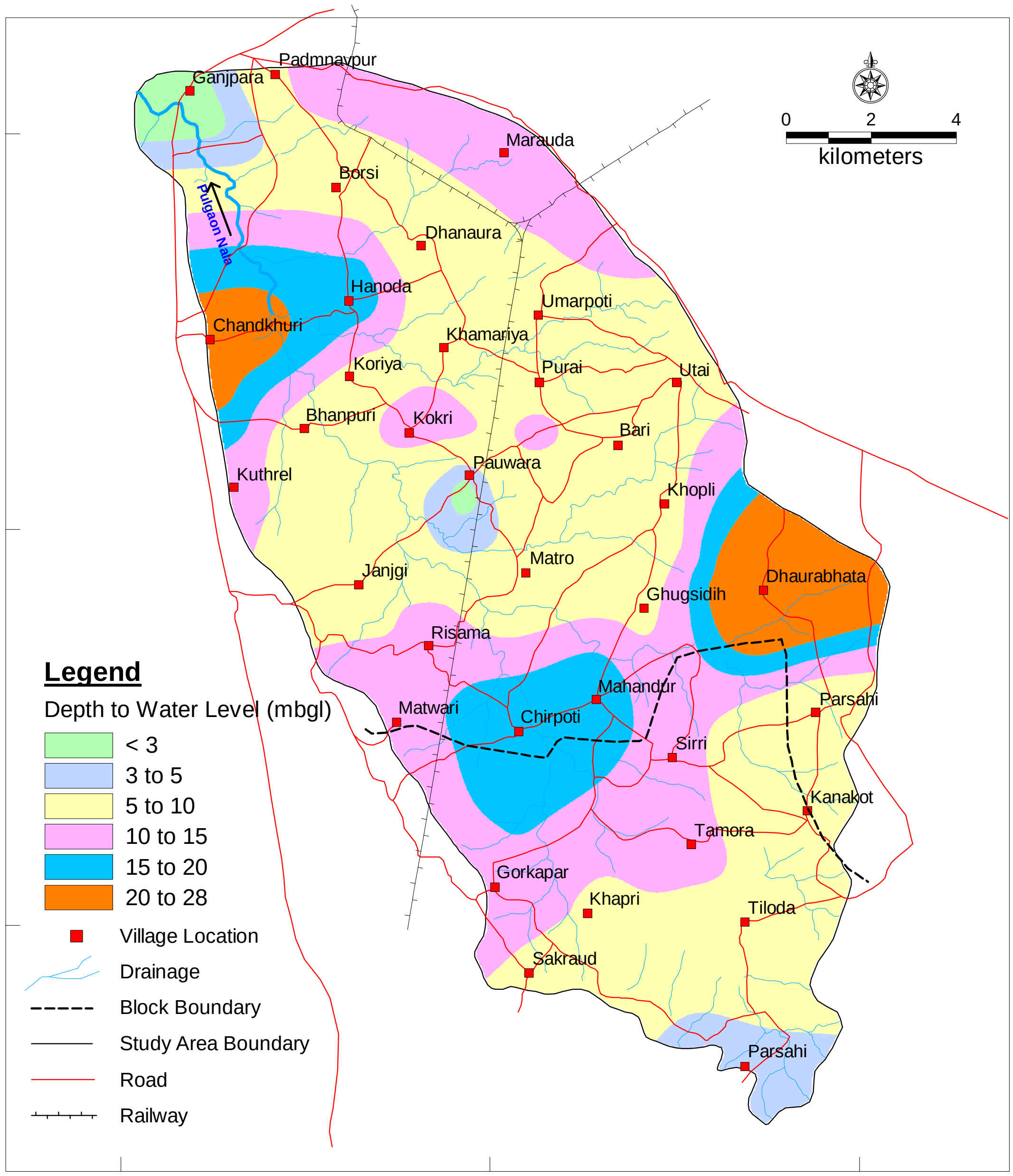


Fig. 2.4: Depth to water level (mbgl) map of the study area (Pulgaon Nala watershed) during May 2016

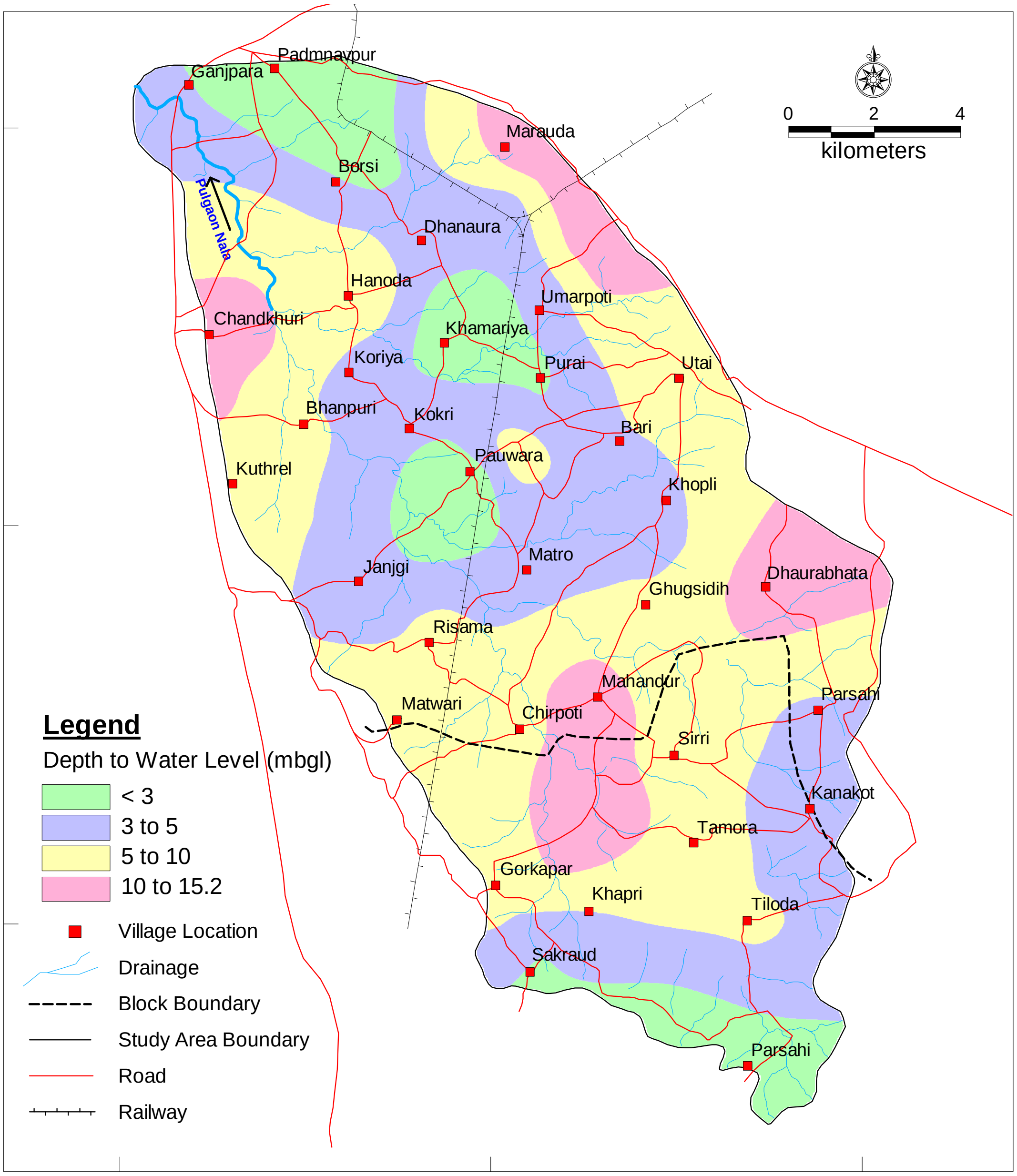


Fig. 2.5: Depth to water level (mbgl) map of the study area (Pulgaon Nala watershed) during November 2016

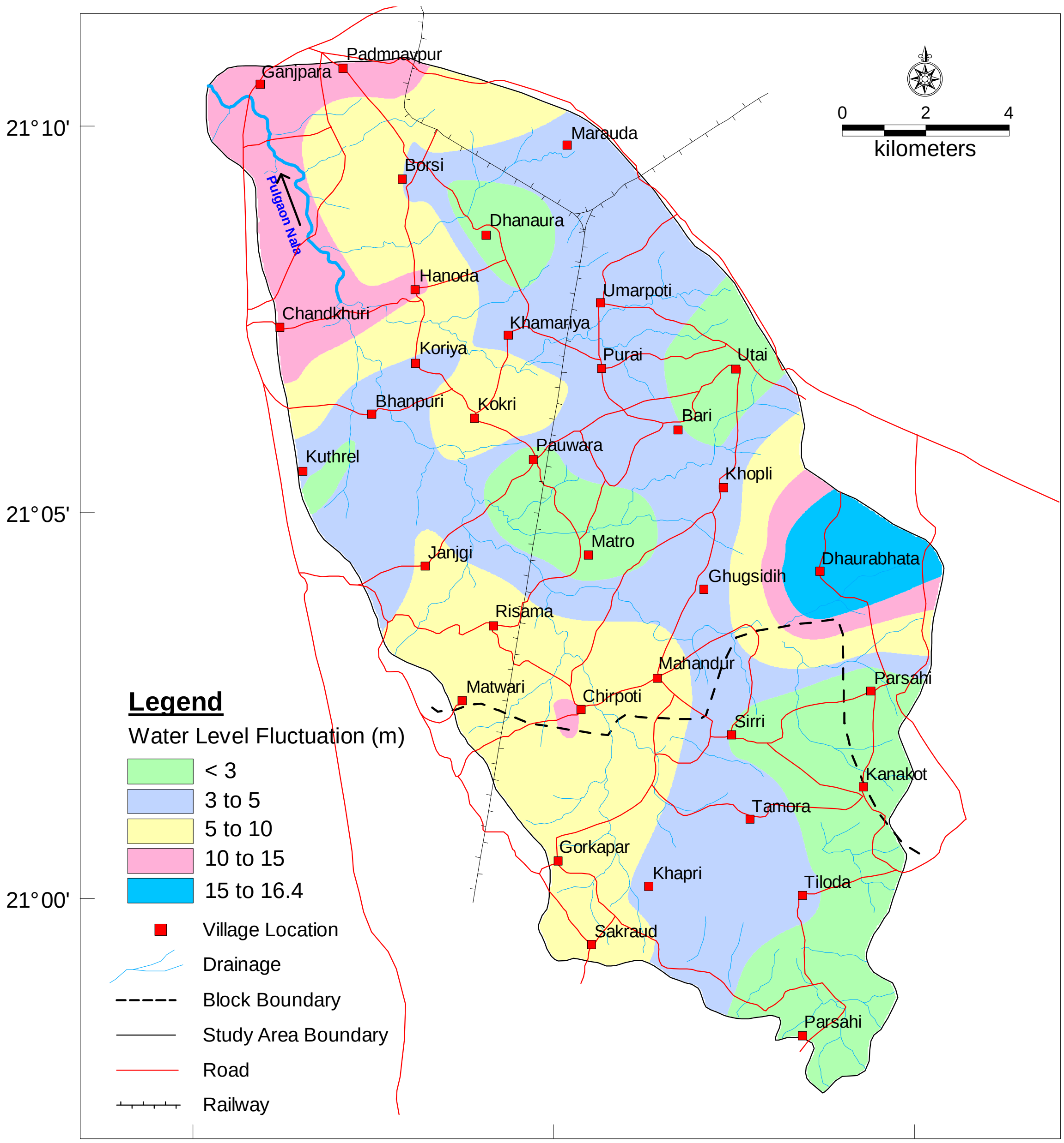


Fig. 2.6: Seasonal water level fluctuation(m) map of the study area (Pulgaon Nala watershed)

Chapter 3

HYDROCHEMISTRY

3.1 INTRODUCTION

Evaluation of ground water quality is as important as its quantity for assessment of ground water resources. Ground water is never pure and contains varying amounts of dissolved solids, the types and concentrations of which depend on their sources, surface and sub-surface environments and rate of ground water movement. The chemical quality of ground water is a function of the quality of the recharge water and the reactions that occur along its flow path, particularly between the moving fluids and the geologic materials. The concentrations of various chemical constituents in ground water depend on the solubility of minerals present, the resident time and the amount of dissolved carbon dioxide. In addition to the natural changes, anthropogenic activities such as sewage disposal, agricultural practices, industrial pollution, etc. also contribute significantly to changes in ground water quality.

The general ground water quality of the study area was studied through analysis of ground water samples collected from 36 bore wells during pre-monsoon season (**Annexure-IV**) and from 50 bore wells during post-monsoon season (**Annexure-V**). Onsite measurements of Temperature, Electrical Conductivity (EC) and pH value of water samples were carried out by using portable kit. The water samples were analysed for concentration of major cations and anions in the Regional Hydrochemical Laboratory of CGWB, NCCR, Raipur.

3.2 QUALITY OF GROUND WATER

The pH of ground water in the study area varies between 7.09 and 8.87 during pre-monsoon season and between 6.8 and 8.8 during post-monsoon season. From the pH values, it is evident that the ground water in the study area is slightly alkaline in nature.

The EC values in the study area vary between 362 µS/cm and 1670 µS/cm during pre-monsoon season and between 327 µS/cm and 2680 µS/cm during post-monsoon season. The higher values of EC during post-monsoon season are resulted due to the leaching of minerals from host rocks due to rainfall recharge. The western and south-western parts of the study area show higher concentrations of EC. The **Fig. 3.1** and **Fig. 3.2** show distribution of EC in ground water in the study area during pre- and post-monsoon seasons, respectively. Total dissolved solids which is the sum total of different cations and anions present in the ground water give an overall idea about the quality of the ground water. It can be calculated by multiplying the EC value with the factor 0.64. The TDS concentration of fresh water varies between 192 mg/l and 1280 mg/l. The higher value of TDS (though within permissible limits) in the ground water in the area is due to the presence of limestone which is susceptible to dissolution.

Total hardness (TH) is defined as the sum of the calcium and magnesium concentrations, both expressed as $CaCO_3$, in mg/L. Although hardness is caused by cation, it may also be discussed in terms of carbonate (temporary) and non-carbonate (permanent) hardness. Carbonate hardness refers to the amount of carbonates and bicarbonates in solution that can be removed or precipitated by boiling. This type of hardness is responsible for the deposition of scale in hot water pipes and kettles. Non-carbonate hardness is caused by the association of the hardness-causing cation with sulphate, chloride or nitrate and is referred to as “permanent hardness”. This type of hardness cannot be removed by boiling.

Desirable and maximum permissible limits (IS: 10500:2012) for TH in drinking water are 200 and 600 mg/l, respectively. The TH values in the study area vary between 25 mg/l and 485 mg/l during pre-monsoon season and between 30 mg/l and 875 mg/l during post-monsoon season. The **Fig. 3.3** and **Fig. 3.4** show distribution of TH in ground water in the study area during pre- and post-monsoon seasons, respectively.

The ranges of concentrations of different cations and anions in ground water during pre- and post-monsoon seasons are presented in **Table 3.1.** The mean concentrations of

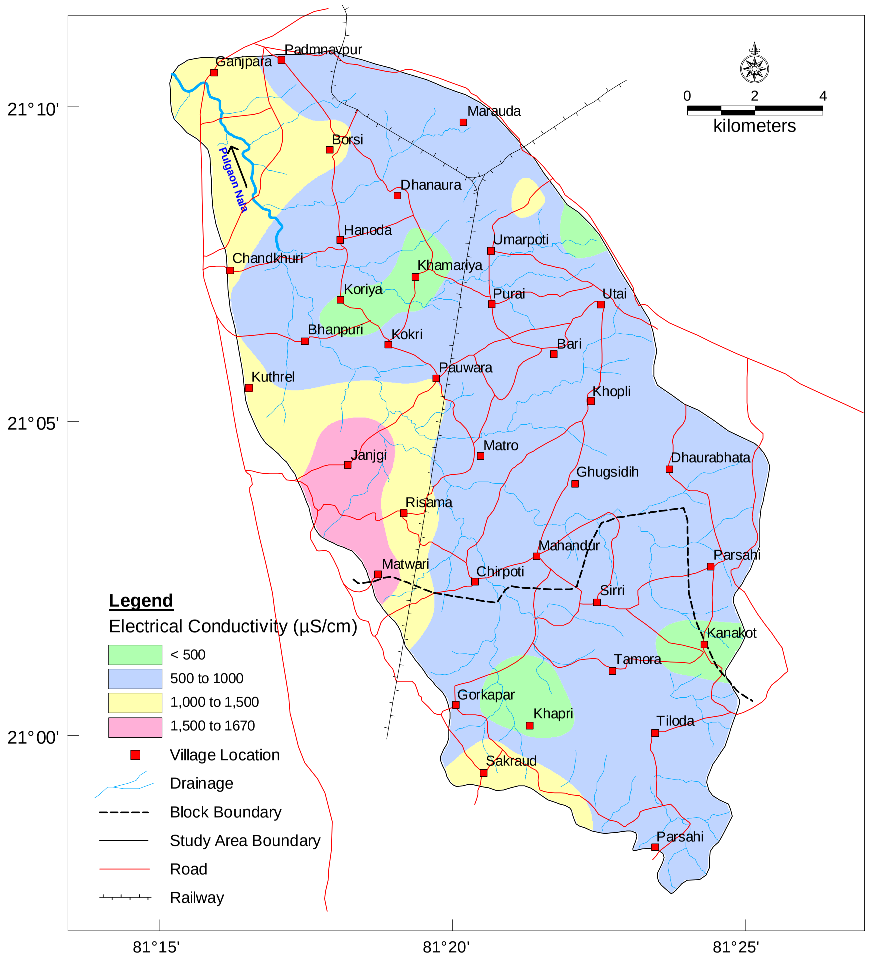


Fig. 3.1: Map showing electrical conductivity (µS/cm) of ground water during pre-monsoon season in the study area

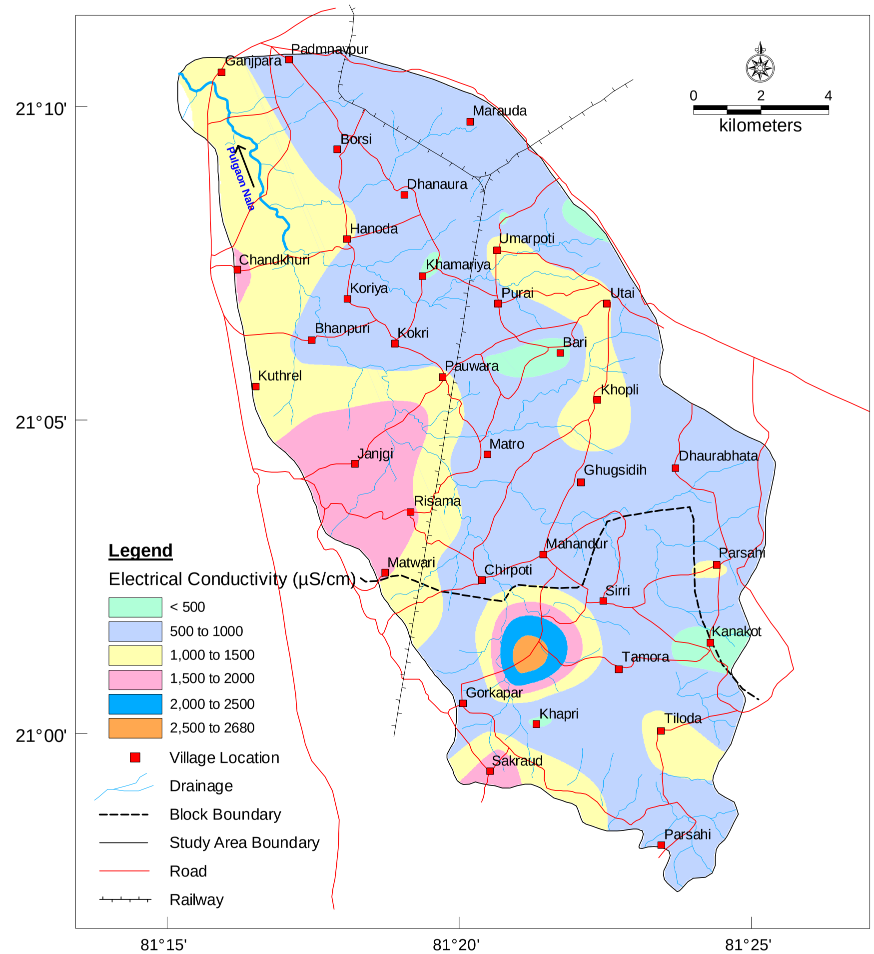


Fig. 3.2: Map showing electrical conductivity (µS/cm) of ground water during post-monsoon season in the study area

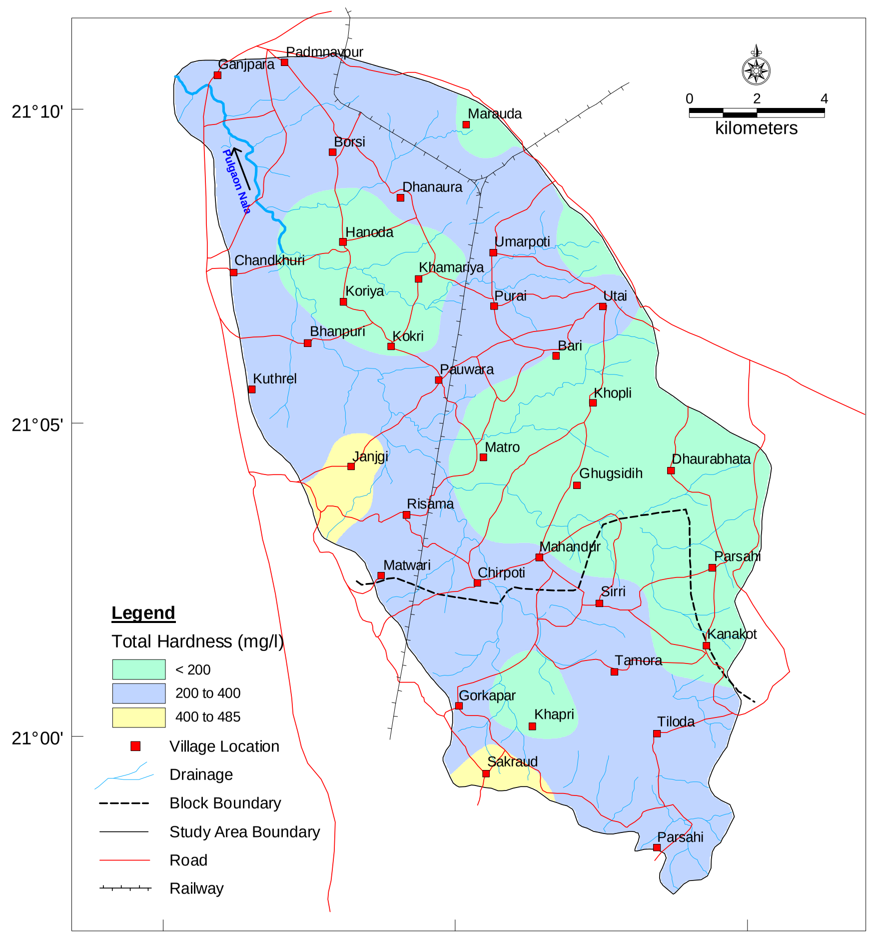


Fig. 3.3: Map showing total hardness (mg/l) of ground water during pre-monsoon season in the study area

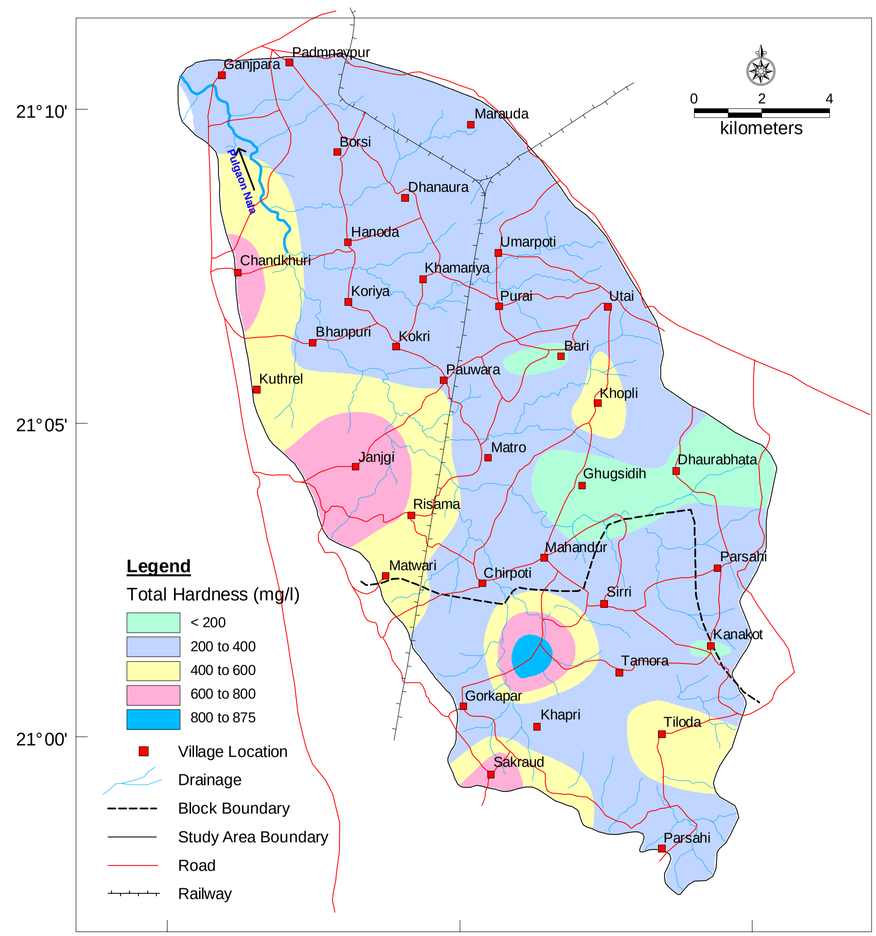


Fig. 3.4: Map showing total hardness (mg/l) of ground water during post-monsoon season in the study area

water quality parameters observed in the study area are presented in **Fig. 3.5**. From the table and figure, it can be observed that the concentrations of all the parameters show higher values during post-monsoon season as compared to the pre-monsoon season indicating enrichment of ground water through dissolution and leaching of host rock during the process of recharge.

Table 3.1: Comparison of concentrations of chemical parameters in ground water during pre- and post-monsoon seasons.

Sl. No.	Parameter		Minimum		Maximum		Mean	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1	pH		7.09	6.8	8.87	8.8	7.45	7.36
2	EC in µS/cm		362	327	1670	2680	815.53	882.36
3	TDS	in mg/l	235.3	212.55	1085.5	1742	530.09	573.53
4	TH		25	30	485	875	245.42	333.89
5	Ca		4	4	204	282	93.61	104.61
6	Mg		1.2	3.6	37.2	40.8	12.13	17.37
7	Na		9	6	191.7	194	42.40	45.56
8	K		0.3	0	48.4	47	3.76	2.49
9	CO_3		0	0	0	0	0	0
10	HCO_3		122	171	451	482	292.11	298.11
11	Cl		14	11	277	561	88.33	108.19
12	SO_4		1.2	3	55.1	152	25.27	40.33
13	F		0	0.1	1	0.7	0.25	0.34

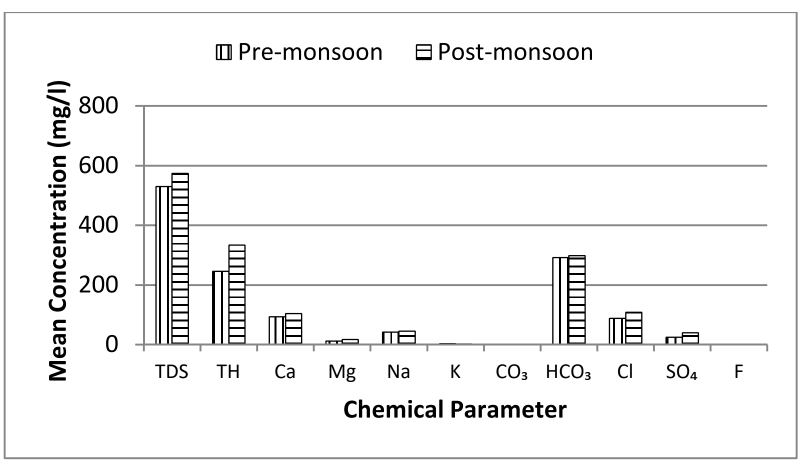


Fig. 3.5: Mean concentrations of water quality parameters observed during pre- and post-monsoon seasons

3.3 SUITABILITY OF WATER FOR VARIOUS USES

The quality of ground water in the study area is studied for its suitability for various uses. The ground water is slightly alkaline in nature. Major chemical constituents of water both during pre- and post-monsoon seasons are well within the permissible limits of the standards prescribed by the Bureau of Indian Standards (BIS) for drinking purposes. In terms of hardness, the water is moderately hard. Overall, the water is commonly potable. **Tables 3.2** and **3.3** show the suitability of the ground water during pre- and post-monsoon seasons for drinking purposes.

Table 3.2: Chemical quality of water (pre-monsoon) for drinking purposes

S. No.	Parameters	Conc.		Range	No of samples	Percentage of samples	Indian standard (BIS)	
		Min	Max				Desirable	Permissible
1	TDS in mg/l	235	1085	<500	19	52.78	500	2000
				500-2000	17	47.22		
				>2000	0	0.00		
2	Total Hardness in mg/l	25	485	<200	12	33.33	200	600
				200-600	24	66.67		
				>600	0	0.00		
3	Chloride in mg/l	14	277	<250	35	97.22	250	1000
				250-1000	1	2.78		
				>1000	0	0.00		
4	Sulphate in mg/l	1	55	<200	36	100.00	200	400
				200-400	0	0.00		
				>400	0	0.00		
5	Fluoride in mg/l	0	1	<1.0	36	100.00	1	1.5
				1.0-1.5	0	0.00		
				>1.5	0	0.00		
6	Calcium in mg/l	4	204	<75	12	33.33	75	200
				75-200	23	63.89		
				>200	1	2.78		

S. No.	Parameters	Conc.		Range	No of samples	Percentage of samples	Indian standard (BIS)	
		Min	Max				Desirable	Permissible
7	Magnesium in mg/l	1	37	<30	34	94.44	30	100
				30-100	2	5.56		
				>100	0	0.00		
8	Sodium in mg/l	9	192	<100	32	88.89	No Guideline	No Guideline
				>100	4	11.11		
9	Potassium in mg/l	0.3	48	<10	33	91.67	No Guideline	No Guideline
				>10	3	8.33		

Table 3.3: Chemical quality of water (post-monsoon) for drinking purposes

S. No.	Parameters	Conc.		Range	No of samples	Percentage of samples	Indian standard (BIS)	
		Min	Max				Desirable	Permissible
1	TDS in mg/l	213	1742	<500	19	38.00	500	2000
				500-2000	31	62.00		
				>2000	0	0.00		
2	Total Hardness in mg/l	30	875	<200	8	16.00	200	600
				200-600	38	76.00		
				>600	4	8.00		
3	Chloride in mg/l	11	561	<250	47	94.00	250	1000
				250-1000	3	6.00		
				>1000	0	0.00		
4	Sulphate in mg/l	3	152	<200	50	100.00	200	400
				200-400	0	0.00		
				>400	0	0.00		
5	Fluoride in mg/l	0.1	0.7	<1.0	50	100.00	1	1.5
				1.0-1.5	0	0.00		
				>1.5	0	0.00		
6	Calcium in mg/l	4	282	<75	16	32.00	75	200
				75-200	29	58.00		
				>200	5	10.00		

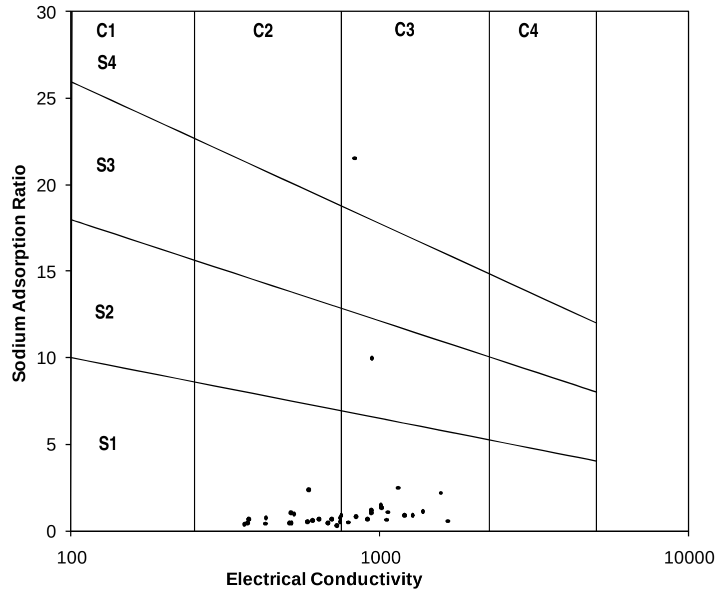
S. No.	Parameters	Conc.		Range	No of samples	Percentage of samples	Indian standard (BIS)	
		Min	Max				Desirable	Permissible
7	Magnesium in mg/l	3.6	40.8	<30	47	94.00	30	100
				30-100	3	6.00		
				>100	0	0.00		
8	Sodium in mg/l	6	194	<100	45	90.00	No Guideline	No Guideline
				>100	5	10.00		
9	Potassium in mg/l	0	47	<10	44	88.00	No Guideline	No Guideline
				>10	6	12.00		

The suitability of ground water in the study area for irrigation purposes was also studied. The sodium absorption ratios (SAR) are calculated and are plotted against EC values for both pre- and post-monsoon seasons and are presented in **Fig. 3.6** and **Fig. 3.7** as US salinity diagrams. The SAR values indicate the degree to which irrigation water tends to enter into cation exchange reaction with soil. High value of SAR indicates a hazard of sodium replacing already absorbed Ca and Mg in the soil, which in turn leads to damaging the soil structure. The formula for calculating the sodium adsorption ratio (SAR) is:

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

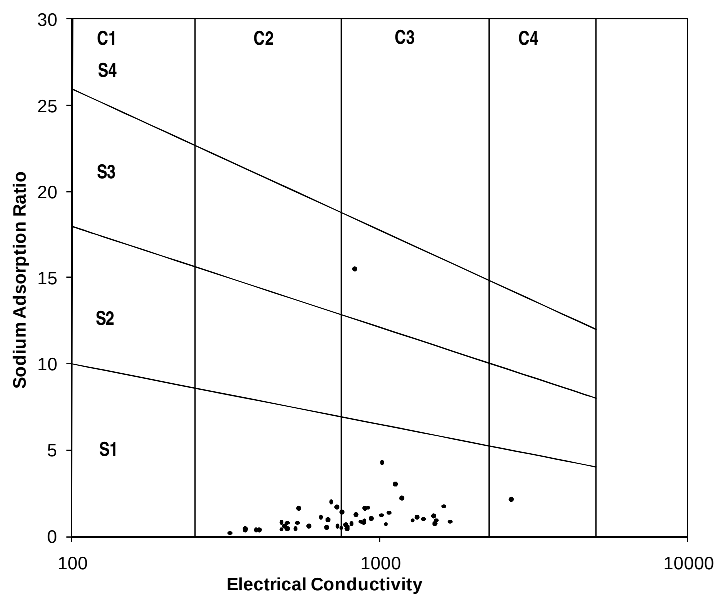
where sodium, calcium and magnesium concentrations are expressed in milliequivalents/litre.

From the figures, it may be seen that the ground water is falling under low sodium hazard zone and under medium to high salinity hazard zone.



S1, S2, S3 and **S4** are Low, Medium, High and Very High Sodium Hazards respectively.
C1, C2, C3 and **C4** are Low, Medium, High and Very High Salinity Hazards respectively.

Fig. 3.6: Suitability of water (pre-monsoon season) for irrigation use. Adapted from U.S. Salinity Laboratory Staff (1954).



S1, S2, S3 and **S4** are Low, Medium, High and Very High Sodium Hazards respectively.
C1, C2, C3 and **C4** are Low, Medium, High and Very High Salinity Hazards respectively.

Fig. 3.7: Suitability of water (post-monsoon season) for irrigation use. Adapted from U.S. Salinity Laboratory Staff (1954).

3.4 EVOLUTION OF GROUND WATER

The groundwater gets enriched in dissolved minerals as it percolates through different lithologies. As it moves underground, it tends to develop a chemical equilibrium with its environment. Mapping of hydrochemical facies in an area gives an idea about the evolution of ground water in that area. Trilinear diagrams used by Piper (1944) can be used to delineate hydrochemical facies, because they graphically demonstrate relationships between the most important dissolved constituents in a set of ground-water samples.

Walton (1970) described a simple but useful classification scheme that divides the central part of the diagram into five subdivisions (**Fig. 3.8**). In the first four of these subdivisions, the concentrations of a specific cation-anion combination exceeds 50 percent of the total milliequivalents per liter (meq/L). Five basic hydrochemical facies can be defined with these criteria:

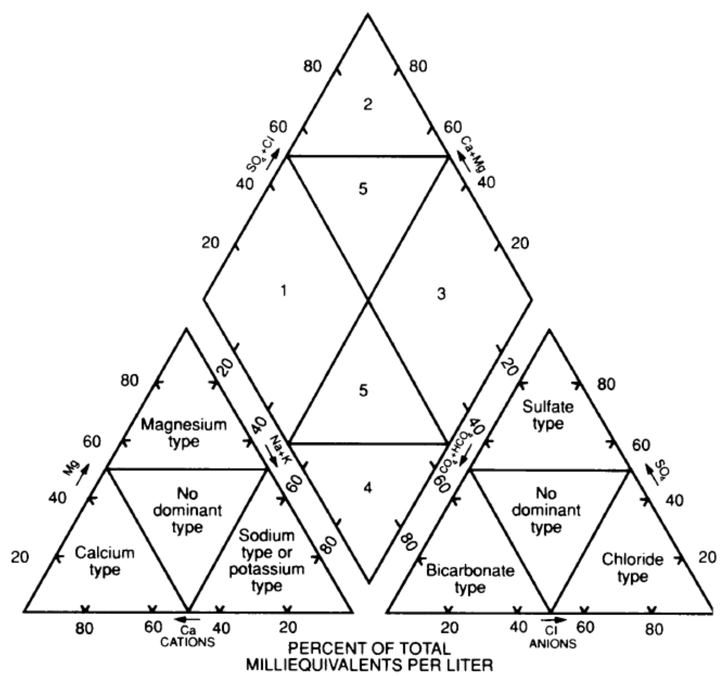


Fig. 3.8: Classification of water based on Piper trilinear diagram

1. Primary Hardness; Combined concentrations of calcium, magnesium and bicarbonate exceed 50 percent of the total dissolved constituent load in meq/L. Such waters are generally considered hard and are often found in limestone aquifers or unconsolidated deposits containing abundant carbonate minerals.
2. Secondary Hardness; Combined concentrations of sulphate, chloride, magnesium and calcium exceed 50 percent of the total meq/L.
3. Primary Salinity; Combined concentrations of alkali metals, sulphate and chloride are greater than 50 percent of the total meq/L. Very concentrated waters of this hydrochemical facies are considered brackish or (in extreme cases) saline.
4. Primary Alkalinity; Combined sodium, potassium and bicarbonate concentrations exceed 50 percent of the total meq/L. These waters generally have low hardness in proportion to their dissolved solids concentrations (Walton, 1970).
5. No specific cation-anion pair exceeds 50 percent of the total dissolved constituent load. Such waters could result from multiple mineral dissolution or mixing of two chemically distinct ground-water bodies.

The plotting of samples on the Hill-Piper diagrams (**Fig. 3.9** and **Fig. 3.10**) show that almost all the samples fall in the 1st and a few in 5th fields of the central diamond shape. This indicates two major hydrochemical facies in the area. The samples which fall in 1st field of the central diamond shape have primary hardness where combined concentrations of calcium, magnesium and bicarbonate exceed 50 percent of the total dissolved constituent load in meq/l and are characteristics of limestone aquifers. The samples falling in the 5th field of the diamond shape indicating no specific cation-anion pair exceeds 50 percent of the total dissolved constituent load. Such waters could result from multiple mineral dissolution or mixing of two chemically distinct ground-water bodies.

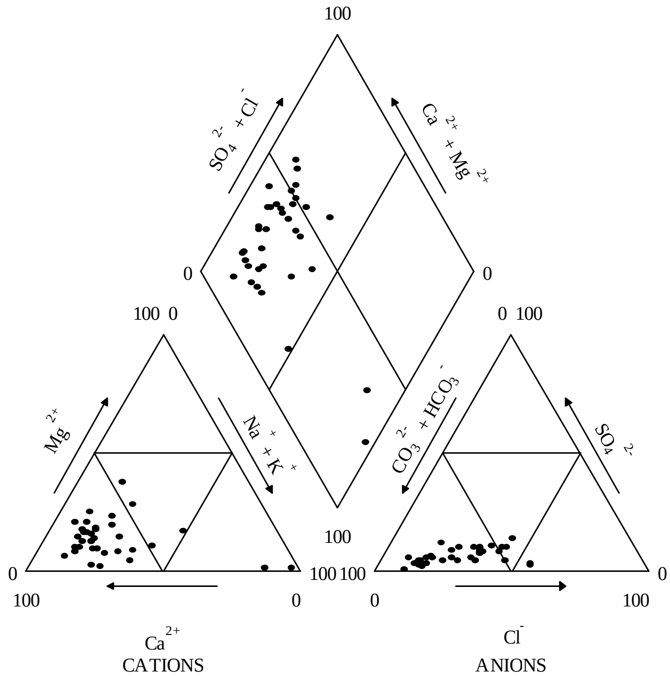


Fig. 3.9: Trilinear plot of water samples collected during pre-monsoon season

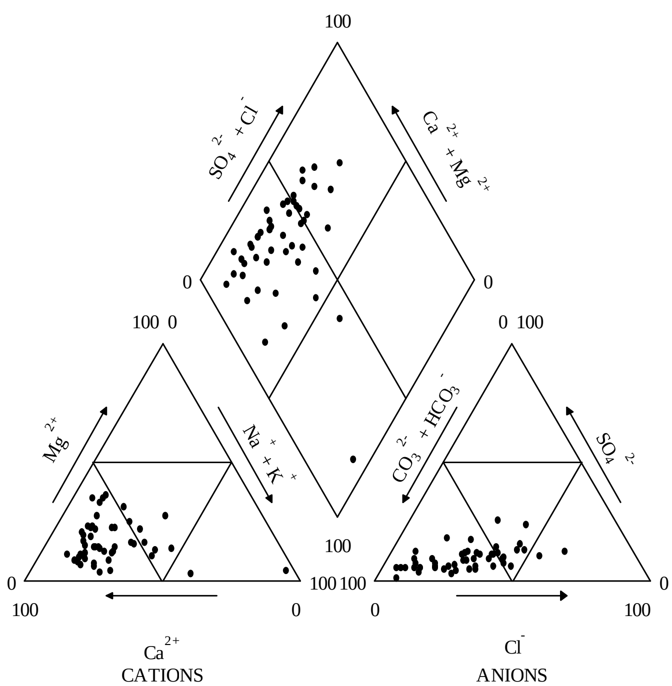


Fig. 3.10: Trilinear plot of water samples collected during post-monsoon season

Chapter 4

STABLE ISOTOPE INVESTIGATION

4.1 ISOTOPES OF HYDROGEN AND OXYGEN

Isotopes are elements with same atomic number and different mass numbers. In other words, isotopes have the same number of protons (and electrons), but different numbers of neutrons. Water is composed of hydrogen and oxygen, so it occurs with different isotopic combinations of these two elements in its molecules. Hydrogen has three isotopes (Emanuel M, 2004), such as

^{1}H—common hydrogen, 1 proton

^{2}H—deuterium (also written D), 1 proton and 1 neutron

^{3}H—tritium (also written T), 1 proton and 2 neutrons

Similarly, oxygen has also three isotopes, and are

^{16}O—common oxygen, 8 protons and 8 neutrons

^{17}O—heavy (very rare) oxygen, 8 protons and 9 neutrons

^{18}O—heavy oxygen, 8 protons and 10 neutrons

The relative amounts of the individual isotope species in each element, expressed in percent, are called the isotopic abundances. In seawater the relative abundances of hydrogen and oxygen isotopes are presented in **Table 4.1.**

Table 4.1: Relative abundance of Hydrogen and Oxygen isotopes in sea water, (Emanuel M, 2004)

Element	Isotope	Relative Abundance (%)
Hydrogen	^{1}H	99.984
	^{2}H (or D)	0.016
	^{3}H (or T)	5×10^{-6}
Oxygen	^{16}O	99.76
	^{17}O	0.04
	^{18}O	0.20

Stable isotopes are non-radioactive forms of atoms. Although they do not emit radiation, their unique properties enable them to be used in a broad variety of applications, including water management. Stable isotopes can be used by measuring their amounts and proportions in water samples. Naturally-occurring stable isotopes of water are used to trace the origin, history, sources, sinks and interactions in water cycles.

The variations in oxygen and hydrogen isotope ratios have applications in hydrology since most samples will lie between two extremes, ocean water and Arctic/Antarctic snow. Given a sample of water from an aquifer, and a sufficiently sensitive tool to measure the variation in the isotopic ratio of hydrogen in the sample, it is possible to infer the source, be it ocean water seeping into the aquifer or precipitation seeping into the aquifer, and even to estimate the proportions from each source. Study of stable isotope ratios of ^{2}H (or D) and ^{18}O has been widely used for establishing the interaction between precipitation, surface water and ground water in an area.

4.2 REPORTING OF ISOTOPIC DATA

Measurements of the stable isotopic compositions of natural substances are conventionally reported in the δ-notation:

$$\delta_X(per\ mil) = \left(\frac{R_X}{R_{Standard}} - 1\right) \times 1000 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(4.1)$$

Where R_X = Isotope ratio in the substance X

$R_{Standard}$ = Isotope ratio in a standard substance

δ is expressed in parts per thousand (per mil or ‰)

The isotopic composition of water is expressed in comparison to the isotopic composition of ocean water. For this purpose an internationally agreed upon sample of ocean water has been selected, called Standard Mean Ocean Water (SMOW) (Craig, 1961).

The isotopic composition of water, determined by mass spectrometry, is expressed in per mil ‰ deviations from the SMOW standard. These deviations are written δD for the deuterium, and δ^{18}O for ^{18}O:

$$\delta D‰ = \frac{(\mathrm{D/H})_{\mathrm{Sample}} - (\mathrm{D/H})_{\mathrm{SMOW}}}{(\mathrm{D/H})_{\mathrm{SMOW}}} \times 1000 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.2)$$

and

$$\delta^{18}\mathrm{O}‰ = \frac{(^{18}\mathrm{O}/^{16}\mathrm{O})_{\mathrm{Sample}} - (^{18}\mathrm{O}/^{16}\mathrm{O})_{\mathrm{SMOW}}}{(^{18}\mathrm{O}/^{16}\mathrm{O})_{\mathrm{SMOW}}} \times 1000 \ldots\ldots\ldots\ldots\ldots (4.3)$$

Water with less deuterium than SMOW has a negative δD; water with more deuterium than SMOW has a positive δD. Similarly, water with less ^{18}O than SMOW has a negative δ^{18}O; water with more ^{18}O than SMOW has a positive δ^{18}O.

4.3 ISOTOPIC FRACTIONATION

Evaporation is a physical process in which energy-loaded water molecules move from the water phase into the vapor phase. Isotopically light water molecules evaporate more efficiently than the heavy ones. As a result, an isotopic fractionation occurs at partial evaporation of water: the vapor is enriched in light water molecules, reflected in relatively negative δD and δ^{18}O values. In contrast, the residual water phase becomes relatively enriched in the heavy isotopes, reflected in more positive δD and δ^{18}O values. The isotopic separation, or fractionation, is more efficient if the produced vapor is constantly removed, as for example by wind blowing away vapors produced above an evaporating pond.

4.4 GLOBAL METEORIC WATER LINE (GMWL)

The Global Meteoric Water Line is an equation defined by the geochemist Harmon Craig (1961) that states the average relationship between hydrogen and oxygen isotope ratios in natural terrestrial waters, expressed as a worldwide average.

$$\delta D = 8.0 \times \delta^{18}\mathrm{O} + 10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.4)$$

A meteoric water line can also be calculated for a given area, and used as a baseline within that area. The GMWL as found by Craig (1961) is given in **Fig. 4.1.** The GMWL has an $r^2 > 0.95$. This high correlation coefficient reflects the fact that the oxygen and hydrogen stable isotopes in water molecules are intimately associated; consequently, the isotopic ratios and fractionations of the two elements are usually discussed together. The meteoric line, has been found, with some local variations, to be valid over large parts of the world. The meteoric line is a convenient reference line for the understanding and tracing of local groundwater origins and movements. Hence, in each hydrochemical investigation the local meteoric line has to be established from samples of individual rain events or monthly means of precipitation. The composition of precipitation is reflected in the composition of groundwater. Common practice is to plot groundwater data on δD and δ^{18}O diagrams, along with the meteoric line of local precipitation as a reference line.

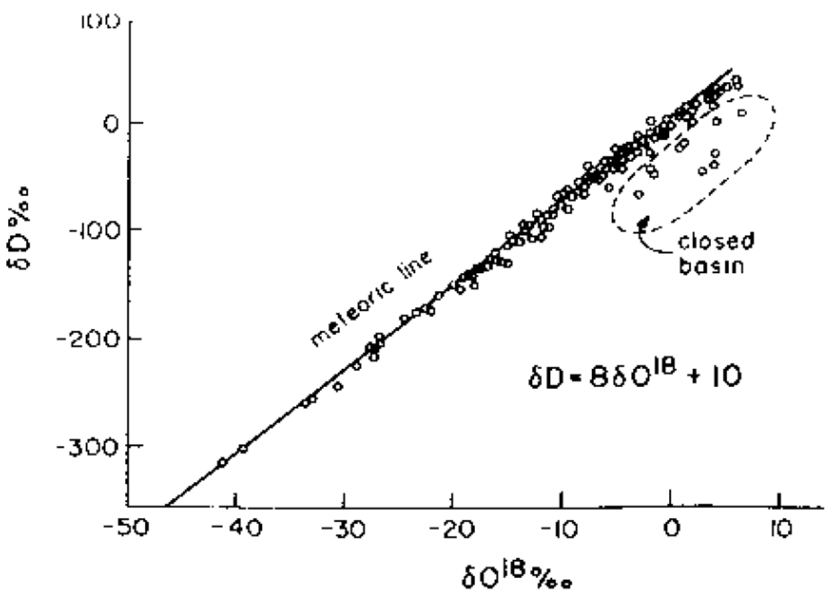


Fig.4.1: Isotopic data of about 400 samples of rivers, lakes, and precipitation from various parts of the world. The best-fit line was termed the meteoric line. Its equation, as found by Craig (1961), is $\delta D = 8.0 \times \delta^{18}O + 10$. The data in the encircled zone of ''closed basins'' is for East African lakes with intensive evaporation.

4.5 COLLECTION AND ANALYSIS OF WATER SAMPLES

4.5.1 SURFACE AND GROUND WATER SAMPLING

To investigate the interaction of surface water and ground water in the study area comprehensive sampling was carried out. A total of 53 ground water samples were collected from bore wells (hand pumps) by purging them for sufficient duration before collection of samples. The ground water samples were collected both during pre- and post-monsoon seasons (**Annexures-II** & **III)**, (**Fig. 4.2**). Similarly 27 water samples were collected from surface water bodies (ponds and reservoirs) in the study area (**Fig. 4.3**). The samples from surface water bodies were collected from deep within the water bodies to avoid the skimming on the surface due to evaporation. The water samples from these water bodies were collected during pre- and post-monsoon seasons as well (**Annexures-VI** & **VII**). One water sample from the Pulgaon Nala was also collected.

Fig. 4.2: Collection of ground water sample from a bore well (hand pump) in the study area.

Fig. 4.3: Collection of surface water sample from Khapri reservoir in the study area.

4.5.2 RAINWATER SAMPLING

In addition, rainwater samples were collected by following the National Programme on Isotope Fingerprinting of Waters of India (IWIN) guidelines prescribed by PRL, Ahmedabad (**Annexure-VIII**). An apparatus for collection of rainwater as well as to measure the amount of rainfall was designed following the IWIN guidelines (**Fig. 4.4**). Collection of rain water samples and measurement of amount of rainfall were done on weekly interval. All due cares were taken to prevent the evaporation loss from the apparatus (**Fig. 4.5**). The apparatus was kept in open to avoid any type of obstacle that may prevent the rainwater from coming into the apparatus during the time of precipitation (**Fig. 4.6**). The rain water samples were collected every week during the time of monsoon. A total of 12 samples were collected spanning a period of four months duration.

Fig. 4.4: Apparatus for collection of rain water samples

Fig. 4.5: Arrangements for prevention of evaporation loss from the rainwater sampling apparatus

Fig. 4.6: Rainwater sampling apparatus kept in open to avoid any kind of interference

Rainfall (cm) was calculated by using the following formula

$$h = \frac{4 \times V}{\pi D^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4.5)$$

where,

h = Rainfall in cm

V = Volume of water collected in the apparatus (cm^3)

D = Diameter of the funnel in the apparatus (cm)

The volume of rainwater collected through the apparatus is presented in **Table 4.2.** A total of 949.09 mm of rainfall was recorded in the study area during the period of measurement from July 17, 2016 to October 16, 2016.

Table 4.2: Computation of rainfall through the apparatus

Date	Volume of water collected (cm^3)	Sample No.	Rainfall (mm)
17-07-16	9700	1	85.12
24-07-16	19500	2	171.13
31-07-16	5400	3	47.39
07-08-16	18600	4	163.23
14-08-16	3000	5	26.33
21-08-16	1150	6	10.09
28-08-16	2900	7	25.45
04-09-16	3200	8	28.08
11-09-16	6700	9	58.80
25-09-16	13200	10	115.84
02-10-16	21000	11	184.29
16-10-16	3800	12	33.35
Total	**108150**		**949.09**

All the samples (ground water surface water and rain water) were collected in air tight plastic bottles. The samples were analysed for δD and δ^{18}O at PRL, Ahmedabad.

4.6 GMWL Vs LMWL

Global Meteoric Water Line (GMWL) traced the isotopic compositions of natural waters originating from atmospheric precipitation and not subjected to surface evaporation. However, local variations in composition of stable isotopes in natural water result from a number of physical and meteorological parameters such as latitude, altitude, distance from the coast, amount of precipitation, and surface air temperature. The variations in isotopic composition are caused by isotope fractionation at the condensation of atmospheric water vapour to precipitation. The air masses lose water as they move along surface temperature gradients from tropical to polar latitudes ("latitudinal effect"), from the sea to inland ("continental effect"), or from lower to higher elevations ("altitude effect").

Like the GMWL, the line derived from precipitation collected from a single site or set of "local" sites known as "Local Meteoric Water Line" (LMWL), can be significantly different from the GMWL. In general, most of these local lines have slopes of 8 +/- 0.5, but slopes in the range of 5 and 9 are not uncommon.

To study the variation of δD and δ^{18}O composition in the natural water i.e. in precipitation the value of δD and δ^{18}O of 12 rainwater samples of the study area are plotted in the δD - δ^{18}O domain. The best fit line i. e. "Local Meteoric Water Line" (LMWL) is constructed for these data and is presented in **Fig. 4.7.**

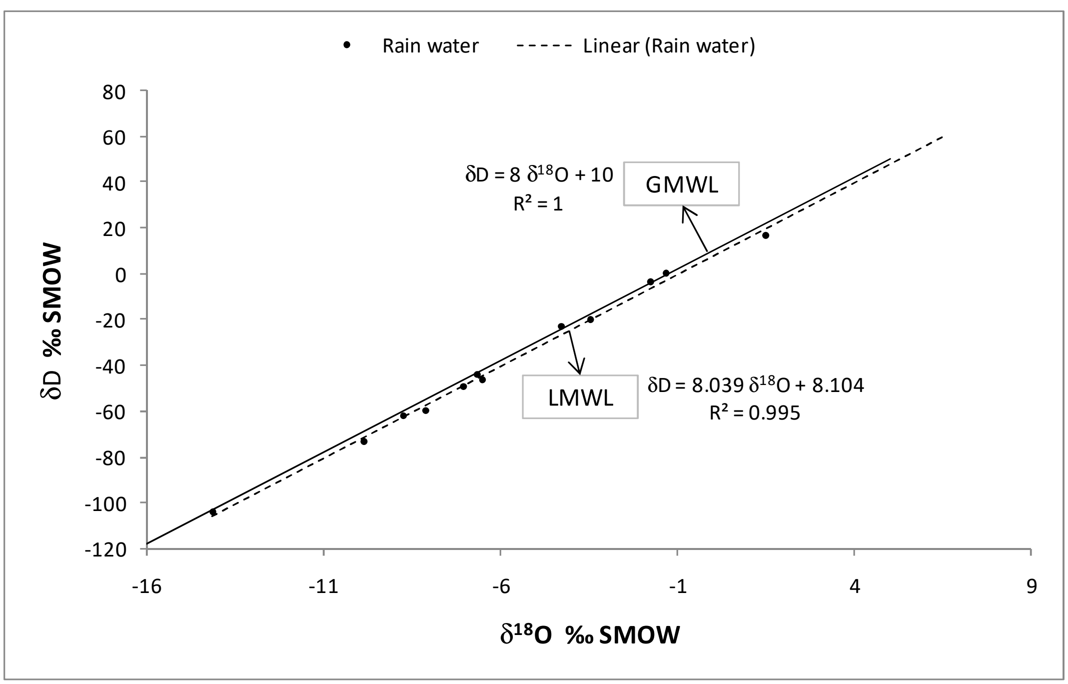


Fig. 4.7: Construction of Local Meteoric Water Line (LMWL)

From the figure it is evident that the LMWL is identical to GMWL though the samples of precipitation plot slightly below the GMWL. Hence there is not much difference between GMWL and GMWL for the study area. The value of δD and δ^{18}O in precipitation in the area have r^2=0.995. The plot of values slightly below GMWL shows little enrichment of precipitation in the study area due to atmospheric evaporation.

4.7 INTERACTION OF SURFACE WATER AND GROUND WATER

The ground water and surface water samples collected during pre- and post-monsoon season from the study area were analysed for δD and δ^{18}O and the results are given in **Annexure-IX** and **Annexure-X**.

The values of δD and δ^{18}O in **surface water samples collected during pre-monsoon season** from village ponds and surface water reservoir are plotted along with the GMWL and LMWL and are presented in **Fig. 4.8.** From the figure it is clear that the samples fall much below the LMWL and the corresponding regression line has also a lesser slope as compared to the GMWL and LMWL. Several processes cause waters to plot off the GMWL. Water that has evaporated or has mixed with evaporated water typically plots below the meteoric water line. These types of water plot along lines with slopes in the range of 2 to 5 and intersect the GMWL at the location of the original un-evaporated composition of the water. The slope of the line for surface water samples in the study area is 5.2. This indicates that the surface water bodies in the area have enriched in the heavier isotopes as a result of fractionation due to evaporation during the pre-monsoon period. Due to higher temperature during pre-monsoon season which causes more evaporation, the lighter isotopes are the first to get evaporated from the surface water bodies leaving behind the available water enriched in heavier ones. The plot of δD and δ^{18}O values of water from Pulgaon Nala shows less enrichment as compared to the waters in rest of the surface water bodies in the area which indicates that the water in Pulgaon Nala has mixture of water from other sources possibly from ground water source as base flow.

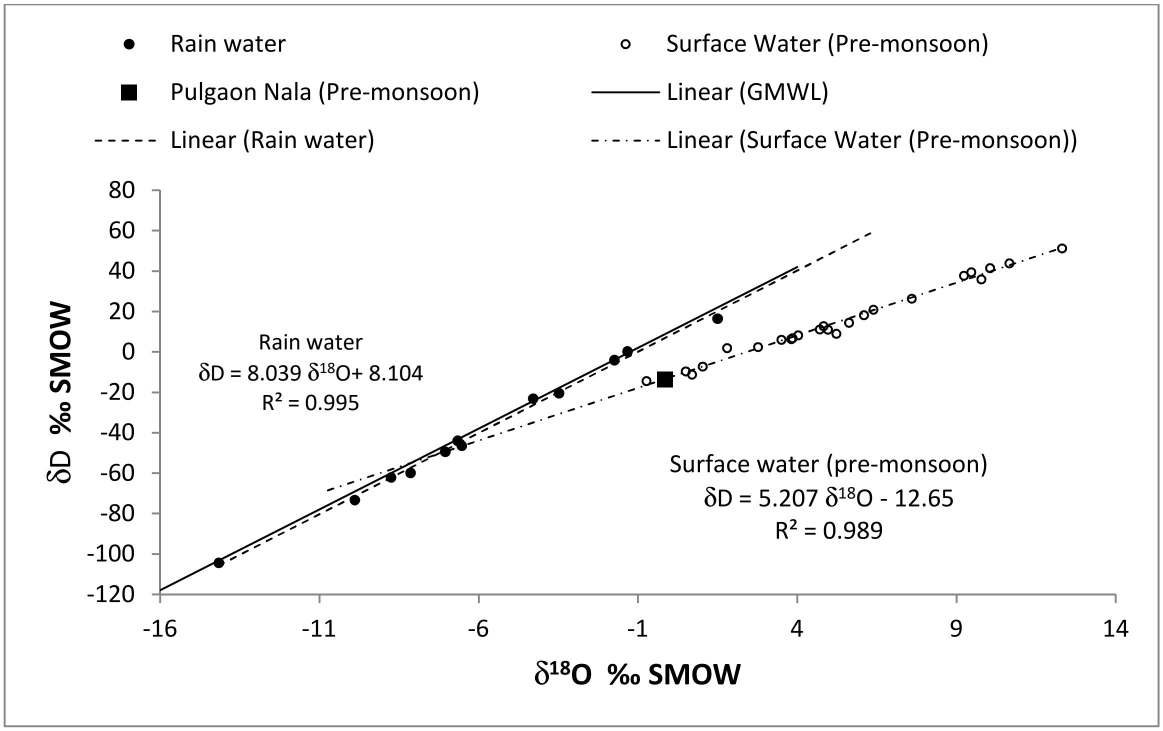


Fig. 4.8: Plot of surface water samples of pre-monsoon season

The plot of δD and δ^{18}O values of **ground water samples collected during pre-monsoon season** in the study area is presented in **Fig. 4.9.** The ground water samples show less enrichment as compared to the surface water samples in the study area. The distinctive enrichment pattern of ground water and surface water in the study area indicate that both waters are not in interaction during pre-monsoon period. Hence, the surface water bodies, mainly the **village ponds are not contributing to the ground water storage during pre-monsoon season**. Whatever contribution is being made by these surface water bodies through infiltration are being utilized for satisfying the soil moisture deficit resulting due to high evapotranspiration loss during pre-monsoon season, thus leaving no surplus percolation to add to the ground water storage.

The δD and δ^{18}O values of surface water collected during post-monsoon season is plotted along with the values of surface water collected during pre-monsoon and is presented in **Fig. 4.10.** The samples of post-monsoon show less enrichment as compared to the pre-monsoon samples and the enrichment is similar for the river water represented by Pulgaon Nala as well. The comparison of enrichment of surface water

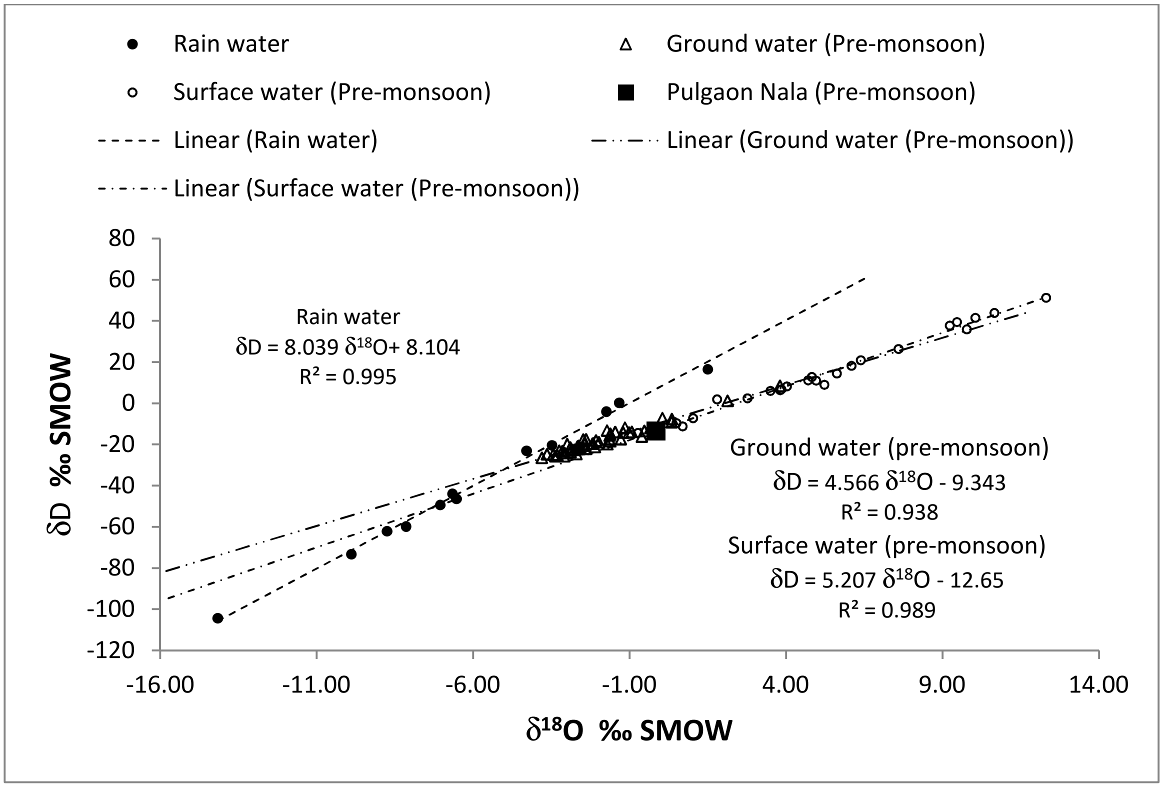


Fig. 4.9: Plot of surface water and ground water samples of pre-monsoon season

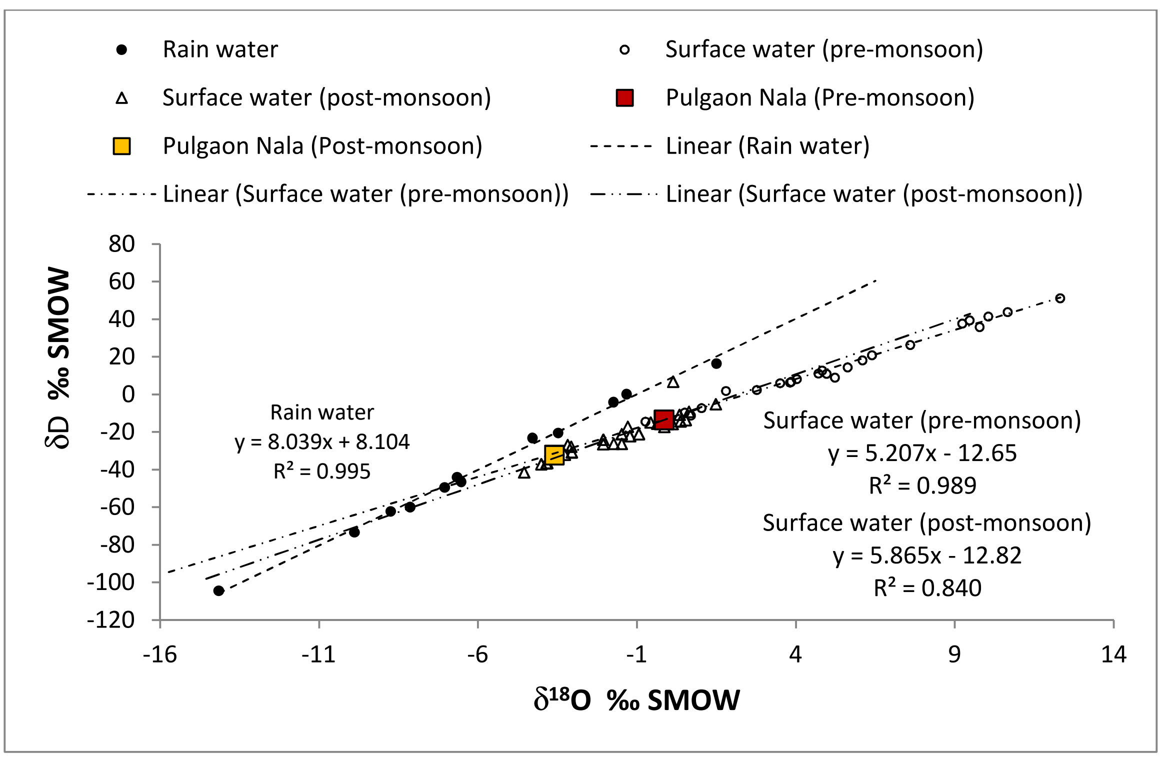


Fig. 4.10: Plot of surface water samples of pre- and post-monsoon seasons

during pre- and post-monsoon seasons show very clear effect of temperature on fractionation caused due to evaporation.

Fig. 4.11 shows the plot of δD and δ^{18}O values of surface water and ground water collected during post-monsoon season. From the figure it is evident that both the surface and ground water in the area have similar isotopic compositions. This indicates that the surface water and ground water are in active interaction with each other. The lesser slope of regression lines for both the surface and ground water samples as compared to that of the regression line of precipitation samples indicate the rock water interaction of the precipitation water as it progressively move above and below the surface. The points of intersection of the regression lines of surface and ground water with the LMWL shows the original un-evaporated composition of the water. From the figure it is evident that both surface and ground water have the same source of origin i. e. precipitation.

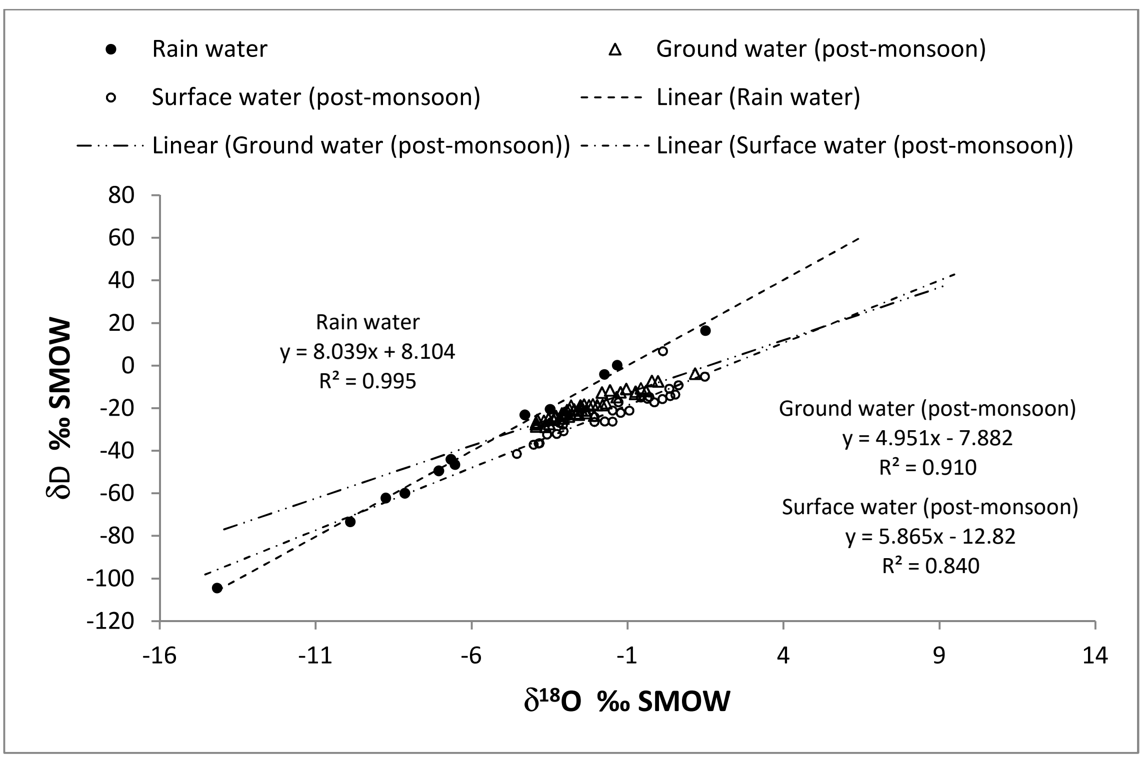


Fig. 4.11: Plot of surface water and ground water samples of post-monsoon season

The δD and δ^{18}O values of ground water collected during post-monsoon season is plotted along with the values of ground water collected during pre-monsoon and is presented in **Fig. 4.12.** The isotopic compositions of ground water during both the seasons do not show any variations. This shows that the source of recharge of ground water is the same during both the seasons and is through precipitation. However, the ground water during pre-monsoon shows a little enrichment which may be due to rock-water interaction.

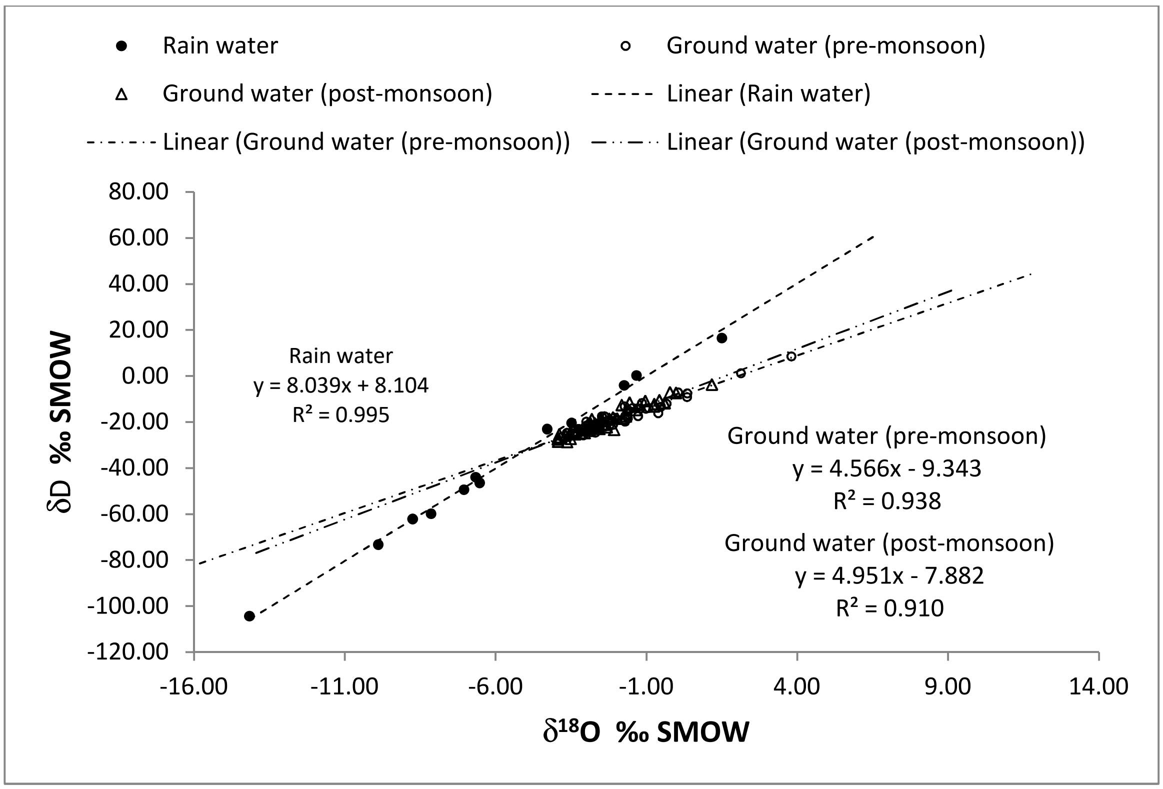


Fig. 4.12: Plot of ground water samples of pre- and post-monsoon seasons

Chapter 5

CONCLUSION AND THE WAY FORWARD

Stable Isotope Investigations to Study Surface Water- Ground Water Interaction in a Hardrock Terrain in Parts of Durg District, Chhattisgarh has been taken up jointly by the Rajiv Gandhi National Ground Water Training & Research Institute (RGNGWTRI), Central Ground Water Board, and Physical Research Laboratory (PRL), a unit of Department of Space, Government of India. A small watershed, Pulgaon Nala watershed bounded by 81°15’11” to 81°25’25” E longitudes and 20°57’29” to 21°10’54” latitudes which falls in the SOI toposheets 64G/8 &64H/4 with an area of around 242 km^2 in Durg and Balod districts of Chhattisgarh State has been taken as the study area. The climate of the study area is sub-tropical. In summer, the day temperature ranges from 36^oC to 42^oC and night temperature ranges from 19^oC to 27^oC. The area receives rainfall from south west monsoon with annual normal rainfall of 1288.8 mm.

Physiographycally the area is part of the Chhattisgarh Plain which is mostly flat in nature. The highest and lowest elevations in the area are 300 mamsl and 280 mamsl respectively. The study area is entirely covered by the rocks of Raipur Group which belongs to Chhattisgarh Supergroup of Proterozoic age and comprise of limestone, shale and sandstone. The ground water in the area occurs under water table and semi-confined conditions. The weathered, cavernous and fractured part of the formation constitutes the aquifers in the area. These formations are the most potential in regards to ground water yield. The weathered zone is restricted to upper 30 m depth. Most of the cavernous zones occur between 10 and 70 m depth and fractures are productive down to 150 m.

Water levels in the study area were measured in 34 bore wells during the pre-monsoon season (in the month of May 2016) and in 38 bore wells during the post-monsoon season (in the month of November 2016). The bore wells tap mainly the semi-confined aquifer that is being used for abstraction of ground water. The water level during the pre-monsoon season varies between 2.03 m bgl and 28 m bgl and during the post-monsoon season the water level varies between 1.4 m bgl and 15.2 m bgl in the study area.

The general ground water quality of the study area was studied through analysis of ground water samples collected from 36 bore wells during pre-monsoon season and from 50 bore wells during post-monsoon season. The ground water in the study area is slightly alkaline in nature with pH value ranging between 7.09 and 8.87 during pre-monsoon season. By and large, ground water in the area is potable in nature. Mapping of hydrochemical facies of the area shows that the ground water is calcium-bicarbonate type and shows characteristics of limestone aquifers.

A total of 53 ground water samples, 26 water samples from surface water bodies (ponds and reservoirs) and one water sample from the Pulgaon Nala were collected both during pre- and post-monsoon seasons. In addition, 12 rainwater samples were collected spanning over a period of four months by following the IWIN guidelines prescribed by PRL, Ahmedabad. All the samples were analysed for δD and δ^{18}O at PRL, Ahmedabad. The Local Meteoric Water Line (LMWL) is constructed with the δD and δ^{18}O of rainfall data which has r^2=0.995.

Plotting of δD and δ^{18}O values of the surface water bodies in the area shows that they are enriched in the heavier isotopes as a result of fractionation due to evaporation during the pre-monsoon period. The distinctive enrichment pattern of ground water and surface water in the study area during pre-monsoon season indicates that both waters are not in interaction. Hence, the surface water bodies, mainly the village ponds are not contributing to the ground water storage during this season. Whatever contribution is being made by these surface water bodies through infiltration are being utilized for satisfying the soil moisture deficit resulting due to high evapotranspiration loss during pre-monsoon season, thus leaving no surplus percolation to add to the ground water storage.

However, the plot of δD and δ^{18}O values of surface water and ground water collected during post-monsoon season shows that both the surface and ground water in the area have similar isotopic compositions. This indicates that the surface water and ground water are in active interaction with each other. Further, the isotopic compositions of ground water during both pre- and post-monsoon seasons do not show any variations. This shows that the source of recharge of ground water is the same during both the seasons and is through precipitation.

Central Ground Water Board being the organization responsible for managing the ground water resources of the entire country needs to carry out more similar kinds of studies to ascertain the interaction of rain water, surface water and ground water in different hydrogeological terrains. The findings of such studies will help ascertain the efficacy of the ongoing massive ground water augmentation through managed aquifer recharge being carried out in the entire country. Through study of stable isotopic signature, the source area of recharge of aquifers can be delineated and necessary measures can be taken up for keeping that area of recharge worthy and safe from any pollution threat due to anthropogenic activities.

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Annexure-I

भौतिक अनुसंधान प्रयोगशाला
(अंतरिक्ष विभाग की यूनिट, भारत सरकार)
नवरंगपुरा, अहमदाबाद - 380 009, भारत
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दूरभाष : 26314000 ई-मेल : root@prl.res.in

PHYSICAL RESEARCH LABORATORY
(A UNIT OF DEPT. OF SPACE, GOVT. OF INDIA)
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Email: desh@prl.res.in

Chairman
M(RGI)

2198
4/12/15

26 November 2015

Dr. Dipankar Saha
Member (RGI)
Central Ground Water Board
Bhujal Bhawan
NH-IV, Faridabad 121001
Haryana

A copy may be sent to RD, RGI

10.12.15

Dear Dr. Saha,

Please find attached two copies of the duly signed MOA between PRL and CGWB for Stable Isotope investigations to study surface water-groundwater interaction in a hard rock terrain in parts of Durg District, Chhattisgarh.

Please note that in Para 3, point a, there is some correction which now reads that responsibility of PRL will be to providing guidance for collection of water samples.

Some of your colleagues from RGI have approached me to discuss various scientific aspects related to this project and they are planning the sampling strategy.

Best Regards

– Sd –
(R.D. Deshpande)

Encl: Two signed copies of MOA

CC:

1. Shri S.K. Biswas, Chairman, Central Ground Water Board (CGWB) and Central Ground Water Authority (CGWA) Ministry of Water Resources, River Development and Ganga Rejuvenation, Govt. of India, Bhujal Bhawan, New CGO Complex, N.H-IV, Faridabad-121001, India.
2. Prof. Utpal Sarkar, Director, PRL, Ahmedabad

Member (RGI)
Dy No. 328
Date 1.9/12/15

MEMORANDUM OF AGREEMENT

BETWEEN

CENTRAL GROUND WATER BOARD
MINISTRY OF WATER RESOURCES
GOVERNMENT OF INDIA
FARIDABAD

AND

PHYSICAL RESEARCH LABORATORY
GOVERNMENT OF INDIA
AHMEDABAD

FOR

Stable Isotope Investigations to Study Surface Water- Ground Water Interaction in a Hardrock terrain in Parts of Durg District, Chhattisgarh.

2015

MEMORANDUM OF AGREEMENT
BETWEEN
CGWB AND PRL

This Memorandum of Agreement hereinafter referred to as MOA signed on ——-——day of -------Year **2015** between Central Ground Water Board, Bhujal Bhawan, NH IV, Faridabad (Haryana) a sub-ordinate office of the Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India, with its registered office at New Delhi hereinafter referred to as CGWB which expression unless otherwise provided shall include its successors, representatives and assignees on the first part AND Physical Research Laboratory, a unit of Department of Space, Government of India, having its registered office at Navrangpura, Ahmedabad – 380 009 (Gujarat), hereinafter referred to as PRL which expression shall include, unless repugnant to the context or contrary to the meaning thereof, its successors or permitted assignees on the other part. Rajiv Gandhi National Ground Water Training & Research Institute (RGNGWTRI) is training and research wing of Central Ground Water Board having its office at Raipur (Chhattisgarh) will execute the obligations of CGWB.

CGWB and PRL may at times be referred to individually as "Party" and collectively as the "Parties" ***WHEREAS*** CGWB and PRL have agreed upon to co-operate in the area of Stable Isotope Studies. The study of stable isotopes will help in identifying and ascertaining the source of recharge to ground water. It will further establish relationship between surface and ground water system. It will also enable qualitative assessment of vulnerability of aquifer system and efficacy of artificial recharge structures in the hard rock aquifer system. In this context, the Parties wish to record here the following main areas of cooperation on mutually agreed terms and conditions:

1. To take up a collaborative Project entitled "***Stable Isotope Investigations to Study Surface Water- Ground Water Interaction in a hard rock terrain in parts of Durg District- Chhattisgarh***".

2. The **responsibility of Rajiv Gandhi National Ground Water Training and Research Institute, CGWB will be to:**
   i. Compile available geological, geomorphological, hydrometerological, hydrogeological data and preparation of hydrogeological information of the study area.
   ii. Establish key observation wells and periodic monitoring of ground water levels.
   iii. Procurement of maps/reports/digital data product etc.
   iv. Establishment of surface water monitoring sites and their monitoring.
   v. Collection of surface and ground water samples for analysis of Deuterium (δD) and Oxygen-18 ($\delta^{18}O$) composition.

3. **The responsibility of PRL, Ahmedabad will be to:**
   a. Collection of water samples from surface and ground water monitoring stations for the study.
   b. Analysis of water samples for Deuterium (δD) and Oxygen-18 ($\delta^{18}O$) composition.

4. **Joint Responsibility**

- Sharing of scientific published and unpublished reports and, surface and subsurface hydrological & water quality data related to the study.
- Planning of investigations and sampling protocols.
- Free exchange of information and data , analysis and interpretation of hydrological, hydrogeological, hydrochemical and stable isotope data.
- Preparation and submission of report.

5. Following **committees would be setup for the supervising & monitoring of the project:**

RGNGWTRI, CGWB	PRL
Member (RM) Regional Director	Dr. R. D. Deshpande, Scientist-SF Geosciences Division

6. Both parties acknowledge the confidentiality of the information which may be transferred between the parties or obtained or developed during the course of this exchange from time to time as being essential to this MOA. However, each party shall be free to disclose the information as it is after publication of final report with consent of both the parties in the public domain as required to be disclosed by official authorities in accordance with applicable law or regulation.

7. This MOA shall be effective from the date on which it is executed by the Parties and will continue for a period of two years and may be extended by mutual consent as per the requirement of the study. However, this MOA may be terminated at any time by mutual agreement on one month's notice at any time by either Party.

8. While the Parties agree to co-operate and otherwise act in good faith with the view to the successful implementation of all activities not to be financially binding on the Parties as there is no financial binding on either Party. This MOA is intended to mutual understanding of the Parties hereto as at the date thereof.

9. Any notice, request or other communication required or permitted to be given under this MOA shall be in writing in the English language and shall be delivered in person or by recognized courier service or facsimile or email, at addresses as follows:

IF TO CGWB	IF TO PRL
The Member (RGI), Central Ground Water Board Bhujal Bhawan NH-IV, Faridabad-121001 Haryana. Tel No. 0129-2477103/123 Fax No. 0129-2477200 Email: chmn-cgwb@nic.in	Director Physical Research Laboratory Navrangpura Ahmedabad-380 009 Tel: +91-79- 2630 8550 /2631 4241(O) Fax: +91-79-2630 0374 Email: director AT prl.res.in

10. The parties expressly acknowledge that this MOA is constituted between the Parties in relation to the subject matter as mentioned hereinabove in Clauses 1, 2 3, 4 and 5. This MOA shall supersede all previous oral and written communications, representations and under taking between the Parties.

11. Each of the Parties recognizes that the successful implementation of this MOA to the mutual satisfaction and benefit of both Parties will require a significant degree of cooperation and good faith on behalf of both Parties. Each of the Parties resolves to act in good faith and in accordance with the spirit of this MOA to implement the provisions in accordance with the mutual desire and in the interests of the Parties.

12. ARBITRATION

Except as otherwise provided elsewhere in the contract, in the event of any dispute or difference relating to, arising from or connected with the contract, such dispute or difference shall be mutually discussed between the Parties and finalized to the satisfaction of both the parties.

13. HOLD HARMLESS

The CGWB agrees to the hold PRL harmless from any claim or damages arising from the CGWB's performance of work under this contract. CGWB shall also hold PRL harmless without any limitation from any claims or damages raised or damages suffered by the CGWB.

14. ENTIRE CONTRACT AND AMENDMENTS

This MOA will be signed along with attached signed addends and / or subsequent agreements, which will constitute the entire agreement between the CGWB and PRL. No prior written or oral representations shall be binding and all amendments and /or subsequent agreements shall be in writing and signed by a party of equal position as those of the executing parties hereto.

IN WITNESS WHEREOF the Parties hereto have duly executed this MOA.

The ______ _________ day of ____ _________ year__ 2015 ___ .

For CENTRAL GOUND WATER BOARD by:

D. Saha 10/9/2015

Name- Dr. Dipankar Saha

Title- Member (RGI)

In the presence of

Witness 1 (Dr A Mukherjee Sc D)

Witness 2 Ranjan Ray 10/9/2015 (R.K. RAY) Scientist 'C'

For **PHYSICAL RESEARCH LABORATORY** by:

Name- Dr. R. D. Deshpande R D Deshpande 22/09/2015

Title- Scientist-SF (Geosciences Division)

In the presence of

Witness 1 (Vibhas Singh Gupta) 18/11/15

विंग कमांडर (रिटायर्ड) विभास गुप्ता
Wg Cdr (Retd.) Vibhas Gupta
रजिस्ट्रार Registrar
भौतिक अनुसंधान प्रयोगशाला
Physical Research Laboratory
(A Unit of Department of Space, Govt. of India)
Navrangpura, Ahmedabad-380 009

Witness 2 (B. G. Vaishnav) 19/10/2015

डॉ. बी. जी वैष्णव Dr. B. G. Vaishnav
प्रधान, शैक्षणिक सेवा HEAD, Academic Services
भौतिक अनुसंधान प्रयोगशाला
Physical Research Laboratory
भारत सरकार, अंतरिक्ष विभाग की यूनिट
(A Unit of Department of Space, Govt. of India)
नवरंगपुरा, अहमदाबाद - 380009 भारत
Navrangpura, Ahmedabad - 380009 India

Ground water sampling locations, depth to water level and onsite chemical parameters (pre-monsoon season) in Pulgaon Nala watershed

Sl. No.	Location	Source	Date	MP (magl)	DTW (mbmp)	Field Parameters				
						Temp. (°C)	pH	EC (µS/cm)	TDS (mg/l)	Salt (mg/l)
1	Ganjpara	HP	03-05-16	0.5	2.53	27.6	7.3	1115	787	547
2	Padmanavpur	HP	03-05-16	0.5	12.33	29	7.3	758	533	369
3	Adarsh Nagar (Borsi)	HP	03-05-16	0.5		29.6	7.2	760	537	371
4	Borsi	HP	03-05-16	0.5	7.3	29.5	7	1010	713	499
5	Dhanaura	HP	03-05-16	0.5	6.33	29.4	7.5	655	459	317
6	Hanoda	HP	03-05-16	0.5	17.72	29.3	7.9	978	692	481
7	Chandkhuri	HP	03-05-16	0.5	23.32	29.8	7.2	995	695	486
8	Marauda	HP	04-05-16	0.5	14.07	28.6	7.5	515	366	252
9	Risali	HP	04-05-16	0.5		30	7.2	795	562	390
10	Risali1	HP	04-05-16	0.5		28.5	7.3	832	589	402
11	Khamariya	HP	04-05-16	0.5	6.15	28.6	7.7	444	316	216
12	Kokri	HP	04-05-16	0.5	12.3	28.9	7.4	540	383	259
13	Pauwara	HP	04-05-16	0.5	3.13	30.1	7.4	1040	734	513
14	Kodiya	HP	04-05-16	0.5	8.26	28.6	7.7	448	316	216
15	Bhanpuri	HP	04-05-16	0.5	9.12	28.3	7.5	616	437	301
16	Kuthrel	HP	04-05-16	0.5	11.15	28.3	7.3	1025	723	493
17	Newai	HP	05-05-16	0.5		29.6	7.1	625	443	305
18	Newai Bhata	HP	05-05-16	0.5		28.9	7.6	685	486	335
19	Umarpoti Bhata	HP	05-05-16	0.5		28.4	7.6	492	348	238
20	Umarpoti	HP	05-05-16	0.5	7.87	27.6	7.4	750	528	366
21	Purai	HP	05-05-16	0.5		29	7.4	935	660	459
22	Boridih	HP	05-05-16	0.5	10.45	29.6	7.6	537	380	261
23	Kargadih	HP	05-05-16	0.5		29.6	7.6	435	308	211
24	Khopli	HP	05-05-16	0.5	7.9	29.1	7.3	1150	811	549
25	Ghugsidih	HP	05-05-16	0.5	9.28	29	9.3	887	629	436
26	Daurabhata	HP	05-05-16	0.5	28.5	28.9	7.8	606	430	297
27	Utai	HP	05-05-16	0.5	9.23	29.5	7.4	622	441	303
28	Parsahi	HP	06-05-16	0.5	6.1	27.5	7.4	877	613	427
29	Sirri	HP	06-05-16	0.5	11.06	28.8	7.4	678	481	332
30	Machandur	HP	06-05-16	0.5	19.45	27.8	7.3	788	555	385
31	Chirpoti	HP	06-05-16	0.5	18.35	27.6	7.5	706	496	343
32	Risama	HP	06-05-16	0.5	12.83	27.7	7.2	1200	850	597
33	Matwari	HP	06-05-16	0.5	13.78	28.4	7.1	1470	1020	724
34	Matrodih	HP	06-05-16	0.5	6.9	28.6	7.2	823	582	404
35	Janjgiri	HP	06-05-16	0.5	9.03	28.1	6.9	1600	1130	772
36	Kanakot	HP	09-05-16	1	6.54	28	7.8	381	265	182
37	Tamora	HP	09-05-16	0.5	11.68	28.8	7.5	738	522	361
38	Pangri	HP	09-05-16	0.5		28.5	7.2	1590	1120	784

Sl. No.	Location	Source	Date	MP (magl)	DTW (mbmp)	Field Parameters				
						Temp. (°C)	pH	EC (µS/cm)	TDS (mg/l)	Salt (mg/l)
39	Khapri	HP	09-05-16	0.5	10.18	28.9	7.6	400	282	193
40	Gorkapar	HP	09-05-16	0.5	14.38	29	7.4	550	392	270
41	Sakraud	HP	09-05-16	0.5	9.1	28.6	7.1	1290	909	636
42	Rahud	HP	09-05-16	0.5		29	7.1	1226	848	602
43	Mundra	HP	09-05-16	0.5		28.4	9	1285	912	645
44	Parsahi	HP	09-05-16	0.5	4.16	27.7	7.5	896	634	439
45	Tiloda	HP	10-05-16	0.5	8.8	27.9	7.3	852	606	421
46	Bhilai Sector 5	HP	10-05-16	0.5		27.5	7.5	538	381	259
47	Bhilai DPS	HP	10-05-16	0.5		27.8	7.5	490	345	237
48	Dumardih	HP	10-05-16	0.5		28.4	7.6	455	323	222
49	Parewadih	HP	10-05-16	0.5		29.7	7.8	386	273	187
50	Morid	HP	10-05-16	0.5		28.4	7.7	459	326	222
51	Dundera	HP	10-05-16	0.5		29.3	7.3	601	422	292
52	Joratarai	HP	10-05-16	0.5		29.2	7.3	734	521	361
53	CISF Campus	HP	10-05-16	0.5		30.2	7.6	388	275	189

HP: Handpump

Ground water sampling locations, depth to water level and onsite chemical parameters (post-monsoon season) in Pulgaon Nala watershed

Sl. No.	Location	Source	Date	MP (magl)	DTW (mbmp)	Field Parameters				
						Temp. (°C)	pH	EC (µS/cm)	TDS (mg/l)	Salt (mg/l)
1	Ganjpara	HP	28-11-16	0.5	3.55	27.4	7.4	1038	732	476
2	Padmanavpur	HP	28-11-16	0.5	2.15	28.4	7.2	750	526	339
3	Adarsh Nagar (Borsi)	HP	28-11-16	0.5		26.8	7.3	748	527	339
4	Borsi	HP	28-11-16	0.5	3.1	29	7.2	840	590	382
5	Dhanaura	HP	28-11-16	0.5	4.42	28.3	7.4	815	577	364
6	Hanoda	HP	28-11-16	0.5	7.5	29.1	7.86	1100	780	513
7	Chandkhuri	HP	28-11-16	0.5	12	27.9	7.2	1490	1050	687
8	Marauda	HP	29-11-16	0.5	15.7	28.5	7.5	663	468	280
9	Risali	HP	29-11-16	0.5		30.1	7.4	820	563	364
10	Risali1	HP	29-11-16	0.5	4.16	28.8	7.3	873	629	406
11	Khamariya	HP	29-11-16	0.5	2.8	28.6	7.5	532	369	241
12	Kokri	HP	29-11-16	0.5	3.9	28.4	7.4	573	405	260
13	Pauwara	HP	29-11-16	0.5	2.1	29.4	7.3	1320	930	602
14	Kodiya	HP	29-11-16	0.5	4.18	28.9	7.6	539	382	246
15	Bhanpuri	HP	29-11-16	0.5	6.07	28	7.3	975	685	445
16	Kuthrel	HP	29-11-16	0.5	8.23	28	7.1	1380	979	648
17	Newai	HP	30-11-16	0.5		29.9	7	730	512	331
18	Newai Bhata	HP	30-11-16	0.5	12.44	29.1	7.5	726	513	332
19	Umarpoti Bhata	HP	30-11-16	0.5		28.5	7.5	519	371	239
20	Umarpoti	HP	30-11-16	0.5	3.77	28	7.1	1160	820	530
21	Purai	HP	29-11-16	0.5	3.52	28.1	7.3	895	635	412
22	Boridih	HP	29-11-16	0.5	6.03	29.6	7.5	550	384	247
23	Kargadih	HP	30-11-16	0.5		28.9	7.8	403	285	184
24	Khopli	HP	30-11-16	0.5	4.33	28.8	7.1	1385	979	647
25	Ghugsidih	HP	30-11-16	0.5	5.9	28.8	9.4	938	665	435
26	Daurabhata	HP	30-11-16	0.5	12.12	28.3	7.6	592	423	206
27	Utai	HP	30-11-16	0.5	6.95	28.8	7.26	1240	876	578
28	Parsahi	HP	01-12-16	0.5	5.12	27.6	7.2	1115	785	510
29	Sirri	HP	01-12-16	0.5	8.11	29.2	7.3	985	700	455
30	Machandur	HP	01-12-16	0.5	12.6	27.9	7.3	847	536	355
31	Chirpoti	HP	01-12-16	0.5	8.24	27.7	7.3	835	590	385
32	Risama	HP	01-12-16	0.5	6.46	27.5	6.9	1625	1140	758
33	Matwari	HP	01-12-16	0.5	7.92	27.5	7.05	1580	1120	740
34	Matrodih	HP	01-12-16	0.5	4.43	28.8	7.1	860	610	288
35	Janjgiri	HP	01-11-16	0.5	3.8	28	6.9	1820	1270	854
36	Kanakot	HP	02-12-16	1	4.36	28.2	7.6	422	319	207
37	Tamora	HP	02-12-16	0.5	8.11	28.8	7.3	955	674	396
38	Pangri	HP	02-12-16	0.5	15.55	28.8	6.97	2650	1860	1250

Sl. No.	Location	Source	Date	MP (magl)	DTW (mbmp)	Field Parameters				
						Temp. (°C)	pH	EC (µS/cm)	TDS (mg/l)	Salt (mg/l)
39	Khapri	HP	02-12-16	0.5	5.52	28.7	7.4	532	376	238
40	Gorkapar	HP	02-12-16	0.5	5.97	29	7.35	717	510	258
41	Sakraud	HP	02-12-16	0.5	3.47	28.5	7	1660	1180	780
42	Rahud	HP	02-12-16	0.5		28.6	7	1970	1390	924
43	Mundra	HP	02-12-16	0.5		28	9	1355	922	637
44	Parsahi	HP	02-12-16	0.5	1.9	27.4	7.6	875	618	396
45	Tiloda	HP	02-12-16	0.5	5.73	27.4	7.2	1050	752	479
46	Bhilai Sector 5	HP	01-12-16	0.5		27.9	7.6	754	513	354
47	Bhilai DPS	HP	01-12-16	0.5		28.1	7.4	588	416	269
48	Dumardih	HP	30-11-16	0.5		28.5	7.5	565	400	259
49	Parewadih	HP	30-11-16	0.5		29.2	7.6	544	385	249
50	Morid	HP	30-11-16	0.5		27.8	7.8	376	268	172
51	Dundera	HP	30-11-16	0.5		28.6	7.4	535	370	243
52	Joratarai	HP	30-11-16	0.5		28.7	7.3	790	558	357
53	CISF Campus	HP	02-12-16	0.5		29.3	7.5	414	298	144

HP: Handpump

Ground water quality during pre-monsoon season in Pulgaon Nala watershed

Sl. No.	Location	Source	Date of Collection	pH	EC (µS/cm)	TA	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	F
						mg/l										
1	Ganjpara	HP	03-05-16	7.3	1151	340	335	112	14.4	106.1	1	nd	427	131	55.1	0.7
2	Padmanavpur	HP	03-05-16	7.45	745	285	285	100	8.4	32.1	5.1	nd	354	43	20.5	0
3	Borsi	HP	03-05-16	7.09	1018	345	325	134	2.4	55.2	1.3	nd	348	121	45.3	0.1
4	Dhanaura	HP	03-05-16	7.34	585	235	230	80	8.4	17.3	0.3	nd	122	71	31	0.2
5	Hanoda	HP	03-05-16	7.91	938	65	80	24	1.2	184	1	nd	366	85	44.6	0.3
6	Chandkhuri	HP	03-05-16	7.7	1003	345	260	122	9.6	60	9.2	nd	342	117	48.2	0.1
7	Marauda	HP	04-05-16	7.34	512	215	185	76	6	13.9	0.8	nd	214	32	29.1	0
8	Khamariya	HP	04-05-16	7.47	428	165	160	58	4.8	12.4	0.3	nd	207	21	8.4	0.3
9	Kokri	HP	04-05-16	7.26	518	175	170	56	8.4	29.6	0.4	nd	256	25	9.5	0.8
10	Pauwara	HP	04-05-16	7.3	1065	300	300	104	9.6	43.9	48.4	nd	317	75	15.7	0
11	Kodiya	HP	04-05-16	7.48	425	155	155	60	1.2	19.4	1.8	nd	195	28	10.8	0.1
12	Bhanpuri	HP	04-05-16	7.22	637	245	245	54	26.4	21.9	0.4	nd	317	36	5.5	0.6
13	Kuthrel	HP	04-05-16	7.19	1054	385	325	130	14.4	29.9	11.7	nd	293	156	49.5	0.2
14	Newai Bhata	HP	05-05-16	7.16	1203	475	365	148	25.2	41.4	1.3	nd	384	185	50	0
15	Umarpoti	HP	05-05-16	7.24	739	305	240	102	12	18.4	0.3	nd	317	67	20.4	0
16	Purai	HP	05-05-16	7.26	943	305	340	110	7.2	45.5	2	nd	256	128	42.2	0.2
17	Boridih	HP	05-05-16	7.39	515	230	230	66	15.6	13.2	0.3	nd	268	28	11.5	0.3
18	Ghugsidih	HP	05-05-16	8.87	833	15	25	4	1.2	191.7	1	nd	342	46	22.7	1
19	Daurabhata	HP	05-05-16	7.85	590	150	185	40	12	64.4	1.7	nd	305	21	15.5	0.7
20	Utai	HP	05-05-16	7.38	609	265	210	90	9.6	21	8.5	nd	299	53	13.7	0.1
21	Parsahi	HP	06-05-16	7.36	838	290	175	102	8.4	30.5	4.4	nd	244	103	38.5	0
22	Sirri	HP	06-05-16	7.33	683	275	220	102	4.8	15.8	0.4	nd	256	78	17.5	0.3
23	Machandur	HP	06-05-16	7.54	792	315	220	102	14.4	20.9	0.4	nd	287	96	16.4	0.1
24	Chirpoti	HP	06-05-16	7.36	699	290	240	94	13.2	24.6	0.6	nd	275	57	28.9	0
25	Risama	HP	06-05-16	7.16	1270	490	335	154	25.2	43.7	0.7	nd	451	156	51.1	0
26	Matwari	HP	06-05-16	7.35	1565	450	385	168	7.2	107.6	14	nd	323	245	19	0.2
27	Matrodih	HP	06-05-16	7.34	728	330	125	102	18	10.1	3.7	nd	238	85	27.6	0

Sl. No.	Location	Source	Date of Collection	pH	EC (µS/cm)	TA	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	F
						mg/l										
28	Janjgiri	HP	06-05-16	7.12	1670	665	410	204	37.2	34.7	8.6	nd	360	277	18.3	0
29	Kanakot	HP	09-05-16	7.98	362	150	150	48	7.2	9	0.3	nd	171	21	5.5	0.5
30	Tamora	HP	09-05-16	7.85	738	270	270	90	10.8	26.2	1.4	nd	244	85	24.9	0.4
31	Khapri	HP	09-05-16	7.4	378	140	160	42	8.4	16.8	0.7	nd	195	18	5.4	0.3
32	Gorkapar	HP	09-05-16	7.36	525	200	215	50	18	29	0.7	nd	268	28	7.2	0.4
33	Sakraud	HP	09-05-16	7.14	1373	500	485	142	34.8	55.2	0.9	nd	415	217	30.5	0.3
34	Parsahi	HP	09-05-16	7.52	913	390	310	126	18	28.3	0.6	nd	336	117	33	0.4
35	Tiloda	HP	10-05-16	7.58	941	335	335	118	9.6	41.5	0.7	nd	317	114	35.5	0.3
36	CISF Campus	HP	10-05-16	7.53	373	155	150	56	3.6	11.1	0.3	nd	207	14	1.2	0.1

HP: Handpump

Ground water quality during post-monsoon season in Pulgaon Nala watershed

Sl. No.	Location	Source	Date of Collection	pH	EC (µS/cm)	TA	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	F
						mg/l										
1	Ganjpara	HP	28-11-16	7.1	1130	350	310	92	19.2	121	1.7	nd	427	110	64	0.7
2	Padmanavpur	HP	28-11-16	7	730	200	220	72	9.6	57	20.5	nd	244	67	61	0.2
3	Borsi	HP	28-11-16	7	839	275	310	118	3.6	49	1.1	nd	336	82	49	0.1
4	Dhanaura	HP	28-11-16	7.2	805	210	345	122	9.6	29	0.5	nd	256	107	45	0.2
5	Hanoda	HP	28-11-16	7.4	1011	285	215	80	3.6	142	2.5	nd	348	110	58	0.4
6	Chandkhuri	HP	28-11-16	7.5	1518	305	650	234	15.6	40	17.5	nd	372	245	115	0.2
7	Marauda	HP	29-11-16	7.6	591	185	250	90	6	20	1.3	nd	226	36	51	0.1
8	Risali	HP	29-11-16	7.6	785	240	355	124	10.8	18	0.8	nd	293	96	18	0.2
9	Risali1	HP	29-11-16	7.1	888	210	360	128	9.6	35	0.5	nd	256	117	49	0.3
10	Khamariya	HP	29-11-16	7.3	494	195	215	74	7.2	19	0.4	nd	238	36	15	0.3
11	Kokri	HP	29-11-16	7.2	543	255	215	78	4.8	27	0.4	nd	311	14	16	0.7
12	Pauwara	HP	29-11-16	7.2	1328	195	405	152	6	48	47	nd	238	178	132	0.2
13	Kodiya	HP	29-11-16	7.4	501	215	210	70	8.4	27	3.4	nd	262	18	24	0.2
14	Bhanpuri	HP	29-11-16	7.3	942	320	370	90	34.8	43	0.6	nd	390	92	21	0.6
15	Kuthrel	HP	29-11-16	7	1391	330	515	170	21.6	53	17	nd	403	178	95	0.3
16	Newai	HP	30-11-16	6.9	746	280	340	106	18	21	0.8	nd	342	75	13	0.3
17	Newai Bhata	HP	30-11-16	7.3	682	205	275	78	19.2	34	0.7	nd	250	67	41	0.4
18	Umarpoti Bhata	HP	30-11-16	7.3	477	175	210	62	13.2	14	0.3	nd	214	28	21	0.3
19	Umarpoti	HP	30-11-16	7.1	1075	270	395	104	32.4	63	0.4	nd	329	167	39	0.2
20	Purai	HP	29-11-16	7.2	896	255	310	84	24	63	1.2	nd	311	107	50	0.4
21	Boridih	HP	29-11-16	7.4	503	215	215	64	13.2	17	0.3	nd	262	21	14	0.4
22	Kargadih	HP	30-11-16	7.4	368	165	175	42	16.8	10	0.3	nd	201	11	10	0.3
23	Khopli	HP	30-11-16	7.4	1271	215	475	156	20.4	48	2.5	nd	262	241	62	0.3
24	Ghugsidih	HP	30-11-16	8.8	831	380	30	4	4.8	194	2.1	nd	464	46	17	0.7
25	Daurabhata	HP	30-11-16	7.4	549	260	180	40	19.2	49	1.7	nd	317	11	16	0.6

Sl. No.	Location	Source	Date of Collection	pH	EC (µS/cm)	TA	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	F
						mg/l										
26	Utai	HP	30-11-16	7.2	1181	255	390	116	24	99	1.8	nd	311	135	145	0.3
27	Parsahi	HP	01-12-16	7.1	1014	245	350	116	14.4	53	4.8	nd	299	128	53	0.2
28	Sirri	HP	01-12-16	7.3	885	235	340	112	14.4	35	0.6	nd	287	124	26	0.4
29	Machandur	HP	01-12-16	7.2	778	250	315	98	16.8	26	0.4	nd	305	92	18	0.3
30	Chirpoti	HP	01-12-16	7.3	755	290	250	76	14.4	50	0.8	nd	354	53	20	0.3
31	Risama	HP	01-12-16	6.8	1529	345	580	202	18	52	1	nd	421	213	69	0.1
32	Matwari	HP	01-12-16	7	1503	275	530	194	10.8	60	15.5	nd	336	241	89	0.3
33	Matrodih	HP	01-12-16	7	781	250	340	118	10.8	25	4	nd	305	78	32	0.1
34	Janjgiri	HP	01-11-16	6.9	1699	345	690	252	14.4	53	21	nd	421	266	106	0.2
35	Kanakot	HP	02-12-16	7.5	408	165	195	60	10.8	11	0.2	nd	201	21	11	0.4
36	Tamora	HP	02-12-16	7.6	859	200	335	110	14.4	37	1.9	nd	244	121	37	0.5
37	Pangri	HP	02-12-16	7.4	2680	310	875	282	40.8	141	1.9	nd	378	561	152	0.4
38	Khapri	HP	02-12-16	7.5	477	190	210	60	14.4	25	0.8	nd	232	43	13	0.4
39	Gorkapar	HP	02-12-16	7.7	640	170	215	76	6	35	1	nd	207	64	25	0.4
40	Sakraud	HP	02-12-16	7	1624	395	655	220	25.2	104	1.3	nd	482	277	52	0.5
41	Parsahi	HP	02-12-16	7.4	910	280	320	98	18	69	1.5	nd	342	110	28	0.4
42	Tiloda	HP	02-12-16	7.1	1042	275	460	152	19.2	36	0.7	nd	336	135	46	0.4
43	Bhilai Sector 5	HP	01-12-16	7.4	691	260	200	62	10.8	63	0.4	nd	317	21	40	0.7
44	Bhilai DPS	HP	01-12-16	7.3	529	200	255	60	25.2	15	0.5	nd	244	36	20	0.3
45	Dumardih	HP	30-11-16	8.2	503	170	235	64	18	15	0.5	nd	207	46	17	0.2
46	Parewadih	HP	30-11-16	8.3	368	140	155	50	7.2	11	0.1	nd	171	18	9	0.3
47	Morid	HP	30-11-16	7.1	327	140	170	42	15.6	6	0	nd	171	14	12	0.3
48	Dundera	HP	30-11-16	7.2	675	235	305	90	19.2	19	0.7	nd	287	57	20	0.3
49	Joratarai	HP	30-11-16	8.3	724	230	330	96	21.6	23	0.6	nd	281	78	31	0.3
50	CISF Campus	HP	02-12-16	7.1	394	195	200	50	18	11	0.3	nd	238	11	3	0.2

HP: Handpump

Details of surface water sampling locations, onsite chemical parameters (pre-monsoon season) in Pulgaon Nala watershed

Sl. No.	Location	Source	Date	Field Parameters				
				Temp. (°C)	pH	EC (µS/cm)	TDS (mg/l)	Salt (mg/l)
1	Ganjpara	Pulgaon Nala	03-05-16	29.5	7.9	260	184	125
2	Padmanavpur	Thagda Nahar	03-05-16	28.1	7.9	484	343	235
3	Borsi	Pond	03-05-16	29.7	8.3	1335	945	662
4	Hanoda	Pond	03-05-16	31.8	8.8	351	248	170
5	Chandkhuri	Pond	03-05-16	32.9	9.3	722	510	353
6	Risali	Pond	04-05-16	27.6	8.3	750	527	366
7	Khamariya	Sonua Talab	04-05-16	28.8	8.4	340	241	165
8	Kokri	Aawadipara Pond	04-05-16	29.8	8.5	335	236	162
9	Pauwara	Shitla Taria	04-05-16	30.4	7.8	279	198	136
10	Kodiya	Pond	04-05-16	30	8.8	217	154	106
11	Bhanpuri	Baadaa Talab	04-05-16	30	9.1	363	258	177
12	Kuthrel	Jalendri Talab	04-05-16	31.6	9	1436	1020	717
13	Marauda Reservoir	Marauda Reservoir	05-05-16	26.4	8.6	171	120	84.4
14	Umarpoti	Amha Talab	05-05-16	28.9	8.4	378	268	183
15	Purai	Pond	05-05-16	28.6	8.5	515	365	251
16	Khopli	Tedgi Talab	05-05-16	30.9	8.5	666	469	323
17	Ghugsidih	Pond	05-05-16	31	8.6	241	171	118
18	Utai	Puraiha Talab	05-05-16	32.4	8.8	343	243	167
19	Parsahi	Pond	06-05-16	28	8.6	232	165	114
20	Machandur	Pond	06-05-16	28	8.7	405	287	197
21	Chirpoti	Pond	06-05-16	27.7	7.9	505	358	246
22	Risama	Pond	06-05-16	28.2	9.2	299	212	145
23	Janjgiri	Dongia Talab	06-05-16	29.4	8.5	312	221	152
24	Kanakot	Pankhatia Taria	09-05-16	28.2	7.9	388	276	188
25	Khapri Reservoir	Khapri Reservoir	09-05-16	28.7	9	215	153	106
26	Parsahi	Pond	09-05-16	30.9	9.2	392	278	191
27	Tiloda	Pond	09-05-16	30.8	9.3	522	369	254

Details of surface water sampling locations, onsite chemical parameters (post-monsoon season) in Pulgaon Nala watershed

Sl. No.	Location	Source	Date	Field Parameters				
				Temp. (°C)	pH	EC (µS/cm)	TDS (mg/l)	Salt (mg/l)
1	Ganjpara	Pulgaon Nala	28-11-16	23.4	8.9	333	236	151
2	Padmanavpur	Thagda Nahar	28-11-16	26.5	8.9	374	263	169
3	Borsi	Pond	28-11-16	26.1	8	738	526	341
4	Hanoda	Pond	28-11-16	24.6	9.1	479	337	216
5	Chandkhuri	Pond	28-11-16	27.5	9.5	510	362	233
6	Risali	Pond	29-11-16	25.4	9	487	345	221
7	Khamariya	Sonua Talab	29-11-16	23.5	8.7	330	230	147
8	Kokri	Aawadipara Pond	29-11-16	25.2	9.5	320	226	145
9	Pauwara	Shitla Taria	29-11-16	25	8.5	495	348	226
10	Kodiya	Pond	29-11-16	25.9	9	279	201	130
11	Bhanpuri	Baadaa Talab	29-11-16	26	9.2	310	218	141
12	Kuthrel	Jalendri Talab	29-11-16	25.1	9.4	1030	729	477
13	Marauda Reservoir	Marauda Reservoir	30-11-16	24.2	9	124	88	62
14	Umarpoti	Amha Talab	30-11-16	24	9.2	367	259	165
15	Purai	Pond	29-11-16	24.4	8.9	704	498	316
16	Khopli	Tedgi Talab	30-11-16	25.5	9.4	585	406	263
17	Ghugsidih	Pond	30-11-16	25.8	9.4	200	146	95
18	Utai	Puraiha Talab	30-11-16	25	9	369	262	169
19	Parsahi	Pond	01-12-16	23.2	8.5	282	202	129
20	Machandur	Pond	01-12-16	24	9.4	381	273	174
21	Chirpoti	Pond	01-12-16	24	9.3	452	320	205
22	Risama	Pond	01-12-16	25.4	9.7	269	191	123
23	Janjgiri	Dongia Talab	01-12-16	23.5	8.2	504	359	215
24	Kanakot	Pankhatia Taria	02-12-16	24.2	8.6	468	334	214
25	Khapri Reservoir	Khapri Reservoir	02-12-16	24.7	8.8	197	135	84
26	Parsahi	Pond	02-12-16	23.5	9.5	285	212	136
27	Tiloda	Pond	02-12-16	24.6	9.5	553	382	252
28	Risali Reservoir	Reservoir	29-11-16	24.2	8.1	390	277	169

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National Programme on Isotope Fingerprinting of Waters of India (IWIN)

Rainwater Sampling Protocol

Introduction

The isotopic composition of water, in general, is extremely sensitive to evaporative loss. Therefore, rainwater samples for isotopic analyses should be collected, stored and transported with utmost care, according to the specific procedures given below. In addition, the isotopic composition of rainwater, in a particular rain, event can also be related to weather parameters such as temperature, humidity, amount of rainfall, etc. Therefore, it is equally important to record these weather parameters for each rainwater sample. The high level of precision and accuracy in isotopic measurements, achievable by a modern mass spectrometer, is meaningful only when integrity of samples is assured and associated weather parameters are available for interpretation of isotopic data.

In the following, instructions for setting up the rainwater sampling device and the protocols for rainwater sampling for IWIN are presented. The officer in-charge of the station is requested to go through each and every step and also explain the same to the person responsible for actual sample collection.

Information about the rainwater sampling device

Figure 1. Rainwater sampling Device. Please read the text for description of the numbered items.

A picture of the rainwater sampling device is shown in Figure 1. Various components of this device are: 1. Slotted-angle metallic stand for housing the sampling device; 2. 20-Litre polybicarbonate Carboy for collection of the rainwater; 3. Funnel; 4. Rubber Cork holding the funnel and tightly fixed into the carboy; 5. SS tube pierced through the rubber cork into the carboy; 6. Thin PVC tube connected to SS tube; 7. Thick PVC tube connected to funnel; 8. SS weight connected to the thick PVC tube to keep it straight; 9. Hooks for tying the funnel with the metallic stand by cotton string.

In addition to the major items described above, there are two small items, namely, a circular wire-mesh disk and a small plastic ball, to be fixed inside the cone of the funnel. The position of the wire-mesh disk and the ball inside the funnel is shown in Figure 2 . As shown in Figure 2 There are three stopper hooks inside the funnel which are to be turned downwards, after placing the ball and the disk. This will prevent these two items from coming out of the funnel. The purpose of the ball is to close, as far as possible, opening of the funnel and reduce the evaporation when there is no rainfall. During the rainfall, the ball will be lifted up by its buoyancy and will allow the rainwater to go into the carboy. The purpose of the wire-mesh is to prevent the coarse objects (leaf, paper, etc.) from going inside the carboy, and also to prevent the ball from jumping out of the funnel.

Figure 2. A circular wire-mesh disk and the plastic ball placed inside the funnel.

The pipe of the funnel is passed through the big hole in the rubber cork and an SS tube is passed through a small hole in the funnel as shown in Figure 3.

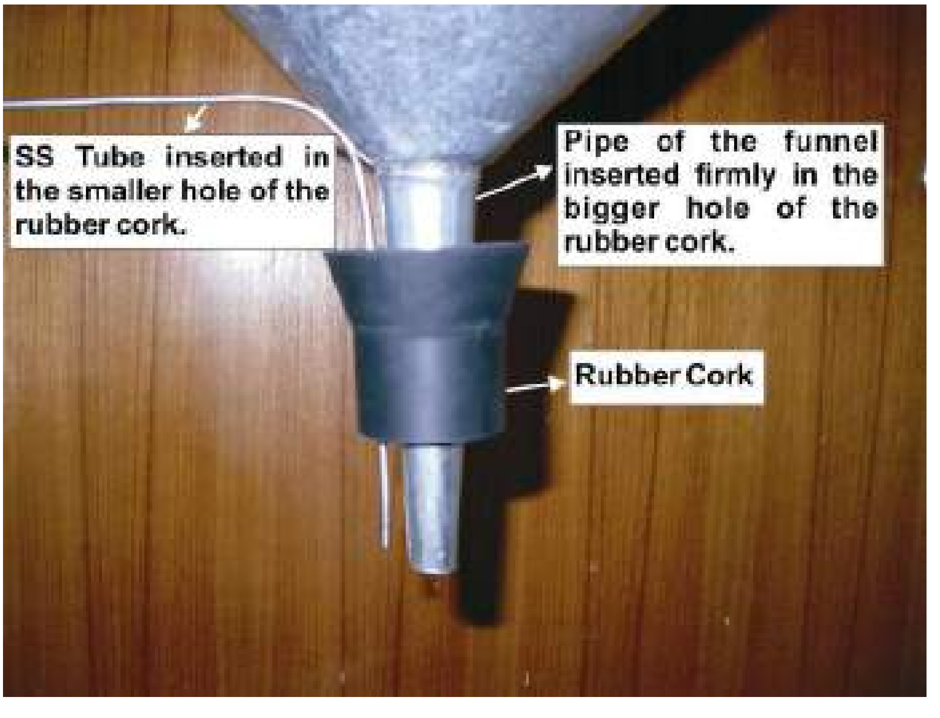

Figure 3. A closer look at how pipe of the funnel and the SS tube are inserted in the holes, provided in the rubber cork.

The purpose of the SS tube is to provide the pathway for air-outlet from the carboy, which becomes air-tight due to rubber cork, tightly fixed into the carboy.

Figure 4. Connections of PVC tubes and SS piece.

A 10 ft long thin PVC tube is connected to another end of the SS tube. This minimises the exchange of air between within and outside the carboy. A thick PVC tube is connected to the pipe of the funnel which transports the rainwater from funnel into the carboy. A stainless steel piece is attached at the end of the thick PVC tube, which keeps the PVC tube straight and just above the base of the carboy. A picture depicting two types of PVC tubes and the Stainless steel piece is shown in Figure 4.

In order to minimise the evaporation of rainwater collected in the carboy, it is protected from direct sunlight by a thick white cloth cover, as shown in Figure 5. The 10 ft long thin PVC tube attached to SS tube should also be passed through the mouth of the cloth cover. The top of the cloth cover is to be tied to the neck of the carboy, using the cloth strips attached to the cover. Similarly, the bottom of the cloth cover is to be tied to the slotted angle stand. The white cover also contains a small zip-window to see the water level in the carboy or to inspect the position of PVC tube and the SS piece.

Figure 5 A cloth cover enclosing the rainwater sampling device.

After firmly inserting the funnel into the rubber cork, the rubber cork should be firmly inserted in the carboy, such that the funnel is vertically aligned with the carboy. The funnel is to be tied to the metallic stand using the cotton rope provided for it, as shown in Figure 5.

Figure 6. graduated cylinder.

A plastic cylinder graduated up to 500 ml (Figure 6) is provided for measuring the amount of rainwater collected in the carboy. This cylinder should be kept covered in a polythene bag while not in use.

The step wise instructions for setting up the rainwater sampling device are given in the following.

Instructions for Setting up the Rainwater Sampling Device

1. The sampling device should not be relocated for the duration of the IWIN sampling programme. Therefore, the location should be chosen carefully.
2. Place the metallic stand on a stable horizontal surface at a location which is:
    a. Preferably on the terrace of a building
    b. Not below any canopy
    c. Not obstructed by any tall structure
    d. Away from the walkway
    e. Not accessible to stray animals
3. Ensure that the stand is firmly resting on the ground and not shaking about. If the stand is unsteady due to uneven ground, level off the ground or re-locate the stand at proper place.
4. Put the additional weight (bricks or any other bulky metallic item, etc) on each of the four extended legs of the metallic stand to ensure its stability.
5. Put the carboy inside the stand such that the carboy rests firmly on the Aluminium base plate of the stand and not shaking about.
6. Take the cloth cover and make it wear over the stand such that only neck of the carboy is visible from the narrow mouth of the cover, as shown in Figure 5. Note that the cloth cover can be worn over the stand and the carboy only if rubber cork with funnel is not attached to carboy.
7. The rubber cork, with the funnel and the SS tube inserted across it, is dispatched to you, as shown in Figure 3. However, ensure by pushing the pipe of the funnel inside the rubber cork, that the funnel is firmly gripped by the rubber cork and does not rotate feely within the rubber cork. Also ensure that one end of the SS tube is firmly inserted across the rubber cork and a 10 ft long thin PVC tube is connected to another end.
8. Attach the thick PVC tube firmly to the funnel, as shown in Figure 4. Ensure that the SS piece is attached to other end of this PVC tube.
9. Hold and lift the rubber cork with one hand and insert the thick PVC tube along with SS piece, inside the carboy, using the other hand.
10. Push the rubber cork firmly inside the neck of carboy until it is no more easily removable and the funnel is positioned vertically aligned to the carboy.
11. Ensure that the thick PVC tube is vertically positioned inside the carboy and that the metallic piece is resting just above bottom of the carboy.
12. The roll of the 10 ft long thin PVC tube attached to SS tube should be inserted within the cloth cover from its mouth.
13. Place the small white ball and the wire-mesh circular disk into the funnel, as shown in Figure 2. Turn the stopper hooks down so that the circular disk does not come out.
14. Tie the mouth of the cloth cover to the neck of the carboy using two cloth strips provided to the cover (see Figure 5). Similarly, also tie the bottom of the cloth cover with the stand using any of the slots in the stand.
15. The funnel is provided with four hooks on its outside to tie the funnel with the stand using these hooks. Use the four pieces of cotton string to tie the funnel with the stand such that the funnel should not be blown away by the wind. However, the string should not be so tightly tied that it can not be opened when required.
16. A graduated cylinder is provided for measuring the amount of rainwater collected over a period of time. Keep it clean (by covering its mouth with a polythene bag), handy and safe, for use when required.

Information about the Sample Bottles

1. The rain water samples are to be collected in the 500 ml or 250 ml plastic bottles (depending on volume of water collected), and sealed with inner stub and pilferage-proof caps. These bottles will be supplied by the IWIN for CRIDA and IMD stations. Other partners have to procure the bottles themselves according to the sample provided by IWIN.
2. **The inner stubs and pilferage-proof caps should be kept separate from the bottle** before sampling due to reasons given below.
3. The **stubs are designed only for a single use** and get tightly fixed into the bottle mouth once fitted. It gets de-shaped while removing from the bottle and may not give perfect sealing if reused. Therefore, stubs should not be fixed into the bottle before sampling and should not be reused if already fixed once into the bottle.
4. After sealing with the inner stub, fix the pilferage-proof cap tightly on the mouth of the bottle.
5. **Once fixed, the pilferage-proof cap should not be opened**, because it is so designed that while re-opening the cap, the seal is automatically broken.
6. Any bottle with its pilferage-proof cap seal broken will be treated as tempered bottle and will not be used for isotopic analyses.

Protocols for Rain water sampling

1. Rainwater samples are to be collected on fortnightly accumulation basis, except where it is decided to collect on daily basis.
2. After setting up the rainwater sampling device according to above instructions, note down the date and time, and temperature and relative humidity. You are requested to use the thermometer and hygrometer available in your institution. Preferably, use the same set of thermometer and hygrometer every time.
3. For the sake of convenience, it is advised to collect the rainwater sample every 1st and 16th day of a month, for fortnightly collection stations. If these dates are holydays, the sample may be collected a day ahead or behind the scheduled date.
4. The carboy will be about half filled with accumulated rainfall of 10 cm. When this occurs before the 15-day sampling period, additional sample should be taken out early following normal procedure. This may be repeated as often as necessary. If additional sample as above is taken, the next sample should be taken on dates of 1st or 16th as the case may be.
5. In case of daily collection station, it is required to be collected everyday in the morning.
6. It is advised to collect the rainwater sample at 10 am. This is the time when sunlight is comparatively mild and the sample can be collected comfortably. The time of 10 am is particularly advantageous for daily collection stations because the rainwater collected overnight is prevented from evaporation during hot day time.
7. Before proceeding for sample collection, keep the measuring cylinder, thermometer, hygrometer, sample bottles and log book handy for use.
8. Remove the rubber cork with all its attachments and then the cloth cover.
9. Remove the carboy out of the stand and shake it in such a way that the collected rainwater and the droplets on the wall of the carboy are well mixed but water is not splashed out of the carboy.
10. Transfer the water into the measuring cylinder and measure the volume of water collected. Note down the volume in the logbook.

11. If volume of the collected rainwater is more than the graduated volume of the measuring cylinder, please measure the rest of the rainwater in successive batches using the same cylinder (or smaller if required) as described in point 15 below. However, it is advised to collect the sample first from the first measured volume of the rainwater as described in points 11 to 14 below.
12. Use a little amount of water from measuring cylinder to rinse / clean the sampling bottle thoroughly.
13. Transfer the remaining water from measuring cylinder into the sampling bottle. Fill the bottle up to the brim, leaving just a little space for the inner stub.
14. **No chemical** (acid/ preservative/ poison, etc.) should ever be added to IWIN water samples.
15. Fix the inner stub tightly into the mouth of the bottle. Screw the pilferage-proof cap tightly on the bottle.
16. If there is still some water left in the carboy to measure the volume, proceed with measuring the volume.
17. Note down in the logbook the total volume of rainwater measured in all the batches.
18. Measure the temperature and relative humidity, and note down the same in the logbook along with date and time of collection together with your and IWIN sample codes.
19. IWIN Sample Code should be written on each packed sample bottle, according to format given in the sample submission data sheet for respective sample collection agency.
20. For writing IWIN Sample Code on the bottle, permanent marker pen should be used and writing should be covered with cello tape.
21. All the information requested in the sample submission data sheet, including the results of the field and laboratory chemical analyses, is to be duly filled as far as possible.
22. Information about the amount of rainfall (in cm), requested in the sample submission data sheet, should be obtained from the weather station in your institute and filled in the sample submission data sheet.
23. In case some information requested in the sample submission data sheet is likely to be available at a later date, it should be so stated by marking LATER. When no information is available and will not be available later it must be marked NAV.
24. If the results of laboratory analyses are available after dispatching the samples to PRL, the same may please be communicated to Physical Research Laboratory (PRL), Ahmedabad, when these become available.
25. All the samples collected from a particular fortnightly collection station of CRIDA, IMD and NRL are to be transported to PRL, Ahmedabad in a batch of 2 samples, by registered post parcel.
26. All the samples collected from a particular daily collection station of CRIDA and IMD are to be transported to PRL in a batch of 6-8 samples.
27. Only a small portion (100 - 250 ml) of samples collected by isotope analysing laboratory (NIH, NGRI, NIO, BARC) are to be sent to PRL in 250 ml bottles for sample repository along with the sample submission data sheet.

δD and $\delta^{18}O$ values in ground water in the study area

Sl. No.	GW_Station	Pre-monsoon		Post-monsoon		Sl. No.	GW_Station	Pre-monsoon		Post-monsoon	
		$\delta^{18}O$ in ‰ wrt SMOW	δD in ‰ wrt SMOW	$\delta^{18}O$ in ‰ wrt SMOW	δD in ‰ wrt SMOW			$\delta^{18}O$ in ‰ wrt SMOW	δD in ‰ wrt SMOW	$\delta^{18}O$ in ‰ wrt SMOW	δD in ‰ wrt SMOW
1	Adarsh Nagar	-0.93	-13.84	-2.9	-23.8	27	Machandur	-0.61	-16.10	-0.7	-12.2
2	Bhilai DPS	-2.39	-21.99	-2.6	-21.0	28	Marauda	-2.77	-22.46	-3.3	-23.9
3	Bhilai Sector 5	-2.41	-21.88	-3.0	-22.2	29	Matrodih	-1.71	-19.77	-3.6	-28.7
4	Boridih	-2.48	-17.51	-2.5	-18.6	30	Matwari	-3.15	-23.14	-3.0	-22.7
5	Borsi	-2.19	-19.55	-3.4	-25.3	31	Morid	-2.63	-20.59	-3.1	-22.4
6	Chandkhuri	-2.60	-22.09	0.0	-7.3	32	Mundra	-2.99	-19.78	-2.8	-18.7
7	Chirpoti	-1.28	-17.36	-0.4	-11.7	33	Newai	-3.64	-24.66	-3.7	-25.8
8	CISF Campus	-2.89	-21.35	-2.9	-20.8	34	Newai Bhata	-3.44	-24.86	-3.9	-28.5
9	Daurabhata	-2.85	-22.30	-3.2	-24.7	35	Padmanavpur	-1.98	-18.85	-2.3	-21.0
10	Dhanaura	-1.61	-14.72	-2.2	-18.6	36	Pangri	-1.46	-13.88	-2.1	-23.4
11	Dumardih	-3.09	-25.70	-3.1	-24.7	37	Parewadih	-3.30	-25.10	-3.3	-23.6
12	Dundera	-3.37	-25.56	-3.9	-26.6	38	Parsahi	-3.08	-24.13	-3.5	-27.3
13	Ganjpara	-2.11	-21.16	-1.8	-18.4	39	Parsahi	-0.34	-11.99	-0.6	-10.5
14	Ghugsidih	-1.20	-14.09	-1.4	-14.7	40	Pauwara	-2.88	-23.54	-3.9	-27.4
15	Gorkapar	-2.49	-20.58	-3.0	-22.1	41	Purai	-3.80	-26.40	-1.7	-17.5
16	Hanoda	-2.67	-20.92	-3.0	-23.0	42	Rahud	-3.25	-22.90	-3.9	-25.3
17	Janjgiri	-2.39	-17.44	-3.5	-24.7	43	Risali	-2.56	-21.65	-2.7	-20.5
18	Joratarai	-2.59	-22.02	-2.5	-20.8	44	Risali1	-1.64	-15.57	-1.2	-12.4
19	Kanakot	-2.16	-19.40	-2.3	-22.2	45	Risama	0.35	-9.10	-0.8	-13.2
20	Kargadih	-2.66	-21.75	-3.0	-22.6	46	Sakraud	-1.15	-11.72	-1.0	-10.8
21	Khamariya	-1.65	-17.33	-2.0	-18.5	47	Sirri	-2.70	-24.55	-2.5	-19.0
22	Khapri	-2.43	-19.67	-2.9	-20.4	48	Tamora	-2.07	-18.00	-2.4	-18.2
23	Khopli	-1.72	-13.14	-1.6	-11.6	49	Tiloda	0.05	-7.10	-0.2	-7.1
24	Kodiya	-0.53	-13.35	-2.6	-22.9	50	Umarpoti	2.13	1.24	1.2	-3.7
25	Kokri	-1.02	-14.14	-3.0	-22.2	51	Umarpoti Bhata	-2.67	-22.28	-2.7	-22.3
26	Kuthrel	0.35	-7.52	-1.8	-12.6	52	Utai	-1.62	-18.37	-2.1	-18.0

SMOW: Standard Mean Ocean Water

δD and $\delta^{18}O$ values in surface water in the study area

Sl. No.	GW_Station	Pre-monsoon		Post-monsoon	
		$\delta^{18}O$ in ‰ wrt SMOW	δD in ‰ wrt SMOW	$\delta^{18}O$ in ‰ wrt SMOW	δD in ‰ wrt SMOW
1	Bhanpuri	9.46	39.50	0.1	6.9
2	Borsi	12.31	51.29	-2.1	-24.0
3	Chandkhuri	10.66	43.91	0.6	-9.1
4	Chirpoti	6.09	18.24	0.3	-10.7
5	Ganjpara	-0.15	-13.43	-3.6	-32.2
6	Ghugsidih	1.03	-7.18	-3.1	-30.7
7	Hanoda	0.70	-11.15	-4.5	-41.4
8	Janjgiri	3.50	6.08	0.1	-15.6
9	Kanakot	3.81	6.41	-0.9	-21.0
10	Khamariya	4.03	8.26	-0.4	-15.5
11	Khapri Reservoir	1.80	1.97	-3.2	-26.8
12	Khopli	4.83	12.82	-1.2	-22.1
13	Kodiya	-0.19	-14.27	-4.0	-37.0
14	Kokri	5.63	14.50	0.5	-13.5
15	Kuthrel	9.78	35.96	-0.3	-14.6
16	Machandur	5.23	9.04	0.4	-14.2
17	Marauda Reservoir	-0.73	-14.36	-3.1	-27.7
18	Padmanavpur	9.23	37.79	-1.3	-17.1
19	Parsahi	0.50	-9.57	-1.5	-26.2
20	Parsahi	7.60	26.41	-0.6	-14.8
21	Pauwara	-0.16	-13.22	-3.9	-36.5
22	Purai	4.96	11.07	-2.1	-26.3
23	Risali	10.05	41.53	-1.5	-21.0
24	Risama	6.39	20.97	-1.7	-26.1
25	Tiloda	4.71	11.19	1.5	-5.1
26	Umarpoti	3.85	6.85	-0.1	-17.1
27	Utai	2.77	2.48	-3.8	-36.4

SMOW: Standard Mean Ocean Water

SELECT FIELD PHOTOGRAPHS

Measurement of water level through bore well in the study area.

Measurement of water level through bore well in the study area.

Collection of ground water samples from purged bore well for analysis of stable isotopic signature.

Collection of ground water samples from purged bore well for analysis of basic parameters.

On site measurement of pH, EC and Temp. of ground water samples

Collection of surface water samples from village pond for analysis of stable isotopic signature

On site measurement of pH, EC and Temp. of surface water samples.

Collection of surface water samples from surface water reservoir for analysis of stable isotopic signature.

Measurement of water level through bore well in the study area during post-monsoon season.

Collection of ground water samples from purged bore well during post-monsoon season for analysis of stable isotopic signature.

Collection of surface water samples from surface water reservoir during post-monsoon season for analysis of stable isotopic signature.

Collection of surface water samples from surface water reservoir during post-monsoon season for analysis of stable isotopic signature.