केंद्रीय भूमि जल बोर्ड

जल संसाधन, नदी विकास और गंगा संरक्षण मंत्रालय

भारत सरकार

Central Ground Water Board

Ministry of Water Resources, River Development and Ganga Rejuvenation

Government of India

Report

on

AQUIFER MAPPING AND GROUND WATER MANAGEMENT PLAN

Haridwar District, Uttarakhand

उत्तरांचल क्षेत्र, देहरादून

Uttaranchal Region, Dehradun

CENTRAL GROUND WATER BOARD
MINISTRY OF WATER RESOURCES,
RIVER DEVELOPMENT AND GANGA REJUVENATION
GOVERNMENT OF INDIA

AQUIFER MAPPING REPORT
HARIDWAR DISTRICT, UTTARAKHAND

UTTARANCHAL REGION
DEHRADUN
OCTOBER – 2016

AQUIFER MAPPING REPORT, HARIDWAR DISTRICT, UTTARAKHAND

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PREFACE

A study on Aquifer Mapping in Haridwar District, Uttarakhand was taken up by Central Ground Water Board, Uttaranchal Region during AAP 2013-14/2015-16 with an objective to identify and map the aquifers at micro level, quantify the availability of the ground water resource and suggest aquifer management plans compatible with the ground water demand, the aquifer characteristics and the basic issues of the area. The study area consists of 6 Blocks of Haridwar district i.e Roorkee, Bhagwanpur, Laksar, Khanpur, Bahadrabad and Narsan.

During the study period, available data was compiled, data gap analysis was carried out and data generated to fill these gaps. Extensive hydrogeological surveys were carried out including village wise well inventory, water level and water quality monitoring, etc. All the data collected using various techniques was studied and synthesized in the form of Aquifer maps incorporating the various attributes of the aquifer system. Based on these Aquifer maps and analysis of data, Aquifer Management Plans were prepared. The study also identifies the major groundwater issues in the study area that need redressal through appropriate management plans.

The support received from different central and state government agencies has helped a lot in completion of this study. I thank and congratulate all of them for such an exhaustive work and completing the work within scheduled timeframe.

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

Place: Dehradun **(Anurag Khanna)**

Date: 25/10/2016 **Head of the Office**

EXECUTIVE SUMMARY

The aquifer mapping study in Haridwar District, Uttarakhand, India was taken up with the objective to evolve an aquifer management plan. The study involves establishing the aquifer disposition and its characterization at 1:50,000 scale using latest state of art technology in the field of hydrogeology and recommending aquifer management plan.

Haridwar district is located in south-western part of Uttarakhand State. It lies from $29^{\circ}35'$ to 30^{0} 40' North latitude and $77^{\circ}43$ ' to $78^{\circ}22'$ East longitude and falls in Survey of India Degree Sheet Nos. 53 J, F, G and K. The geographical area of the district is 2360 km^2. The total study area taken up for the aquifer mapping is about 2000 sq.km. The area includes 6 blocks of Haridwar District i.e Roorkee, Bhagwanpur, Laksar, Khanpur, Bahadrabad and Narsan, Uttarakhand. There exist three tier aquifer system in the study area of indo-gangetic belt of Haridwar district separated by thick confining clay layers of varying thickness. In the study area the nature of alluvial sediment is complex and there is alternation of fine to coarse sediments.

The saturated aquifer system is comprised of fine to coarse-grained sand and gravels. In the bouldery formation (Bhabar belt) the aquifer group has been intervened by thin clay layers which at places are thick are mixed with boulders and cobble, pebble. The southern part of the district contains a good thickness of granular material sediments of older alluvium as well as younger alluvium. Since, the aquifer exist in three-tier system, each of this aquifer group contains considerable thickness of sand. The Aquifer 3-D disposition map reveals that the first aquifer is encountered after sandy clay layer between 5-25 m. The first and the second aquifer are separated by 10-20m thick clay layer. In Bhabhar belt groundwater occurs under unconfined conditions. In Terai belt groundwater occurs under confined conditions. In Gangetic alluvium the groundwater occurs in Semi-Confined/ Confined conditions.

The drilled depth of wells in district ranges between 36.58 to 223.96 m bgl. The water level in these tube wells ranges between 5.85 to 26.40 m bgl with a discharge ranging 21.66 to 46lps. The transmissivity ranges between 176 to 19850 m^2/day. The exploratory well drilled falls under Bhabar zone as well as in Indo Gangetic alluvial plain.

The quality of the Ground Water is also suitable for drinking and irrigational purposes. The E.C. is slightly higher in parts of Laksar block (upto 1535 microS/cm) while rest all other study area it is in between 500 to 900 microS/cm. Ground water level in the study area is about 1.68 m bgl to 23 m bgl whereas deeper groundwater level also exist upto 70 m bgl in foothills of the Siwaliks, where the formation is Bhabar. The Groundwater is the main source of water for fulfilling the demands of irrigation, domestic and industrial purposes. The aquifer disposition and characteristics prevailing in the area has been studied based on exploratory drilling tapping different aquifers. Monitoring of Ground Water regime is done 4 times a year i.e May, August, November and January.

The main Ground Water related problem in the study area is decline in groundwater level and deterioration of groundwater quality especially the heavy metal content in some parts of the study area. The possible causes may be the following 1) the Massive deforestation in the Bhabar zone which is the recharge area of the Tarai aquifers. 2) Rapid increase in the number of shallow tube wells in the region consequent upon increase in agricultural land. 3) General downward trend in the rainfall in the region. And 5) Increase in agricultural practices using Ground Water by constructing shallow tube wells.

Based on the present and past studies certain recommendations are made to sustain and manage the groundwater for further future needs and development.1) To remove the stress on the phreatic aquifer and to avoid the poor quality of groundwater it is recommended to construct deep tubewells in these locations for groundwater extraction and the well design for the deeper tubewells are also recommended. 2) It is quite safe to tap second and third aquifer below 150 meter for further development in the southern part. The upper most aquifer group should be left for shallow borings for the local farmers to use. 3) it has been observed that around Bhagwanpur township the industrial activities are going on and there are a number of sugar mills in Laksar and Chudiala areas the industrialist should be advised to adopt the root top rainwater harvesting system and waste sewerage treatment plant, so that it may not contaminate the ground water. 4) Afforestation in Bhabar Zone will increase recharge in Tarai. 5) Promoting efficient water conveyance and field application devices within the farm viz, underground piping system, Drip & Sprinklers, pivots, rain-guns and other application devices etc. 6) Farmer oriented activities like capacity building, training and exposure visits, demonstrations, farm schools, skill development in efficient water and crop management practices (crop alignment) including large scale awareness on more crop per drop of water through field days, and extension activities. The study recommended development of holistic water management programme which involves controlled use of available fresh water resources as the overall Stage of Dynamic Groundwater Development in the study area had already reaches 65% (97% in Bhagwanpur) and there exist 3 semi-critical blocks also.

ACKNOWLEDGEMENT

The Author is thankful to Shri K.B.Biswas Chairman, Central Ground Water Board for giving the opportunity and guidance throughout the study. I place on record my sincere thanks to Shri Anurag Khanna, Head of Office, Central Ground Water Board, Uttaranchal Region, Dehradun for giving me his constant help and supervision.

The author place on record, sincere gratitude and appreciation to various central and state government departments for providing valuable data on various aspects of the district. Thanks are also due to the various officers of Central Ground Water Board especially Shri Jagdamba Prasad Scientist ’D’ and Shri R.A.Pir Assistant Hydrogeologist for their valuable previous work on Aquifer Mapping of the district .

Sincere thanks is also due to Shri G.D.Barthwal, Scientist ‘D’ for sharing his valuable experience on investigations for groundwater in the Haridwar District.

Finally, I owe it to my senior colleagues and friends, Shri D. Jamlokhi Scientist ‘D’, Shri RaviKalyan Bussa Scientist ‘C’, Ms Amandeep Kaur Scientist ‘B’, Dr Somveer Singh Scientist ‘B’, Shri D. Bagchi, Asstt Hydrogeologist and Ms Monalisa Singh Scientist ‘B’ for constant encouragement regarding the completion of the assignment and at various stages of writing report.

Place: Dehradun **(Vikas Tomar)**
Date: 25/10/16 **Asstt. Hydrologist**

INTRODUCTION

With the growing human population and ever increasing demand for water supply for drinking, agricultural and industrial purpose, pressure has been mounted on this renewable but limited resource. Ground Water is an important source of fresh water. For the scientific exploration of this natural resource a judicious development and management is required.

Objectives:

The report deals with Aquifer Mapping carried out in Haridwar district of Uttarakhand. The primary objective of the Aquifer Mapping Programme is to prepare micro level aquifer information system with 1:50,000 or larger scale aquifer map and develop Aquifer Management Plans, which will allow institutions and stakeholders to effectively understand and manage groundwater resources at local and larger level. Also problems of Ground water pollution, due to unscientific sewerage and industrial effluent disposal has come up. Besides there are inherent ground water quality related issues which upscale with over pumping of aquifers in some areas. Under the Aquifer Mapping Programme micro level aquifer information system on 1:50,000 or larger scale will be prepared by the technically competent department/agency. This will lead to development of Aquifer Management Plans, which will allow institutions and stakeholders to effectively understand and manage groundwater resources at regional and local level.

Scope of the Study:

Apart from the general hydrogeological condition of the district, efforts have been made to present the information which shall help the local state government and other user agencies in planning various development activities for the welfare of the people.

Approach and Methodology:

The general methodology for Aquifer Mapping is to first collect and compile the existing data (thematic maps, geology, hydrogeology, hydrochemical, hydrology, meteorology, subsurface data etc.). All the existing data is projected in common platform and is to be interpreted validated and correlated. Then, all the data is analysed to identify the data gaps/incompleteness in data. After identifying the data gaps, finally the gaps are to be filled (through Data Gap Generation).

Since the Aquifer Mapping is proposed to be taken on 1: 50,000 scale and the thematic layers are to be prepared on the same scale. The data is to be plotted grid wise on the map i.e. 5' x 5' grid (9 x 9 km) and the data gaps are to be identified accordingly. For the subsurface data, the depth information in alluvial formation is to be taken as 300m. Moreover, if there is more than one geological formation in a single grid, the data pertaining to only one formation is available; it will also be treated as data gap.

Area Details:

Haridwar district is located in southwestern part of Uttarakhand State. It lies from 29º35' to 30^0 40' North latitude and 77º43 ' to 78º22' East longitude and falls in Survey of India Degree Sheet Nos. 53 J, F, G and K. Dehradun and Pauri bounds the district in northeast, Bijnor district of Uttar Pradesh in the southeast, southern boundary with Muzaffarnagar district of Uttar Pradesh while the western part is bounded by district Saharanpur. The geographical area of the district is 2360 km^2. Hardwar district has been divided into three Tehsils viz. Roorkee, Bhagwanpur and Laksar and six Development Blocks namely Roorkee, Bhagwanpur, Laksar, Khanpur, Bahadrabad and Narsan and comprises 622 villages. The administrative map of Haridwar district is given at **Fig 1.** Haridwar district has been very well connected with the network of metaled roads and railway lines. The famous holy Ganges originates from Gangotri Glaciers, after traveling 300 kms in the Himalayan ranges enters the plains of Haridwar.

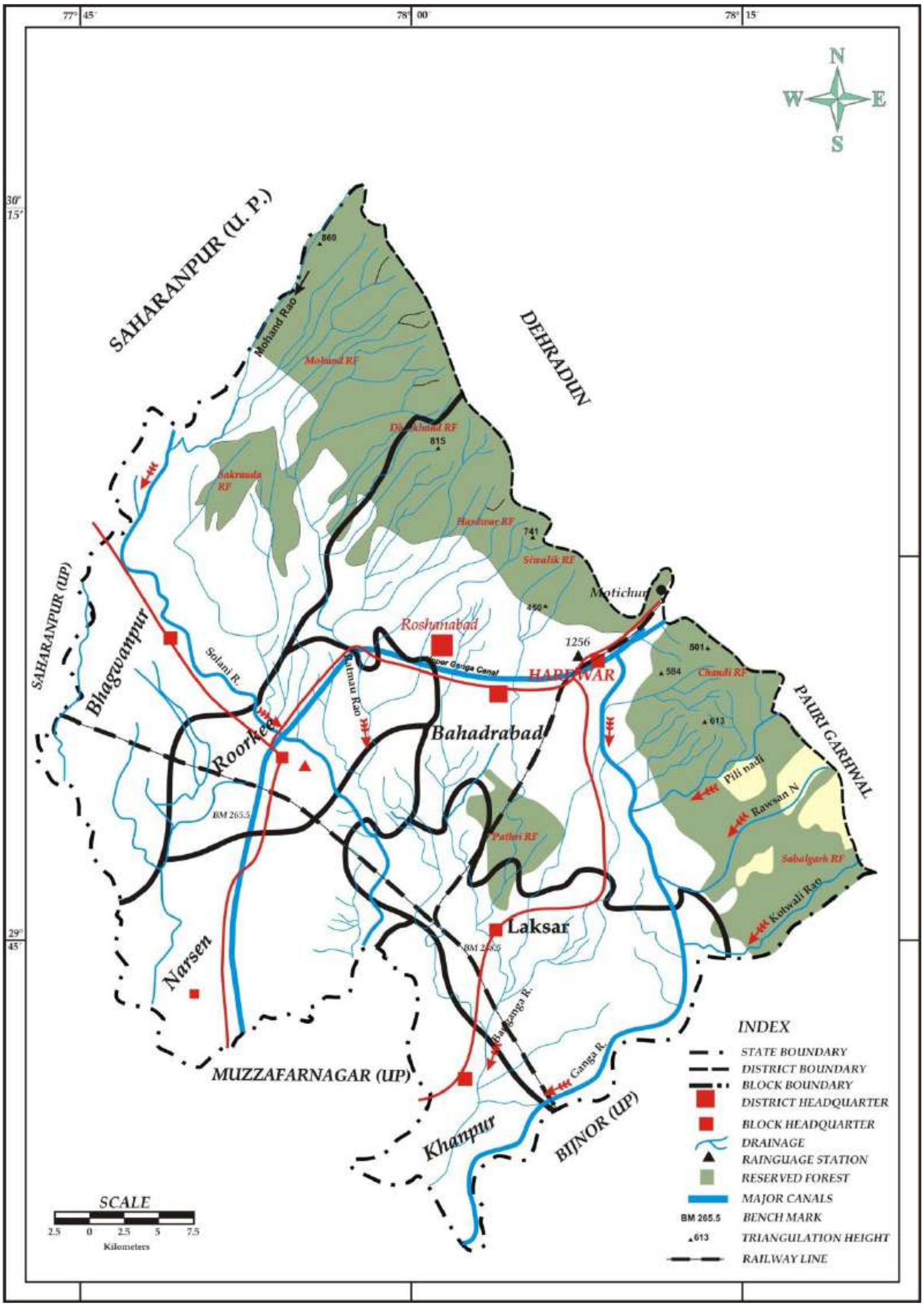


Fig 1: Administrative map of Haridwar district

Brief Description: Data availability, Data adequacy and Data gap analysis and Data generation

One of the important aspect of the aquifer mapping programme was the synthesis of the large volume of data already collected during specific studies carried out by Central Ground Water Board and various Government organizations with a new data set generated that broadly describe an aquifer system. The data were assembled, analyzed, examined, synthesized and interpreted from available sources. On the basis of available data, Data Gaps were identified. The brief data is given below in **Table 1**.

There was also a strong need for generating additional data to fill the data gaps to achieve the task of aquifer mapping. This was achieved by multiple activities such as exploratory drilling, geophysical techniques and hydro-geochemical analysis.

Table 1. Data Availability and Data Gap Analysis in Haridwar District, Uttarakhand

S.No.	Items	Data Requirement	Data Availability	Data Gap
1	Climate	Metereological Stations spread over the project area	1 Metereological Station in NIH Roorkee	Not required
2	Soil	Soil type in area	Different type of soil present in the area	Soil Infiltration Rate across study area
3	Land Use	Latest Land Use pattern	Land use data of 2012-13	Not required
4	Geomorphology	Geomorphological map	Geomorphological map	Not required
5	Geophysics	VES No-77	VES Nos 21	VES Nos 56
6	Exploration Data	21	23	19
7	Monitoring Regime	2 to 3 wells in each blocks	39 monitoring wells	Not required
8	Recharge Parameters	Recharge parameters for different soil and aquifer types based on field studies	Recharge parameters given in Ground Water Resources Estimation	Entire Study area
9	Discharge Parameters	Discharge parameters for different GW abstraction structures	Discharge parameters given in Ground Water Resources Estimation	Entire Study area

Climate and Rainfall

Climate:

District Haridwar comes under hot sub-humid (dry) eco-region with alluvium-derived soils. The eco-region has hot, sub humid (dry) climate. It covers northern Indo-Gangetic Plain, including Piedmont Plain of the Western Himalayas. Also experiences moderate subtropical to humid climate with three distinct season's viz. summer followed by rainy and winter seasons. The hydro-metereological observations are given in **Table 2**.

The temperature begins to rise from March (27.6^{0}C) and reaches to its maximum at during May (37.2^{0}C) with the commencement of monsoon season by the mid of June and the temperature begins to lower by the end of June. During the winter season in the month of December to February the temperature ranges between 24.7^{0}Cto 17.70C.The mean monthly wind speed is highest the summer season when it goes up to 2.4 km/hour in the month of May and June and the minimum wind speed is observed during winter when it is 0.5 km/hour in the month of November. The evaporation is maximum in the month of May 156 mm and minimum 24.5 mm in the month of January.

Rainfall:

The average normal annual rainfall in Haridwar district is 1174.3 mm, out of which 84% is received during monsoon season and only 16% occurs during non-monsoon period. The district receives heaviest rainfall in northern part. The rainfall gradually decreases towards south. The data related to recent trend of rainfall distribution over the district, monthly rainfall during monsoon has been given in **Table 2**. The monthly distribution of rainfall during the monsoon season over the district shows that June, July and August are the wettest month in the district having a rainfall 387.8 mm, 304.7mm and 412.8 mm. The highest rainfall is recorded during the month of August. The monsoons retreat in the first fortnight of October giving a meager rainfall of 24.6 mm. Maximum rainfall occurs in the foothills of Himalayas and gradually decreases towards south.

Sn	Agroecological Zone	Avrage monthly rainfall (mm)	No. of Rainy Days (No.)	Maximum Rainfall intencity			Avrage weekly tem									Potencial Evapo transpiration		
				up to 15 minute (mm)	Beyond 15 but up to 30 min (mm)	Beyond 30 but up to 60min (mm)	Period									Period		
							Summer(April may)			Winter (Oct-March)			Rainy (June Sep)					
							Min	Max	mean	Min	Max	mean	Min	Max	mean	Summer	Winter	Rainy
Name of Block- Bhagwanpur																		
1	Hot Sub humid (Dry)	1141	45	92	45	15	9.3	23.7	16.5	1.1	19.9	10.5	13.1	23.4	18.3	4.04	1.92	3.8
Name of Block -Roorkee																		
2	Hot Sub humid (Dry)	1040	35	90	43	12	1.1	23	12.1	1.3	19.5	10.4	14	23.4	18.7	4.9	1.92	3.9
Name of Block -Narsan																		
3	Hot Sub humid (Dry)	1080	37	91	35	10	10.1	23.7	16.9	1.1	19.3	10.2	12	23.4	17.7	4.04	1.92	3.7
name of block - Bahadrabad																		
4	Hot Sub humid (Dry)	1120	47	88	37	7	9.3	22	15.7	1.2	19.9	10.6	12.8	22.4	17.6	5.1	1.92	3.9
name of block - Laksar																		
5	Hot Sub humid (Dry)	1131	44	90	44	12	10.3	21	15.7	1.2	19.2	10.2	12.9	23.2	18.1	4.04	1.92	4.1
Name of Block- Khanpur																		
6	Hot Sub humid (Dry)	1137	42	93	41	14	9.8	23.7	16.8	1	19.6	10.3	13.1	23.5	18.3	4.04	1.92	4
Distt Haridwar																		
	Hot Sub humid (Dry)	1108	42	91	41	12	8.32	22.85	15.58	1.15	19.57	10.36	12.98	23.22	18.10	4.36	1.92	4

Table 2: The Climatological, Rainfall distribution and Monthly Rainfall data of Haridwar District

Physiography:

The general, Haridwar district can broadly be divided in to physiographic units viz. the structural hills, the upper piedmont plain or the Bhabar and the Tarai or the lower piedmont plain.

Structural Hills

The complete northern and northeastern part of the Haridwar district is covered by the structural hills called the Siwaliks. This unit shows high relief and deep incised drainage with steep and sharp lenticular hill slopes and well defined crest line (northern boundary of the district). The run-off is high due to the rugged topography and homogenous lithology. The part of Siwalik falling in the district has middle and upper Siwaliks composed of sand stones, conglomerates, sands, clay, silt etc. The lower Siwaliks are missing in this district. These hills are traversed by many local minor and major faults.

The Bhabar

The second unit lying just below the foothills of Siwaliks locally called as Bhabar. This unit is characterized by Boulders, cobbles, pebbles sands and clays etc. with relatively dry terrains fringing the Siwalik foothill belt and lying at higher elevation as compared to plains having a steeper gradient around 10 to 20 meters/kms. These terms have thus geographic and geomorphological connection. Geologically the term Bhabar is used to describe the deposits formed along the foothill zone by coalescence of series of alluvial and talus cones, composed of heterogeneous materials ranging in texture from boulders, gravels to sand and silt. Locally this composition is governed by the parent rock Siwaliks and the drainage system and this varies from place to place. This Bhabar area covers most of the Bhagwanpur block and some part of Bahadrabad block.

Tarai or the plains

Just below the Bhabar zone lies the Tarai or plains or the lower piedmont plain. This shows almost a plain surface sloping towards south with very low gradient around 1.2 meter/kms. This area is characterized by course to fine grained sand, gravels, clays etc. This third unit plain is further divided in to lower piedmont plain, the older alluvial plains and the younger alluvial plains.

The lower piedmont plain shown flat to undulating plains with gradient towards south and southeast having micro relief. The older alluvial plains also showed flat to undulating topography. It is characterized by the sediments brought by river Ganga and Solani consisting of older alluvium. The younger alluvial plains lies along the river Ganga and Solani shows flat to gently sloping, slightly undulating terrain formed by extensive deposition of sediments brought by the rivers. It comprises of younger unconsolidated alluvial material of varying lithology and consisting of fluvial landforms like palaeo channels, meander, scar and point bars. Flood plains also exist all along the rivers, by deposition of sediments brought of recent origin.

Geomorphology

Morphostratigraphically, there are two units or surfaces viz., an older upland or interfluve area free from floods-the **Bangar**, and a younger low land called the **Khadar**, a flood prone area. Latter is also known as the flood plain defined by palaeo banks of the river. The upland based on gradient and sediment characteristics, is further divisible in to tow units the Piedmont zone (Bhabar), and the Varanasi plain.

The piedmont zone is a narrow, southerly sloping upland adjoining the Siwalik Hills or sub-Himalayas. It is made up of unsorted coarse clastic sediments (bounders, pebbles etc.) of the Varanasi alluvium of middle to upper Pleistocene age, and recent alluvial and colluvial fans, It has a high gradient plain as compared to the Varanasi plain with slope varying from about 10m/km in the northern part to about 0.4 m/km in the southern part around Tarai. It is in this zone that most of the small seasonal river draining the sub-Himalaya disappears. These streams reappear as spring line at distal end that merges with Varanasi plain, and locally forms the swampy conditions-the Tarai. There is high moisture content which support dense forest. It lies to the south of Bhabar zone and imperceptibly merges with the Varanasi plain in the south where the gradient is 0.14 m/km. The Varanasi plain is an almost flat erosional surface formed after late Pleistocene glaciations. It has a very low gradient towards southeast or to east. The development of four levels of relict palaeo-bluffs is seen along the left bank of Ganga River downstream and upstream of Bijnor district. The resultant prominent terraces are leveled as Daranagar (T_2) Mandawar (T_3) and the Chandokh-Roorkee (T_4) Terraces in ascending order. These are considered as evidences for the different stage in the evolution of drainage system related to post – glacial climate fluctuations (cold to war humid) in the beginning of the present day climate, and also to westward shift of course of Ganga River.

The flood plain or the Bangar-surface postdates the last glaciations in Late Pleistocene, and is the youngest geomorphic surface, which developed in Middle Holocene after the onset of the present day warm and humid climate. It is further subdivided in to two unit's viz., the Old Flood Plain and the Active Flood Plain. The Old Flood Plain is defined by palaeobanks with bluffs, showing development of 2 to 4 levels or terraces, the highest being erosional in nature and locally preserved. This surface did not receive any alluviation. The lower terrace is made up of Terrace Alluvium. This surface gets flooded during exceptionally high floods and is characterized by levees, meander scroll, ox-bow lakes and abandoned channels. The Active Flood Plain, on the other hand, gets flooded annually, and is defined by banks of the present day or active river. The active channels keep oscillating. At places, where the river about against a palaeobanks, there is undercutting resulting in collapse of palaeobanks on the convex sides of the meander causing erosion of the upland surface. The flood plain is characterized by point-bar, channel bar-sands and over bank silts. The morphostratigrapy in Haridwar district is given below in **Table 3.**

The detailed geomorphological map prepared by Remote Sensing Application center, Lucknow has been attached herewith along with the legends and land forms present in the Haridwar district **Fig 2.**The Bhabar formation or the bouldery formation, occurring along the south of the Siwalik Hills in variable lateral; and aerial extent formed at the foot hill by coalescence of several alluvial fans, in the map has been described as Upper Piedmont Plain (PPU) and flat to undulating plain with gradient towards southwest having micro relief, with finer sediments has been term as Lower Piedmont Plain (PPL). Structural hills have been marked with (SH).

Table.3 Morphostratigraphy in Haridwar District

Age	Morphostratigraphic Units			Morphological Features
Late Holocene to Present	Ganga Plain	Flood Plain (Khadar)	Active Flood Plain	Oscillating/migratory active channel defined by banks with point-bar, channel bar sands and over bank silts
			Old Flood Plain	Defined by palaeobanks with bluffs and showing developments of terraces, the highest locally developed/preserved is erosional and did not receive alleviation while lower, filled up by Terrace alluvium, gets flooded during high floods. Characterized by levees, meander scrolls, ox-bow lakes and abandoned channels.
Late Pleistocene to Early Holocene		Varanasi Uplands or interfluves area free from flood (Banger)	Piedmont Zone (Bhabar)	A narrow southerly sloping northern part of the upland adjoining Siwalik hills With moderate southerly gradient, seasonally active fluvial channel dying out and reappearing as spring line at distal end merging with the Varanasi plain and forming local swampy (terai) conditions.
			Varanasi Plain	Almost flat with south-easterly gradient, characterized by low sandy mounds and ridges in northern part (Bhur surface) and wide extensive clayey sourthern part with soil alkalization, abundant relict fluvial features- palaeochannels with meander cutoffs, ox-bow lakes and tals.

Land use:

Total geographical area of Haridwar is 2.43 lac ha out of which, 1.62 lakh ha land is under cultivation, which amounts to 67% of total land. Among land for agricultural use, 13 % is under rainfed and 87 % area is under irrigation. Total Forest area in Haridwar district is 0.84 lac ha. Land holdings of the farmers in the blocks having area less than 1 ha, is three times more than having areas of land above 2 ha indicating that number of marginal and sub marginal are highest.

Soil:

Soils play an important role in ground water recharge and the agriculture production of the area. The land of Haridwar district is highly fertile. The important soils of the district are Ultisols, which are the brown hill soil, occurring all through the northern part of the district in Siwaliks. These are the soils with a horizon of clay accumulation and low base supply. The Entisols are the soils also called the Bhabar soil occurs all along the foothills of Siwaliks and extends up to Tarai. These are soils without pedogenic horizons. Though these soils consist of boulders, pebbles, sand, silt and clay but are also highly fertile. Molisols soil occurs in the southern part of the district also called the Tarai soil, which consist mainly of the fine-gained sand, silt and clay. These are soils with a nearly black; organic-rich surface horizon and high base supply. These three types of soils are mineral soils with organic matter less than 25%. This is the most fertile soils of the district.

Drainage:

River Ganga is the major drainage system of the area. It enters in the district at the boundary of Haridwar and flows southwardly draining the eastern part of the district. One stream emerges from river Ganga at near Shahpur Sheetlakhera and passes through Bhogpur, Sultanpur Patti and Raisi called Ban Ganga River. River KotwaliRoa, Rasawan Nadi and Pili Nadi emerging from Siwalik Hills in the eastern part of the district are the tributary of River Ganga River Ganges and Solani are the perennial rivers.

The other prominent river in the area is Solani, which drains the central part of the district. The Solani River originates from Saharanpur. SiplaNadi joins Solani river between Bhagwanpur and Roorkee. MohandRoa, ChillawalRoa, the seasonal tributaries meets Solani River at the northern part of the district. These rivers originate from Siwaliks at the northern end and passes through the Bhabar belt lying below the foothills of Siwaliks. The other major tributaries of Solani River are Ratmau Rao and GholnaRao, Apart from these rivers other seasonal river/nalas also contributes the river Solani. The drainage pattern in the district is sub dendetric to dendetric and trills. The drainage courses of most of the nalas out falling in the various tributaries are broad, flat and occupied with cobbles, boulders and gravels. Most of these nalas are torrential, carried surface run off which fluctuate gently and are losing springs.

Substantial seepage is expected to be taking place from such streams during the monsoon period. Beyond the monsoon season most of these nalas as well as tributaries go dry. However, in Tarai belt, the drainage is more or less perennial as it receives effluent seepage through the ground water body-giving rise to number of springs on depressions along the nalas. A drainage map of Haridwar district showing all the major and minor river system is attached herewith geomorphology at **Fig 2.**

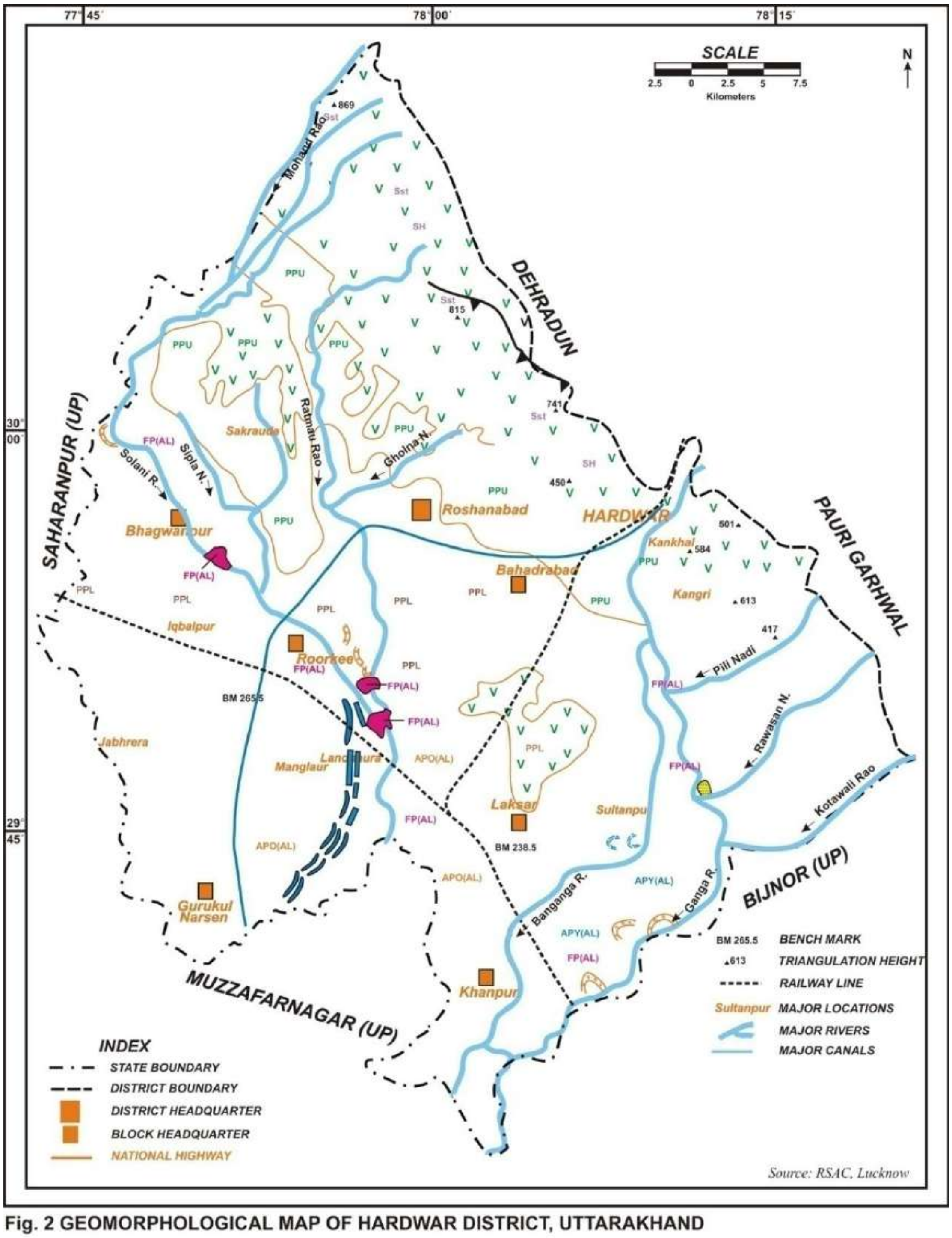
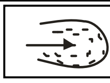
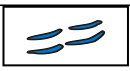
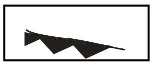


Fig. 2 GEOMORPHOLOGICAL MAP OF HARDWAR DISTRICT, UTTARAKHAND

5

LEGEND

MAP SYMBOL	GEOMORPHIC UNIT	LITHO STRAT IGRAP HY	STRUCTURE	DESCRIPTION	GROUND WATER PROSPEC TS
....	SAND BAR	RIVER SAND	-	Ganga, Yamuna and Solani rivers have produced extensive and deposits of varying sizes along their margins through the fluvial action. The area is good for shallow to deep aquifers with good quality of groundwater.	Good to excellent
FP	FLOOD PLAIN (FP)	ALLU VIUM (AL)	-	Surface of relatively smooth, low lying, flat land adjacent to the Ganga, Yamuna and Solani rivers comprises unconsolidated, coarse to fine sand with silt and clay. The area is repeatedly inundated during the floods. Good for shallow to deep aquifers.	Good to very good
RI.	RAVINES (RA)	ALLU VIUM (AL)	-	Network of gullies formed due to the erosion by surface runoff in deep alluvium along Kali & Silakhala rivers. It is composed of unconsolidated alluvium with varying lithology.	Poor
APY	YOUNGER ALLUVIUM PLAIN (APY)	ALLU VIUM (AL)	-	Flat to gentle sloping, slightly undulating terrain formed by the extensive deposition of sediments by the rivers Ganga and Yamuna. it comprises younger unconsolidated alluvium materials of varying lithology & consisting of fluvial landforms like palaeochannel, meander scar and point bar.	Good to very good
APO	OLDER ALLUVIUM PLAIN (APO)	ALLU VIUM (AL)	-	Similar to younger alluvial plains but formed at early stage by the rivers and consisting of older alluvium.	Good to excellent
PPL	LOWER PIEDMONT PLAIN (PPL)	ALLU VIUM (AL)	-	Flat to undulating plain with gradient towards southwest having micro relief, sediment varies from fine clastic to coarse clastic with variable runoff and infiltration. Flowing wells are common. Feasible for construction of tubewells even at shallow depth.	Very Good
PPU	UPPER PIEDMONT PLAIN (PPU)	ROCK DEBRI S	-	It occurs all along the south of Siwalik hills in variable lateral and areal extent formed at the foot hills by the coalesence of several alluvial fans comprising boulders, gravel, sand and clay. The water table is expected at deeper level (locally called Bhabar)	Moderate to Good
SH	STRUCTURAL HILLS	SAND STON E (Sst)	-	This unit shows high relief and deep incised drainage with steep and sharp hill slop and well defined crest line (northern boundary of the district). The runoff is high due to rugged topography and homogenous lithology.	Moderate to Good along linear valleys
LANDFORMS					
VvVvV	VEGETATION ANOMALY		-	Dense vegetation indicates the presence of loose alluvial material and good quality of groundwater. Dense vegetation indicates the presence of loose alluvial material and good quality of groundwater.	Good
	OLD MEANDER		-	Gently sloping, crescent shaped features formed by drying up to abandoned meandering river channels developed along the rivers Ganga and Yamuna.	Excellent
	MEANDER SCAR		-	An abandoned meander often filled with alluvium and covered with vegetation.	Good to Excellent
	PALAEOCHA NNEL		-	Abandoned and buried river channels in alluvial plains.	
STRUCTURAL FEATURES					
	THRUST FAULT		Confirmed Thrust Confirmed Fault	Bhimgoda thrust and Ganga, Yamuna faults are delineated.	Moderate to good

Agriculture and Cropping Pattern in Area:

Haridwar district is a part of Ganga floodplain. Extremely north of the district is carved by Himalayan foothills called the Siwaliks. The land of Haridwar district is highly fertile even in Bhabar area, which is occupied with boulders and pebbles. In the Bhabar area the surface soil carried by the nalas in this area are rich in minerals but the crops mainly depends on the monsoon because of lack of tube wells and canals. This bouldery formation lying in the foot of Siwalik, in the area is called Bhabar. Its agricultural products besides the mills and factories in urban area also control the economy of the district. Area under Kharif is 0.96 lakh ha (Irrigated – 0.93 and rainfed 0.02 ha) whereas area under Rabi is 0.51 lac ha ((Irrigated – 0.49 lac and rainfed 0.02 lac ha). Area under summer crop is very less (0.12 lac ha). Area under horticulture and plantation crop is also very less (0.016 lac ha) which is solely irrigated. The most important crops in the district are sugarcane, wheat and paddy. The crops grown among the cereals are rice, maize, sorghum, pearl millet in Kharif, wheat and Barley in Rabi and maize in Zaid season. In oilseeds, the major crops are soybean, groundnut, til and sunflower in kharif, mustard in Rabi and sunflower in Zaid. Among pulses, pigeon pea, urd, moong and cowpea in kharif, gram, pea and lentil in Rabi and urd/moong in Zaid season. The cropping intensity is 150 percent. The block wise land utilization, block wise agriculture, crop wise percentage of area under main crops are **given in Table 4, 5, 6 and 7.**

Irrigation:

Though the Upper Ganga canal and the Central Ganga canal passes through the district but the irrigation facilities through canal have not been developed to considerable extent in the whole of the district. The southwestern part of the district, in Narsan, part of Roorkee and Bhagwanpur block the irrigation is done through canals (Deoband branch, main Basera distributary etc.) but in most of the part of district canal irrigation is very less. Bhabar or the area lying at the foothills of Siwaliks are lacking irrigation facilities due to bouldery formation and run off zone as well as because of its very deep water level. Therefore, this area remains depends on rainfall for its crops. The maximum irrigation in the district is done through tube wells, which consists stress on the ground water. The 84% of irrigation in the district is done through tube wells and only 15% of irrigation is done by the canal network system. Only 1% of irrigation is done by the other sources. The block wise gross sown area and irrigation block wise irrigated areas though different sources are given in **Table 5 and 6.**

Table.4 Block wise Land Utilization in District Haridwar (in Hectares)

S.No.	Block Name	Total Geographical Area	Area Under Agriculture				Area Under Forest	Area under Wasteland	Area Under Others uses
			Gross Cropped Area (1)	Net Shown Area (2)	Area Sown more than once (1-2)	Cropping intensity (%)			
1	BHAGWANPUR	30276	27696	23080	8709	153	275	2004	4564
2	ROORKEE	22329	18054	15045	5677	158	0	1104	3644
3	NARSAN	28446	24681	20552	7755	166	0	1345	4545
4	BAHADRABAD	46053	32372	26977	10180	168	2856	2840	10651
5	LAKSAR	25924	24335	20279	7652	165	12	1545	3492
6	KHANPUR	14611	13188	10990	4147	165	705	320	1296
	TOTAL DISTRICT	**167639**	**140326**	**116923**	**44122**	**165**	**3848**	**9158**	**28192**

Table.5 Block wise Gross Sown Area and Irrigation in District Haridwar (in Hectares*)*

Block	**Kharif (Area in ha)**			**Rabi (Area in ha)**			**Jayad (Area in ha)**			**Total (Area in ha)**		**Total**	**Net Area Irrigated**	**Gross Area Irrigated**
	Irrigated	**Rainfed**	**Total**	**Irrigated**	**Rainfed**	**Total**	**Irrigated**	**Rainfed**	**Total**	**Irrigated**	**Rainfed**			
BAHADRABAD	17282	900	18182	10515	660	11175	4029	0	4029	31826	1560	33386	18688	27383
LAKSAR	18946	0	18946	7972	0	7972	1105	0	1105	28023	0	28023	16069	21855
KHANPUR	10501	0	10501	3837	0	3837	492	0	492	14830	0	14830	20775	27308
ROORKEE	13748	630	14378	7625	506	8131	1661	0	1661	23034	1136	24170	23279	31303
BHAGWANPUR	15000.16	1090.92	16361	11144.5	670.5	12103	3787.26	241.74	3879	29931.92	2411.08	32343	20485	27743
NARSAN	18034	0	18034	8278	0	8278	1427	0	1427	27739	0	27739	10915	14315
T. DISTRICT	**93511.16**	**2620.92**	**96402**	**49371.5**	**1836.5**	**51496**	**12501.26**	**241.74**	**12593**	**155383.9**	**5107.08**	**160491**	**110211**	**150207**

Table.6 Block wise irrigated area Through Different Sources in District Haridwar (in hectares)

BLOCK	CANALS	TUBEWELLS		DUG WELLS	PONDS	OTHERS	TOTAL
		GOVT.	PRIVATE				
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
BHAGWANPUR	-	1312	17197	-	-	-	18580
ROORKEE	168	1082	14678	-	-	8	15997
NARSAN	8501	966	11761	-	-	-	21205
BAHADRABAD	4262	690	16236	-	-	1658	22876
LAKSAR	-	206	20087	-	-	-	20375
KHANPUR	-	133	10646	-	-	-	10822
TOTAL DISTRICT	**12931**	**4389**	**90605**	**-**	**-**	**1666**	**109855**

Table.7 Block wise Agriculture in District Haridwar (in hectares)

YEAR /BLOCK	**Paddy**		**Wheat**		**Barley**		**Maize**		**Sugarcane**		**Total Pulses**		**Total Edible**	
	Total	Irrig.	Total	Irrig.	Total	Irrig.	Total	Irrig.	Total	Irrig.	Total	Irrig.	Total	Irrig.
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
BHAGWANPUR	1860	1838	8943	8893	19	3	276	8	11502	11244	291	17	11389	10759
ROORKEE	1788	1759	6260	6245	1	-	10	-	9389	9357	115	11	8174	8015
NARSAN	1717	1709	6646	6635	7	1	-	-	15139	15174	83	13	8453	8358
BAHADRABAD	3471	3439	9614	9586	22	5	335	17	12013	11907	264	27	13706	13074
LAKSAR	2369	2336	6548	6532	-	-	33	17	15357	15321	42	6	8992	8891
KHANPUR	2371	2338	3090	3075	-	-	-	-	7674	7651	13	-	5474	5413
TOTAL DISTRICT	**13576**	**13419**	**41101**	**40966**	**49**	**-**	**654**	**42**	**71128**	**70654**	**808**	**74**	**56188**	**54510**

Geology

The northern and northwestern part of the district Haridwar is covered by high steep hills of Himalayas called Siwalik Range. The altitude of Siwalik varies between 600 to 900 meters. The geology of foothills of Himalayas was mapped by ONGC. In the outer most rage lying just north to the district the upper Siwaliks followed by middle Siwaliks are exposed. The area has also been studied and described by Mathur and Shahni (1964) and Roopke and Sharma.

The middle Siwaliks in this area is largely consists of lower alterations of clay and sand stone sequence and an upper sequence of massive sand stones. The upper part is frequently split up by clays in to a more argillaceous sequence. The thickness of middle Siwaliks is around 2000 meters.

Table.8 General Stratigraphic sequence of Haridwar District

Era	Period	Age	Formation	Group	Lithology
Cenozoic	Neogene	Holocene	Younger alluvium Terraces, channels, flood plains, fans, paleochannels	Newer/Younger Alluvium	Sands of various grade, silt and clays
		Middle to Upper Pliestocene	Older Alluvium (Bhabber and Terai)	Ramnagar/ Varanasi/ Ambala	Boulders, Cobbles, Pebbles, Gravels, Sand, Silt & Clay
		Pliestocene to Early Pliestocene	Sedimentaries	Middle Siwaliks	Sandstone with boulders,cobbles, Pebbles, Conglomerate and associated Clay
				Upper Siwaliks	Conglomerates, Sandstones, Siltstones, Shales with boulders,Pebbles, Sands and Clay

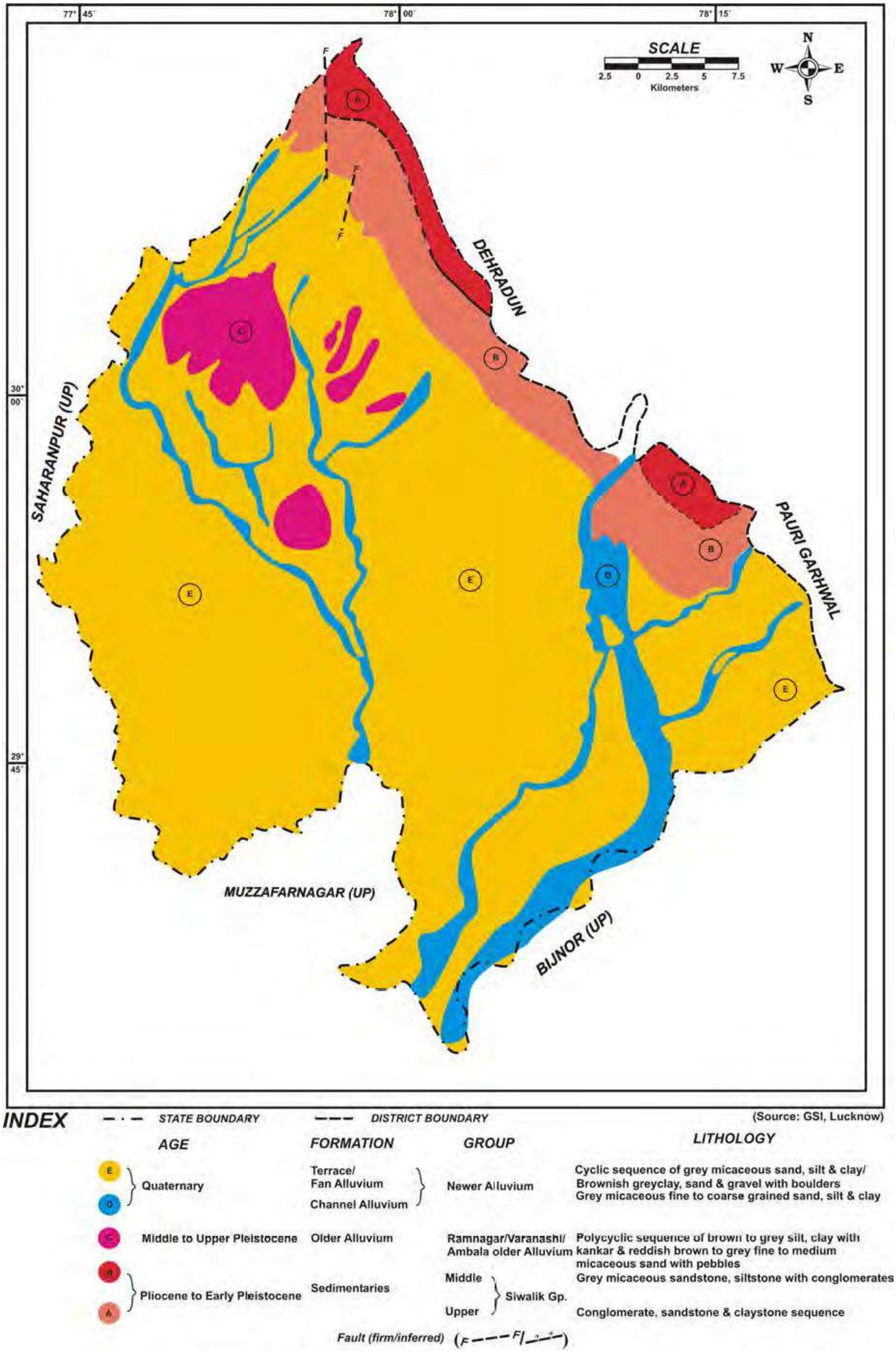


Fig 3: Geological Map of Haridwar District

The upper Siwaliks are mostly redaceous consisting of sand stone, boulders, pebbles, conglomerates, shale, slit and clay. The maximum thickness of upper Siwaliks is around 1000 meters. Middle Siwaliks have steep hills which are dipping towards south up to 20^0 to 60^0. These middle Siwaliks has traversed by many minor faults.

Just below the Siwaliks are the Bhabar area which is characterized by the alluvial fans, which are consists of boulder, cobbles, pebbles, gravel with clay and silts. The source sediments have governed the lithological composition of the Bhabar formation. The sediments of the Bhabar area are heterogeneous in composition and texture, as the sediments are not only derived from the foothill but also from higher land area in Himalayas. Mostly the boulders, pebbles, cobbles, gravels and sand have been derived from Upper Siwalik conglomerate bed. The alluvium has been extended down to south in complete district. The texture has also changed as we go from north to south depending upon the duration, distance of transportation and nature of deposition of sediments. The older and younger alluvial plains consist of various grades of sands, grave, silt and clay. The sand bars, flood plains, point bars, palaeochannels meanders has been created by the riverine agencies in younger alluvium along the rivers. In general the geological sequence in the Haridwar district is given as below **in Table 8**. The geological map of Haridwar district is given in **Fig 3.**

Hydrogeology

Haridwar district shows different hydrogeological conditions due to its variegated geological settings and topography. The district is occupied by Siwaliks in the extreme north and northeastern part. Here the ground water occurs in the form of spring and seepage. Below it lies the boulder formation called Bhabar. The Bhabar belt along it's along its northern fringe constitutes the main intake or recharge zone. Ground water in this zone is unconfined to semi-confined in nature. The hydraulic gradient or the water in the boulder formation is generally deep. The depth to water becomes comparatively shallower in the peripheral portion. Below Bhabar, towards south Tarai from a narrow belt along the northern margin of the Gangetic alluvium of newer quaternary age and older alluvium of middle to upper Pleistocene age and is separated by sporadic spring line. The spring line is not very much clear but it has been observed seepage and water oozing out in nalas and rivers on Biharigarh-Bandarjud road. The water level along the spring line is very shallow. The spring line sporadically again visible at Chiriapur in Rasawannadi and KotwaliRoanadi. Free flowing or artisan conditions prevail in the area east of Haridwar- Chiriapurraod between Raswannadi and KotwaliRoanadi in some part of the Area. The major part of the district is covered by drainage system of seasonal and perennial rivers causing different depth to water level in the area. The hydrogeological map of Haridwar district is given in **Fig 4.** The block-wise hydrogeological conditions in the district is described here under.

1. Bhagwanpur Block:

Bhagwanpur block comprising an area of 315 km. (excluding forest) lying north of district and extends up to northwestern part of the district. Broadly the road (national highway) leading from Mohund-Bhagwanpur-Chudiala forms the western boundary of the Bhagwanpur block. The main occupation is agriculture in the area and is being developing as industrial area. Bhagwanpur block can distinctly be divided in to three geomorphologic units. The northern most part of Bhagwanpur block is occupied by the rocks of upper and middle Siwaliks ranging in altitude from 400 to 869 m above mean sea level. Below the structural hills of Siwalik lies the upper piedmont plain consisting of rock debris, occurs all along the south of Siwalik hill in variable lateral and areal extent formed at the foot hills by the coalescence of many alluvial fans comprising of boulders, cobbles, sands, gravel and clay (locally called as Bhabar) the marshy and swampy land is marked at the junction between Bhabar and Tarai formation at certain places which act as discharge zone.

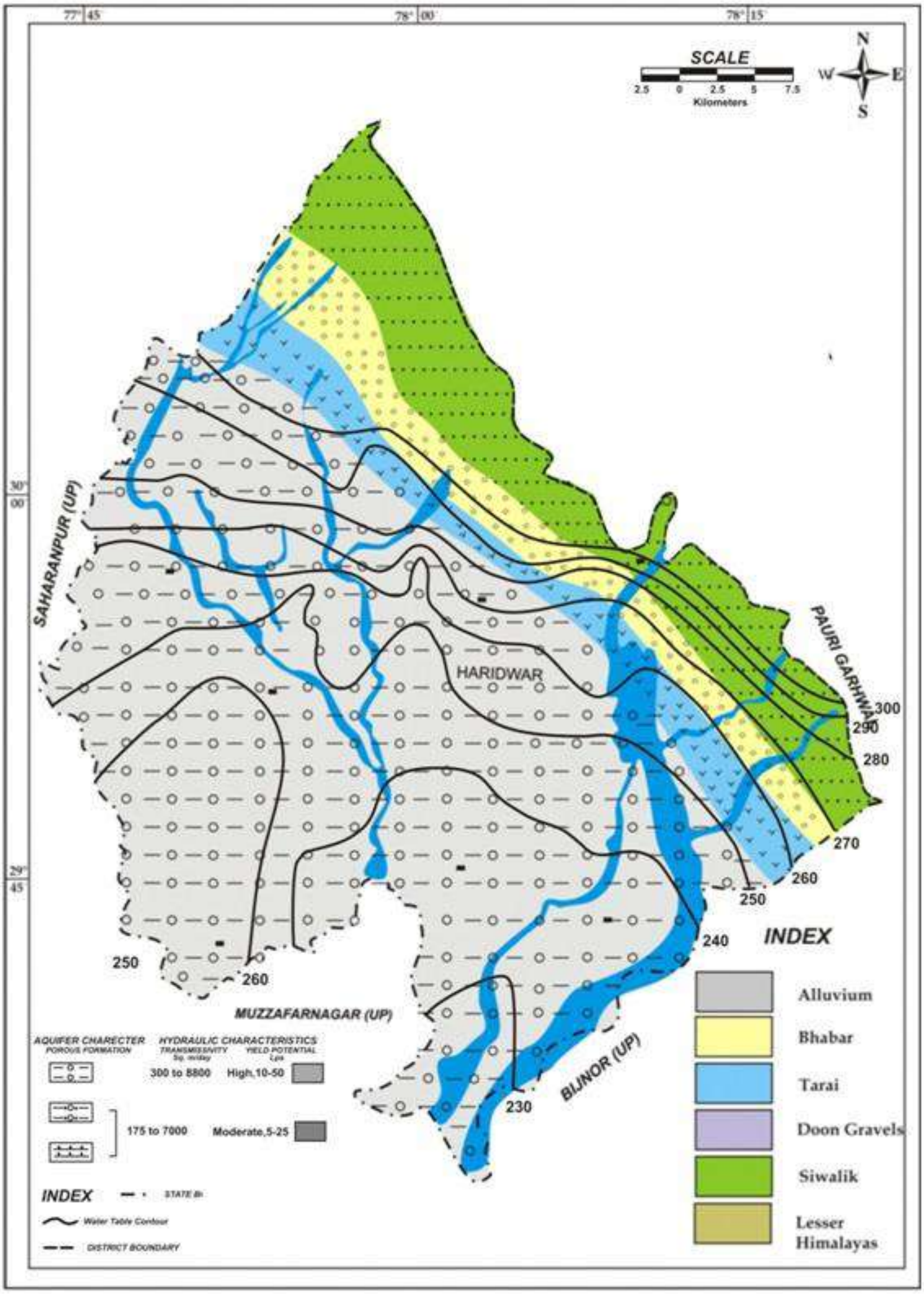


Fig 4: Hydrogeological Map of Haridwar District

Further south of this formation (south to Solani River) the area is occupied by the formation of lower piedmont plain comprised of sands of difference grade clay and silt. The water level shows difference behavior in all the three existing formation. The ground water in the hills emerges in the form of seepage and springs while the water level is deep in the Bhabar zone.

The water level is quite deep in tube wells. In general the water table in this unit ranges between 3.98 to 9.67 m bgl. South of the Solani river in third unit in lower piedmont plain the water level ranges from 3.48 to 22.69 m bgl during pre-monsoon and 1.57 to 17.76 m bgl during post-monsoon respectively The major central part of the block contains deep water level up to 21 m bgl. The seasonal fluctuation ranges between -01.7 to 6.46 m. The depth to water level map of Haridwar district for the year 2015 is given in **Fig 5.**

2. Bahadrabad Block:

Bahadrabad district is the biggest block in Haridwar district. It covers an area of about 466 sq. km. this block is situated in the north eastern part of the district. Its northern boundary touches Dehradun district and eastern boundary touches the district Pauri Garhwal. Bahadarabad block also possess the same topography/geomorphology as the Bhagwanpur block. The similar hydrogeological condition prevails in the block. The ground water in Siwaliks occurs in the form of seepage/springs, water level is deep in the Bhabar area which becomes shallower in the Tarai region of the block. During the pre-monsoon period the depth to water level ranges between 3.25 m bgl and13.53 m bgl, and 69.30 m bgl observed at Laldhang. The reason being deeper water level at Laldhang as it is located at foothills of the Siwaliks, where the formation is Bhabar. In general the water levels are deeper in Bhabar formations. Upper Ganga Canal passes through the center of the block. The Bhabar formation roughly extends up to Upper Ganga Canal. Below it or the south of the canal lower piedmont plain or the Tarai exists. The water level is shallower south of Upper Ganga Canal. The seasonal fluctuation ranges between -13.0 to 17.1 meters. The formation south of canal consists of clay sands and silt. The shallow water level in the area may be because of the effect of Upper Ganga Canal and other rivers flowing in the area. This also forms part of Khadar because of the newer flood pains deposited by these rivers.

3. Roorkee Block:

Roorkee block covering an area of 217 sq. km. lies in the center of the district between Bhagwanpur and Bahadarabad block. The sub-surface formations this bloc consists of cyclic sequence of grey micaceous sand, silt and clay/brownish grey clay, sand and gravels with occasional pebbles and boulders of terrace, fans and channel alluvium of quaternary age. The depth to water level in most of this block lies between 3.20 to 19.39 m bgl. At certain places the depth to water table observed in tube wells rests between 11.00 to 18.00 m bgl. The seasonal fluctuation ranges between 0.47m to 3.65 meters.

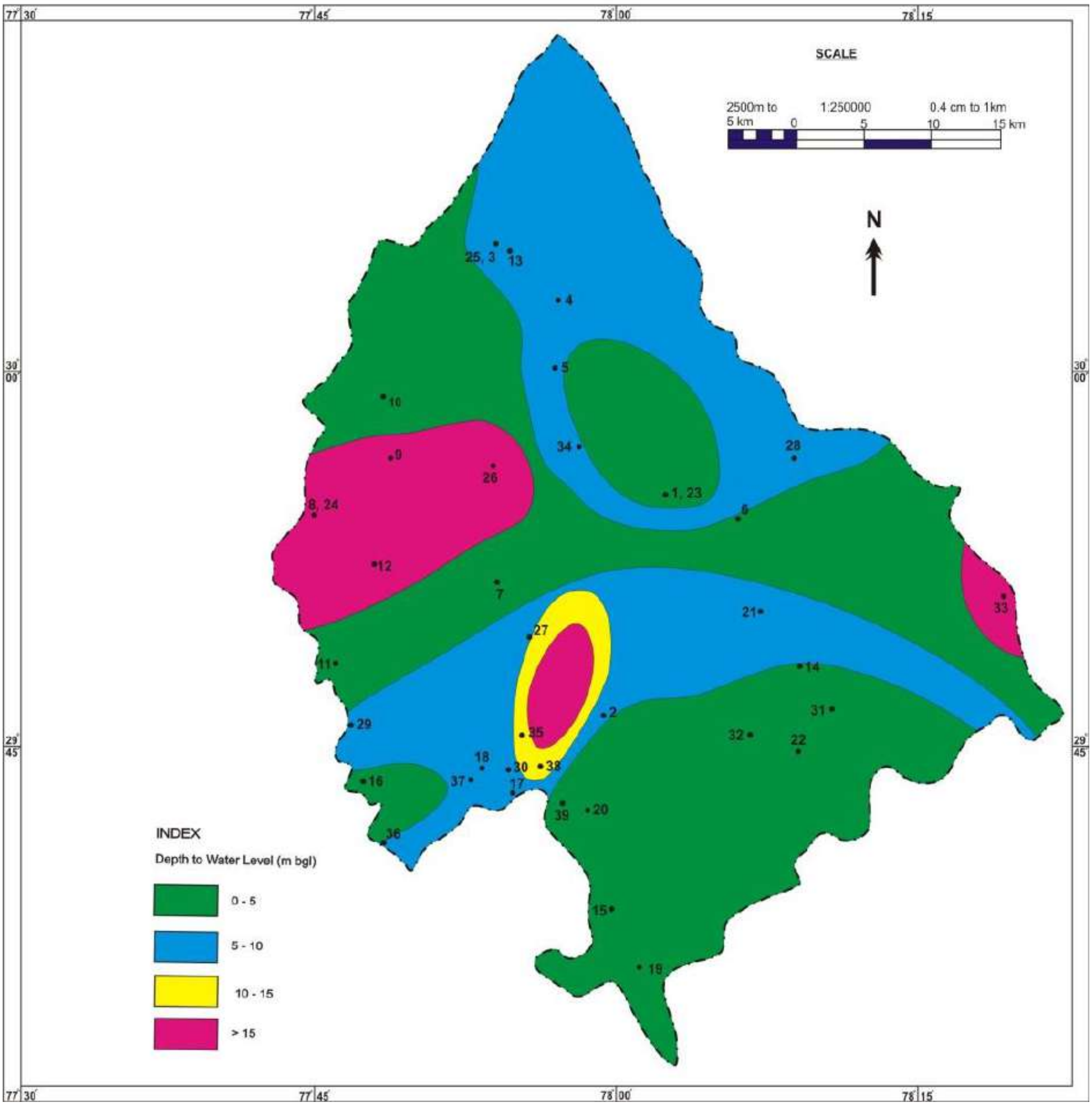


Fig 5: Depth to Water Level Map for the Year 2015 of Haridwar District

4. Narsan Block:

Narsan block lies in the southwestern part of the district having an area of about 273 sq. M. consists of the same formation as of Roorkee. The sediment of lower piedmont plain occupies the block/ It consists of sands, gravels silt and clay of recent quaternary age. The depth to water level in the area ranges between 4.0 m bgl to 19.0 m bgl. At certain place it has been reported to 17.00 to 19.00 m bgl. The seasonal fluctuation ranges between 0.34 meter to 2.15 meters.

5. Laksar Block:

The Laksar block lying in the south-eastern part of the district form a part of Khadar. Khadar is a local terminology used for the areas occupying the flood plains of the rivers and recent sediments deposited by the rivers. It consists of mainly fine sand, silt and clay. Ground water occurs in this area is in unconfined condition. Here the ground water occurs at very shallow depth. The pre-monsoon post-monsoon depth to water level in this area ranges between 4.38 to 5.69 m bgl and 2.32 to 2.53 m bgl respectively. The seasonal fluctuation ranges between 1.85 to 5.69 meters.

6. Khanpur Block:

Khanpur block lies extremely south of the Haridwar district in flood plains of Ganga, Bangana and Solani rivers. This area is also called Khadar. It also consists of the same formation as of Laksar block. The depth to water in this area is also very shallow. Formation consists of fine grained sand, silt and clay of recent age. In general the depth to water level in entire area is less than 5m bgl. The pre-monsoon and post-monsoon depth to water measured in the area ranges between 1.96 to 4.75 m bgl and 1.68 to 3.0 m bgl respectively. The seasonal fluctuation ranges between -0.5 to 1.88 meters.

Long Term Depth to water Level:

The long-term water level has been examined from the Ground Water Monitoring Wells (National Hydrograph Stations) of Haridwar district from 7 stations viz. Rampur, Jwalapur, Laksar, Shahpur, Landaura, Bahadrabad and Raipur and is given in **Table 9**.

Table.9 Long Term Hydrograph Data of GWMW (DTW m bgl)

Well Location	Year	Jan	May	Aug	Nov
Shahidwala Grant (DW)	2006	NA	NA	11.63	12.12
	2007	12.43	13.3	12.87	18.21
	2008	13.23	14.04	10.24	12.18
	2009	12.54	13.24	13.5	13.08
	2010	13.39	14.59	11.26	10.92
	2011	11.2	12.7	10.3	8.9
	2012	10.09	12.19	11.3	11.13
	2013	11.68	12.63	9.2	8.93
	2014	9.2	10.60	9.4	8.06
	2015	8.95	10.91	9.9	9.74
Bahadrabad (DW)	2002	3.7	4.15	2.18	3.17
	2003	3.4	4.75	3.22	1.27
	2004	4.08	4.91	4.92	4.9
	2005	5	5.4	3.36	3.04
	2006	4.04	5.1	4.12	4.18
	2007	5.58	5.49	4.38	6.36
	2008	5.73	4.78	3.35	4.36
	2009	4.62	4.31	4.87	4.97
	2010	5.1	5.56	2.5	1.97
	2011	3.17	NA	2.48	4.82
	2012	4.31	5.4	3.59	5.09
	2013	5.63	5.44	10.15	4.41
Roorkee	2005	6	7.55	6.06	5.66
	2006	5.72	6.45	6.1	6.12
	2007	6.55	7.52	5.48	9.10
	2008	6.48	7.79	5.2	5.96
	2009	6.16	7.74	6.71	6.36
	2010	6.1	7.04	5.3	5
	2011	4.8	6.75	3.86	5.06
	2012	5.98	7.68	4.95	6.72
	2013	6.36	7.98	4.58	5.49
	2014	4.98	7.30	6.7	6.88
	2015	6.23	8.3	6.05	6.64
Jhabreda	2006	NA	NA	10.34	10.24
	2007	10.64	11.58	12	15.08
	2008	9.82	12.34	9.13	9.68
	2009	8.68	9.51	10.38	9.13
	2010	8.62	9.34	9.66	6.72
	2011	6.88	7.52	0.44	6.54
	2012	5.63	11.24	3.42	9.54
	2013	8.26	11.16	4.84	8.88
	2014	7.39	10.17	9.14	9.40
	2015	9.15	9.98	5.76	9.64
Hussainpur DW	2005	2.24	3.28	2.3	1.63
	2006	1.73	4.73	1.83	2.4
	2007	2.42	2.93	0.76	3.87
	2008	2.68	3.44	1.11	2.93
	2009	3.9	3.81	1.67	2
	2010	2.17	4.04	1.13	2.76
	2011	1.86	3	0.91	2.26
	2012	2.54	4.49	1.58	2.57
	2013	2.29	4.15	1.48	2.2
	2014	2.13	4.73	2.63	2.47
	2015	1.98	4.38	1.77	2.53

The analysis of the data reveals that there is minor declining trend at Bahadrabad station while other stations shows minor rising trend in water level. Though the well at Roorkee is showing declining trend in pre-monsoon while rising trend in post-monsoon. The pre-monsoon and post-monsoon long-term trend ranges between -0.39 to 0.094 m/year and -0.71 to 0.148 m/year respectively. The hydrograph analysis results given in the following **Table 10** and hydrographs are shown in **Table 11.**

Table 10. Long Term Hydrograph Analysis Results

S.No.	**Location**	**Trend Equation**	**No of Years data used**	**Water Level Trend m/yrs**	
				Pre	**Post**
1	Shahidwala Grant	y = -0.391x + 800.3	10	-0.39	-0.71
2	Bahadrabad	y = 0.087x - 169.6	12	0.087	0.148
3	Roorkee	y = 0.094x - 182.5	10	0.094	-0.073
4	Jhabrera	y = -0.128x + 268.7	10	-0.128	-0.291
5	Hussainpur	y = 0.084x - 166.6	10	0.084	-0.067

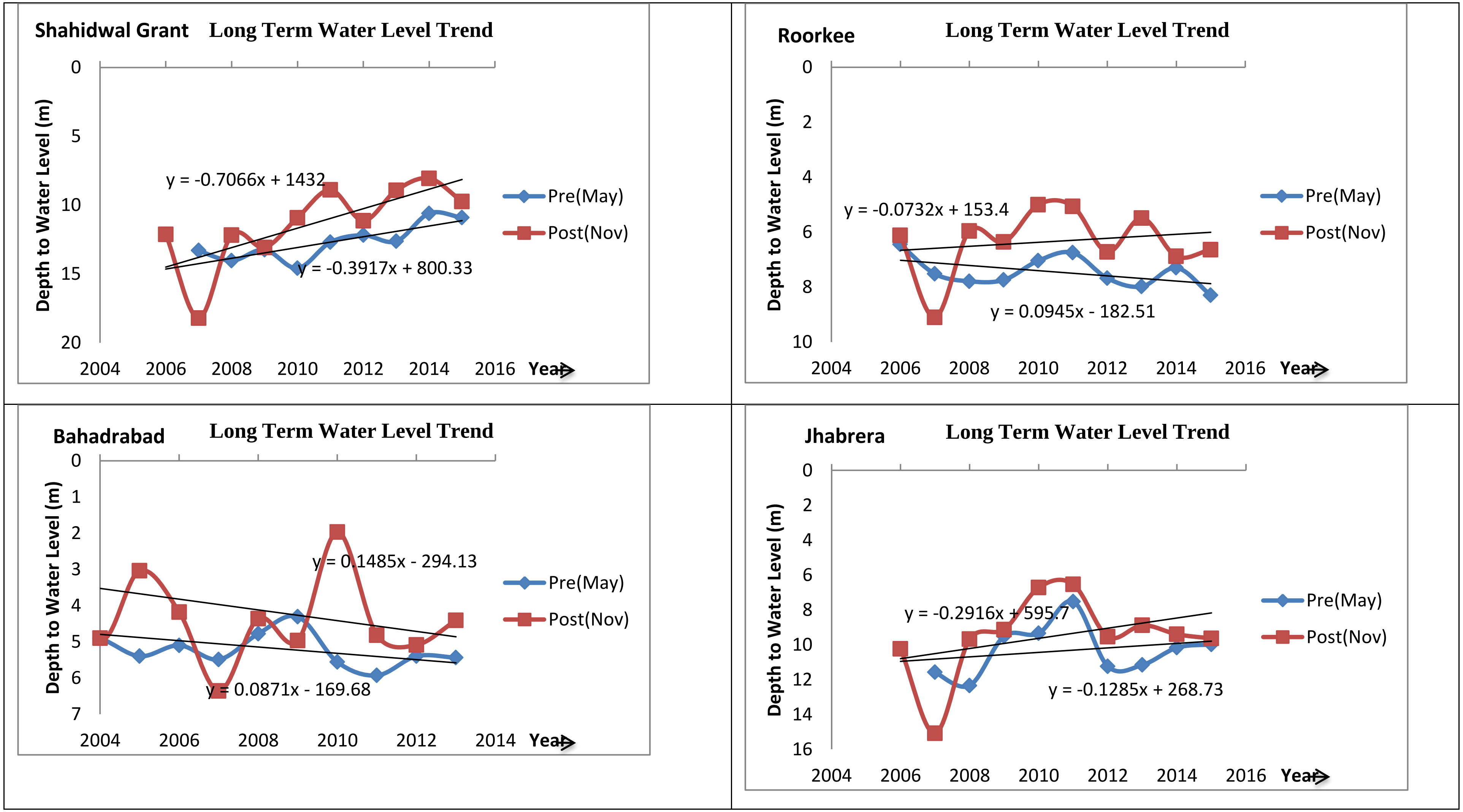


Table 11: Hydrographs of different location in Haridwar district.

Hydrochemistry

The water samples from Dug wells, hand pumps and tube wells were collected during the study in Haridwar district. These samples were analyzed in the Chemical laboratory of CGWB, Northern Region, Lucknow. The water samples were analyzed to determine the Electrical Conductance, total dissolved solids, hydrogen ion concentration and cat ions like Silicon, Iron, Calcium, Magnesium, Sodium and Anions-Sulphate, Chloride, Carbonates and Bi-carbonates.

Ground water in its natural form is clear, colorless, transparent and does not contain suspended material or bacteria. But due to its slow movement in ground it has a long contact with earth material it dissolves certain minerals and soluble. Its quality also deteriorates due to anthropogenic activities. The chemical quality of ground water varies from place to place depending upon the lithology, aquifer material and chemistry of the sediments or rocks irrigation practices an urban activity. The chemical constituents in solution dissociate in to electrically charged negative and positive particles called anions and cat ions.

The water samples were collected in plastic container to avoid unpredictable changes in physico-chemical characteristics. The testing of samples was done according to the procedure prescribed by BIS, (IS: 10500, 2012). Present study comprises of interpretation and analysis of water samples collected from thirty nine different monitoring stations at all over district. The samples were analyzed for different chemical, physical parameters and the results were carefully studied and analyzed. The collected groundwater samples were analyzed for Electrical conductivity, pH, total hardness (TH) as CaCO3, calcium (Ca2+), sodium (Na+), potassium (K+), bicarbonate (HCO_3), chloride (Cl^-), sulfate (SO_4), nitrate (NO_3), and fluoride (F^-), following the standard water quality methods . The evaluation of chemical characteristics of groundwater and suitability of groundwater quality was for drinking purposes.

Table 12: Chemical date of Haridwar District

Location	Block	Lat.	Long.	Aquifer Type	pH	E.C mS/cm at 25°C	HCO3	Cl	F	NO3	SO4	TH as CaCO3	Ca	Mg	Na	K	SiO2
Budhwa Shahid	Bhagwanpur			U.C	8.00	505	305	7.1	nd	18	7.1	260	72	19.5	8.5	1.4	22
Shahidwala Grant	Bhagwanpur	30.09	77.90	U.C	7.90	581	329	7.1	nd	34	6	300	76	26.8	8.3	1.3	20
Buggawala	Roorkee			U.C	8.10	564	342	7.1	nd	23	5.4	290	76	24.3	9.2	1.4	22
Bandarjud	Bahadrabad	30.05	77.94	U.C	8.00	592	366	14	nd	5.5	2.5	295	64	32.8	14	1.6	24
Rathaura	Bahadrabad	30.01	77.94	U.C	7.80	570	354	7.1	nd	0.25	2.8	230	32	36.5	35	2.7	25
Kota Muradpur	Bhagwanpur			U.C	8.00	628	403	7.1	nd	0.18	3.2	260	56	29.2	39	2.4	26
Teliwala	Roorkee			U.C	7.90	902	317	92	nd	33	71	360	108	21.9	63	2.9	15
Imlikhera	Roorkee	29.93	77.89	U.C	8.10	564	354	7.1	0.12	1.4	6.3	135	28	15.8	80	1.9	18
Bahabalpur	Bhagwanpur	29.99	77.81	U.C	8.00	559	354	11	0.08	1.8	2.7	245	48	30.4	29	1.8	20
Bhagwanpur	Bhagwanpur	29.94	77.81	U.C	8.10	812	329	96	0.12	0.81	37	350	72	41.3	44	3.6	21
Chudiyala	Bhagwanpur	29.91	77.76	U.C	7.69	620	378	14	0.36	nd	10	275	56	32.8	29	3.2	25
Iqbalpur	Bhagwanpur	29.87	77.80	U.C	7.97	455	262	18	0.52	nd	9.1	200	44	22	20	4.6	26
Jhabrera	Narsan	29.81	77.78	U.C	7.75	950	354	78	0.33	26	80	360	68	46	70	8.4	25
Khera Jat	Narsan	29.68	77.81	U.C	8.15	455	244	11	0.14	5.1	25	230	52	24	8.1	3.8	30
Narsan	Narsan	29.71	77.91	U.C	8.15	545	281	25	0.2	nd	36	280	60	32	7.5	4.3	26
Libraheri	Narsan	29.76	77.87	U.C	7.75	1535	494	128	0.13	86	177	490	64	80	80	119	28
Manglore	Roorkee			U.C	7.86	544	299	11	0.21	1.3	37	270	68	24	6.9	5.9	22
Landhaura	Roorkee	29.81	77.93	U.C	7.75	550	329	7.1	0.11	7.7	13	250	64	22	23	3.2	32
Sikhar	Narsan	29.76	77.92	U.C	8.10	655	378	14	0.04	23	11	315	76	30	19	2.5	32
Amkheri	Roorkee	29.74	77.94	U.C	8.15	397	220	11	0.3	11	7.8	180	48	15	11	2.8	28
Mundlana	Narsan	29.74	77.91	U.C	7.88	665	329	35	0.13	29	23	290	76	24	31	4	31
Hussainpur	Laksar	29.78	78.00	U.C	8.20	465	287	11	0.03	0.08	4.3	185	36	23	30	5	24

Laksar	Laksar			U.C	7.70	1500	390	128	nd	3.8	310	610	88	95	92	11	14
Goverdhanpur	Khanpur	29.71	77.96	U.C	7.90	725	427	21	0.01	0.31	17	200	44	22	87	5.1	20
Khanpur	Khanpur	29.60	78.01	U.C	8.20	630	366	21	0.19	nd	18	180	40	19	74	7	19
Dallawala	Khanpur	29.57	78.03	U.C	8.05	800	403	43	0.1	0.94	45	230	60	19	88	8.1	20
Roorkee	Roorkee	29.86	77.90	U.C	8.16	332	171	7.1	0.44	nd	22	155	40	13	8.2	2.9	19
Bahadrabad	Bahadrabad	29.92	78.04	U.C	8.00	262	128	7.1	0.21	nd	20	120	36	7.3	5.3	0.49	20
Sarai	Bahadrabad	29.91	78.10	U.C	7.66	756	342	35	0.17	31	43	230	60	19	35	72	17
Panjaheri	Bahadrabad			U.C	8.18	505	256	21	0.14	9.5	23	235	68	16	17	4.8	12
Dhanpura	Bahadrabad	29.85	78.11	U.C	8.04	588	256	28	0.13	36	44	270	52	34	22	4.8	20
Shahpur Sitlakhera	Bahadrabad	29.76	78.11	U.C	7.98	730	342	28	0.21	41	42	310	68	34	19	36	20
Bikkhampur	Laksar	29.75	78.14	U.C	7.76	585	317	14	0.23	0.18	30	280	60	32	17	4.3	23
Bhogpur	Narsan	29.78	78.17	U.C	8.19	940	427	43	0.23	25	67	315	84	26	39	91	22
Sultanpur	Laksar			U.C	7.70	1095	415	85	nd	49	82	435	92	50	62	20	23
Dudha Dayalwala	Bahadrabad			U.C	7.84	537	281	14	0.05	0.1	34	225	56	21	22	2.2	24
Laldhang	Bahadrabad	29.85	78.31	U.C	7.85	572	305	7.1	nd	8.3	35	280	88	15	15	1.5	17
Shyampur	Bahadrabad			U.C	7.86	598	336	14	0.01	15	21	295	72	28	8.7	3.4	19
Bhupatwala	Bhagwanpur			U.C	8.10	555	329	14	0.08	1.7	12	260	72	19	21	2.1	22

Concentration in mg/l, U.C = Unconfined

Geophysical

Surface geophysical methods provide a relatively quick and inexpensive means to characterize the sub-surface. Surface geophysical methods measure the physical properties of the sub-surface such as electrical conductivity or resistivity, magnetic permeability, density or acoustic velocity etc.

The resistivity surveys were carried out at proposed drilling sites with an objective to:

- Delineate the boulder bed/s with their depths and thickness.
- Delineate the ground water potential granular zone/s with their depths and thickness.

Electrical surface geophysical methods can be used to detect changes in the electrical properties of the sub-surface. The electrical properties of soils and rocks are determined by water content, mineralogical clay content, salt content, porosity and the presence of metallic minerals. However, typically the resistivity of the water has a larger effect on the bulk resistivity than the soil or rock type. Variations in these electrical properties of soils and rocks, either vertically or horizontally, produce variations in the electrical signature measured by surface geophysical tools.

Data Acquisition

A total of nine sites were shown where resistivity surveys were to be conducted. The names of the sites are as below:

1) Bhagwanpur
2) Sikandarpur
3) Latherdewa Sheikh
4) Nanhera Anantpur
5) Chudiala
6) Manakpur (Adampur)
7) Latherdewa Hun
8) Ramnagar, Roorkee City.
9) Mundlana (drilling was in progress).

In all a total of 10 VES were conducted at the above said sites. At these sites, VES points were selected in such a way, that the maximum current electrode separation was achieved, so that the deeper sub-surface information can be deciphered. But at some sites, due to the irrigated agriculture fields, the larger spread was not possible. In order to achieve the maximum electrode separation and avoid the irrigated fields, some VES were conduted around 500 to 900 m away from the proposed drilling sites. The Schlumberger soundings were conducted with the maximum current electrode separation (AB) ranging from 340 m to 900 m, due to the spread constraints arising from field restrictions. Current electrode separation were expanded in steps of 2 m up to AB/2 = 20 m and then in increment of 5 m up to AB/2 = 100 m, with appropriate MN separation.

Table 13: The details and location of VES points in Haridwar District.

S. No.	Site Name	AB/2 (m)	Location
1	Bhagwanpur	200	At the corner of the field of Sh. Karam Singh, adjacent to the Mango orchard. Behind the B.D Inter College building & playground.
2	Sikandarpur	200	At the corner of Junior High Secondary School playground. Near volleybal gound & ajacent to Barat Ghar.
3	Latherdewa Sheikh	440	In the field of Aslam s/o Mustafa, adjacent to the field of Sarbad s/o Musaraf. Along the road. VES point is around 550 m away from the J.H.S. School.
4	Nanhera Anandpur VES-1	430	In the sugarcane field of Sh. Omprakash Tyagi near Jaypee cement factory & pond – Dabur.
5	Nanhera Anandpur VES-2	170	At the corner of land, proposed for school.
6	Chudiala	450	In the field of Sh. Ram Nath, along the cart track.
7	Manakpur (Adampur)	440	In the Popular tree field of Sh. Raj Pal.
8	Latherdewa Hun VES-1	260	Under the Banyan tree, at the proposed site.
9	Latherdewa Hun VES-2	280	In the field of Sh. Bhagmal, along the canal, around 600 m away from VES-1.
10	Mundlana	240	Near the house of Najin & Feroz Munshi. About 100 m from the drilling site.
11	Ramnagar (Roorkee)	-	Site in urban area, park surrounded with houses having total spread of around 40 m.

The VES were conducted using the microprocessor based DDR – 4 M resistivity meter, manufactured by IGIS, Hyderabad. The resistivity meter consists of 'Battery Backup' unit for current supply and 'Measuring Unit' for feeding the positions of current electrodes, potential electrodes and displaying the measurements. The measurements are directly displayed as 'Apparent Resistivity'. The details and location of VES point along with their half-current electrode separation is given in **Table 13**.

Exploratory Drilling

The Central Ground Water Board has constructed 33 tube wells in the district. Out of which, twenty six are exploratory wells, six are observatory wells and one is piezometer drilled at Roorkee University. The hydrogeological details of the tube well drilled by CGWB is given in **Table 14** and also shown on the groundwater exploration map in **Fig 6.**

Table 14: Hydrogeological details of Exploratory Wells Drilled by CGWB, in Haridwar District Uttarakhand State

Sno	Village	Block	Toposheet No.	Lat.	Long.	Type of Well	Depth (m)	Well Completion	Diameter(mm)	SWL (mbgl)	Discharge(lps)	Drawdown(m)	T (m2/day)	Sp. Capacity(lpm/m of dd)
1	Baleki Yusufpur	Bhagwanpur	53 G/13	29.89	77.79	EW	201	195	200	18	36.6	4.43	408	496.6
2	Chauli Sahabuddinpur	Roorkee	53 G/16	29.99	77.77	EW	201	185	200	16.4	26.6	5.72	176	622
3	Chudiala	Bhagwanpur	53 G/13	29.91	77.77	EW	201	189	200	18	30	4.25	339	706
4	Dhandera	Roorkee	53 G/13	29.84	77.90	EW	201	187	200	18	33.3	3.9	377	1346
5	Kisanpur Jamalpur	Bhagwanpur	53 G/13	29.92	77.84	EW	201	190	200	14	35	4.45	299	472
6	Mahi gran Parao	Roorkee	53 G/13	29.88	77.88	EW	201	185	200		21.66	3.49	626	1195
7	Nagal Piloni	Roorkee	53 G/13	29.97	77.88	EW	200	175	200	15	35	8.63	577	185
8	Padli Gujjar	Roorkee	53 G/13	29.84	77.87	EW	201	189	200		34.58	2.84	1822	767
	Ramnagar	Roorkee	53 G/13	29.87	77.88	EW	179	168	200		33.33	3.85	1648	459
10	Sigroda	Roorkee	53 G/13	30.00	77.85	EW	200	172	200		35	9.99	307	223
11	Sikanderpur Bhainswal	Bhagwanpur	53 G/13	29.96	77.77	EW	200	175	200	20	33.33	5.98	925	375
12	Sirchandi	Bhagwanpur	53 G/13	29.93	77.76	EW	200	151	200	22	30	5.22	264	344
13	Raipur	Bhagwanpur	53 G/13	29.95	77.80	EW	203	160	200	1	35	7.02	791	433
14	Lather deva hun	Roorkee	53 G/13	29.79	77.81	EW	200	182	200	6.26				
15	Manglaur	Roorkee	54 G/13	29.79	77.88	EW	204	180	200					
16	Lather deva hun	Roorkee	55 G/13	29.84	77.83	OW	178	178	200					
17	Bindu Khadak	Bhagwanpur	51 G/13	29.86	77.73	EW	200	185	200					
18	Bhagwanpur	Bhagwanpur	52 G/13	29.94	77.81	EW	200	190	200					
19	Manakpur Adampur	Bhagwanpur	53 G/13	29.84	77.75	EW	200	185	200					
20	Mundlana	Gurkul Narsen		29.74	77.92	EW	201	171	200		46			

21	Manglaur	Gurkul Narsen		29.79	77.88	OW	185	180	200					
22	Lather deva Sheikh	Roorkee	53 G/13	29.84	77.83	EW	200	178	200		40			
23	Lather deva Sheikh	Roorkee				OW	175	175	200					
24	Sikanderpur Bhainswal	Bhagwanpur				OW	180	175	200					
25	Lalwala Mazbata	Bhagwanpur	53F/16	30.05	77.94	EW	65.9			18.1	16.01	8.83	298	108.8
26	Landhaura	Roorkee	53G/13	29.81	77.93	EW	224			15.98	38.33	3.55		647.88
28	Landhaura–1	Roorkee	53G/13	29.81	77.93	OW								
29	Landhaura–2	Roorkee	53G/13	29.81	77.93	OW								
30	Roorkee	Roorkee	53G/13	29.86	77.90	Pz	205			5.85				
31	Jwalapur–1	Bahadrabad	53K	29.93	78.10	EW	36.6			26.4				
32	Jwalapur–2	Bahadrabad	53K	29.96	78.11	EW	45.7			26				
33	Jwalapur–3	Bahadrabad	53K	29.96	78.11	EW	85.3			20.61	34.36	1.71	19850	1207

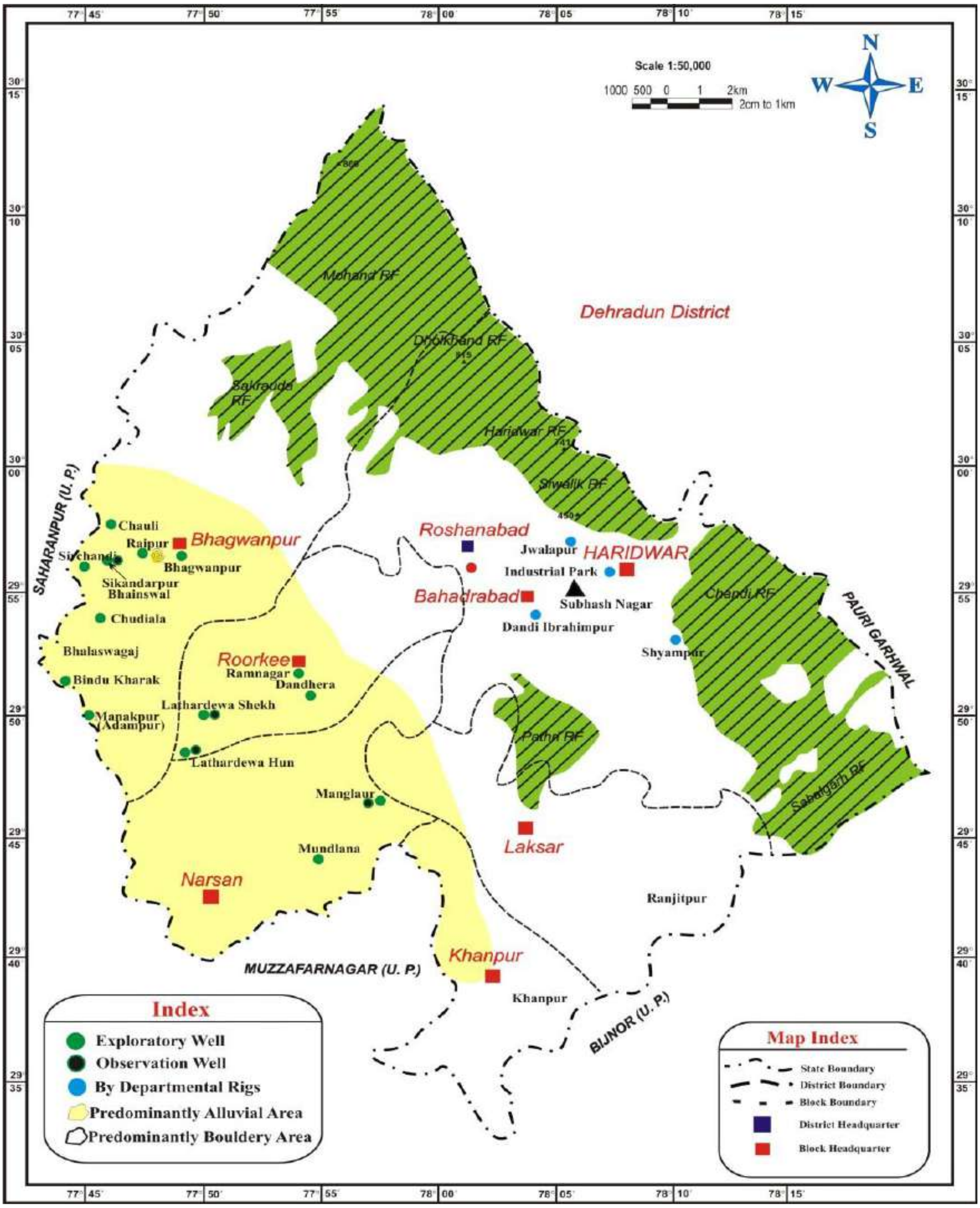


Fig 6: Groundwater Exploration Map of Haridwar District

Ground Water Exploration:

As far as ground water exploration is concerned Central Ground Water Board has constructed 33 tube wells in the district. Out of which, twenty six are exploratory wells, six are observatory wells and one is piezometer drilled at Roorkee University. The drilled depth of these wells ranges between 36.58 to 223.96 m bgl. The water level in these tube wells ranges between 5.85 to 26.40 m bgl with a discharge ranging 21.66 to 46lps with drawdown 1.71 to 9.99 m. The transmissivity range between 298 to 2300 lpm with drawdown 1.71 to 8.83 m. The transmissivity ranges between 176 to 19850 m^2/day. The exploratory well drilled falls under Bhabar zone as well as in Indo Gangetic alluvial plain.

Chemical Qualities of Shallow Ground Water:

The water samples collected from phreatic zone were analyzed. The details of chemical constituents found in shallow water are given in **Table 12**. The analysis reveals the following characteristics:-

1) **Electric Conductance (E.C.):-** The E.C. Value of the ground water in phreatic zone of Haridwar district varies from 262 at Bahadrabad to 1535 at Libberheri. The E.C. is slightly higher in Laksar block while rest all other part it is in between 500 to 900
2) **Hydrogen ion concentration: -** The hydrogen ion concentration is indicative of acidic and alkaline nature of water. The pH value should be measured at the spot itself. The Value of pH has been determined only after bringing the sample in to laboratory. The pH value in all the samples is in between 7.66 to 8.2 indicating that the ground water in Haridwar district is alkaline in nature.
3) **Carbonate and Bi-Carbonates: -** Carbonate is not found in the water samples collected from the phreatic zone. However, the Bicarbonates range between 128 mg/l, to 494 mg/l at Siwalik Hills.
4) **Chlorides:-** The Chloride concentration in phreatic aquifer over the entire district ranges between 7.1 mg/l to 28.0 mg/l excepted at some villages like Jhabrera, Sultanpur, Bhagwanpur, Teliwala, have concentration ranging from 70 mg/l to 96 mg/l whereas the highest concentration of chloride is found at Libherheri and Laksar which is 128 mg/l. The Chloride content shows the very good quality of ground water.

5) **Sulphate**: - The excess concentration of Sulphate increases the soil salinity, though Sulphur is an essential element in plant nutrition and in the form of Sulphate it is readily available to the plants. The concentration of Sulphate in the ground water of the district ranges between 2 to 80 mg/l except at Laksar where the Sulphate value has been determined to 310 mg/l.

6) **Fluoride**: - The Fluoride concentration in the phreatic ground water in the district is negligible. It ranges between 0.01 mg/l to 0.52 mg/l. As such the ground water in the district is safe for drinking and irrigation purpose.

7) **Nitrate: -** Nitrate concentration in this shallow ground water is either nil or well within the permissible limit of 45 mg/l. However, the nitrate ranges from nil to 34 mg/l except at Libberheri and Sultanpur where the nitrate concentration is beyond the permissible limit having value of 86 mg/l and 49 mg/l respectively. Thus the water is suitable for drinking and agriculture purpose.

8) **Calcium: -** Calcium is the most common constituent of natural water and is controlled by dissolved cozgas. The absence of Calcium in drinking water may cause rickets and teeth defectiveness while presence of excess Calcium may cause gaut and urinary problems. However, the concentration of Calcium present in the ground water 28 mg/l to 108 mg/l except at Teliwala and Laksar where it has raised up to 108 and 92 mg/l respectively. The maximum desirable limit of Calcium is 75 mg/l and the maximum permissible limit is 200 mg/l. Thus the concentration of Calcium is well within the desirable limits as per BIS.

9) **Magnesium: -** Magnesium is one of the constituents that cause hardness in water. Its lower concentration is not harmful but the higher concentration is laxative. The desirable limit of Magnesium is 30 mg/l and permissible up to 100 mg/l for drinking purpose. The concentration of Magnesium ranges between 7.3 mg/l to 95 mg/l.

10) **Total Hardness as $CaCo_3$:-** The total hardness as $CaCo_3$ in ground water ranges between 120 mg/l to 360 mg/l except at at some villages like at Liberheri and Sultanpur where it is between 435 to 490 mg/l, whereas the highest concentration of 610 mg/l is found at Laksar village. The concentration of $CaCo_3$ shows that groundwater in the district is hard in nature.

11) **Sodium: -** The high concentration of the Sodium in ground water may cause alkaline soil and harmful for the persons suffering from hypertension, cardial, renal and other vesicular ailments. However, the concentration of Sodium ranges from 5.3 gm/l to 92

mg/l. except at Laksar it has raised to 92 mg/l. The ground water is suitable for domestic and agriculture purpose.

12) **Potassium:-**The concentration of Potassium in ground water was not determined. It suitable for domestic and irrigation purpose.

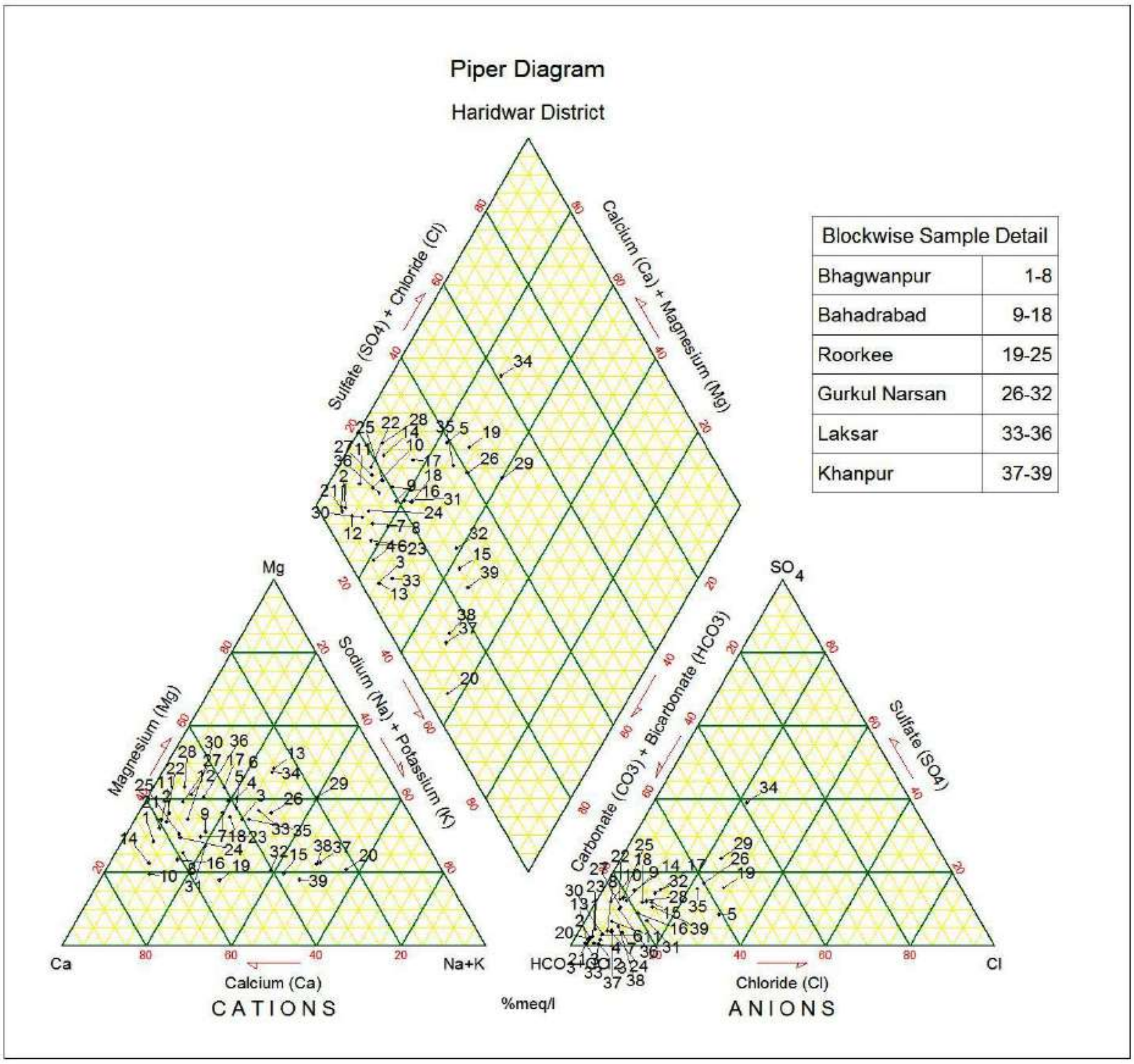


Fig 7: Groundwater Samples of Haridwar District Plotted in Piper-Trilinear diagram

An overall view of the Chemical quality of ground water from phreatic aquifer as given in **Table 12** indicates that, the quality of water is very good and all the chemical constituents present in the water are well within the permissible limit. The all-chemical constituents in ground water at some places have shown a little higher concentration, although it is also with in permissible limit.

Piper diagrams (**Fig 7**) are an example of water quality diagrams which are probably the most frequently used today. The subdivisions of the trilinear or piper diagram depict that Mg-HCO_3

type of water was predominated in almost all the blocks of the Haridwar District except in Khanpur block where NaCa-HCO_3 type of water is dominated which causes infiltration problem which is evident by the shallow water level prevailing in the block.

So, on the whole, ground water from phreatic aquifer in Haridwar district is generally fresh, potable, and free from any type of contamination and thus fit for human consumption.

Geophysical Survey Results

In all a total of 10 VES were conducted at different sites. At these sites, VES points were selected in such a way, that the maximum current electrode separation was achieved, so that the deeper sub-surface information can be deciphered.

Interpretation:

The values of ρ_a were plotted against the related half-current electrode separation on double logarithmic scale paper of moduli 62.5 mm. The curves were carefully smoothened for the interpretation. Preliminary quantitative interpretation of VES curve was attempted by semi empirical 'Auxiliary Point' method with the help of two-layer master curves and auxiliary point charts of Orellana – Mooney (1966). The VES curves were also analyzed by indirect method of curve break / kink for deciphering boulder beds depth. The details of VES interpreted results for two representative sites are as follows:

- The surveyed area comprises of a horizontally layered sequence of clay, silt, sand, gravels, pebbles and boulders.

- The resistivity sounding curves obtained in the area are of QK, KA & H type. The interpreted true resistivity of the field VES curves indicates 7 to 16 sub-stratum geo-electrical layers.

- The sub-surface geological formations in the area are characterized by resistivity value in the range from 2 Ohm-m to 12500 Ohm-m.

- The resistivity values less than 10 Ohm-m indicates clay and resistivity values in the range of 10 Ohm-m to 25 Ohm-m indicates the formation comprising of clay mixed with silt, fine to medium sand.

- The resistivity values in the range of 25 Ohm-m to 75 Ohm-m indicates ground water promising formation comprising of medium to coarse sand, gravel and pebbles.

- The resistivity values above 75 Ohm-m, depending upon the consolidation and depth, indicates formation being semi-consolidated to hard boulder bed.

- The thin granular / clay / boulder zones at deeper depths, sandwiched between two thick layers, were not picked up in interpretation - limitation of technique.
- At the Mundlana drilling site, the boulder bed encountered in drilling at the depth of 86 m bgl is in corroboration with the geophysical interpreted geo-electrical layer having the resistivity of 840 Ohm-m in the depth range of 80 to 136 m bgl and also by the indirect method depth range of 90 – 95 m bgl.

1) Bhagwanpur

At this site, one VES was conducted with AB/2 of 200 m at the corner of the field of Sh. Karam Singh, adjacent to the Mango orchard, behind the B.D Inter College building & playground. The electrode spread was restricted to AB/2 of 200 m due to the Roorkee – Dehradun road on eastern side. The interpreted true resistivity of the field VES curves indicates 11 sub-stratum geo-electrical layers. The resistivity-sounding curve obtained at this site is of QA type (Figure 1). The interpretation of VES gives the sub-surface information upto the depth range of 213 m bgl. The details of interpreted true layer resistivity and thickness are given in Table 15.

Table 15: The interpreted results of VES at Bhagwanpur.

True Resistivity (Ohm-m)	Thickness (m)	Depth Range (m bgl)	Inferred Geology
102	0.76	0.0 – 0.76	Top surface soil.
31	0.46	0.76 – 1.22	Medium to fine sand.
39	6.6	1.22 – 7.82	Medium to coarse sand.
24	49.4	7.82 -57.2	Medium to fine sand.
82	8.4	57.2 – 65.6	Boulder gravel mixed fmt.
19	14.0	65.6 – 79.6	Medium to fine sand.
93	14.4	79.6 – 94.0	Boulder gravel mixed fmt.
21	30.0	94.0 – 124.0	Medium to fine sand.
280	52.0	124.0 – 176.0	Boulder gravel mixed fmt.
16	37.5	176.0 – 213.0	Medium to fine sand.
135	--	213.0 - --	Boulder gravel mixed fmt.

The resistivity value in the range of 75 to 300 Ohm-m indicates sand, gravel mixed boulder bed. There are four such interpreted layers in this VES at the depth ranges of 57 – 66, 80 – 94, 124 – 156 and below 213 m bgl.

2) Sikandarpur

At this site, one VES was conducted with AB/2 of 200 m at the corner of Junior High Secondary School playground, near volleyball ground & adjacent to Baratghar. The electrode spread was restricted to AB/2 of 200 m due to the irrigated field on eastern side. The interpreted true resistivity of the field VES curves indicates 10 sub-stratum geo-electrical layers. The resistivity-sounding curve obtained at this site is of KA type (Figure 1). The interpretation of VES gives the sub-surface information upto the depth range of 101 m bgl. The details of interpreted true layer resistivity and thickness are given in table 16.

Table 16: The interpreted results of VES at Sikandarpur.

True Resistivity (Ohm-m)	**Thickness (m)**	**Depth Range (m bgl)**	**Inferred Geology**
36	1	0.0 – 1.0	Top surface soil.
18	1	1.0 – 2.0	Medium to fine sand.
77	1.6	2.0 – 3.6	Coarse sand with gravel pebbles.
780	0.59	3.6 - 4.2	Boulder formation / dry sand
280	8	4.2 – 12.2	Boulder gravel mixed fmt.
74	37.4	12.2 – 49.6	Coarse sand with gravel pebbles.
2	5.2	49.6 – 54.8	Clay
12	38.9	54.8 – 93.7	Clay mixed silt to fine sand.
345	7.56	93.7 – 101.3	Boulder gravel mixed fmt.
42	--	101.3 - --	Medium to fine sand.

The resistivity value in the range of 75 to 780 Ohm-m indicates gravel mixed boulder bed. There are two such interpreted layers at this site in the depth ranges of 4 to 49 and 94 to 101.3 m bgl. Clay layer is also likely to be expected at the depth range of 50 to 55 m bgl.

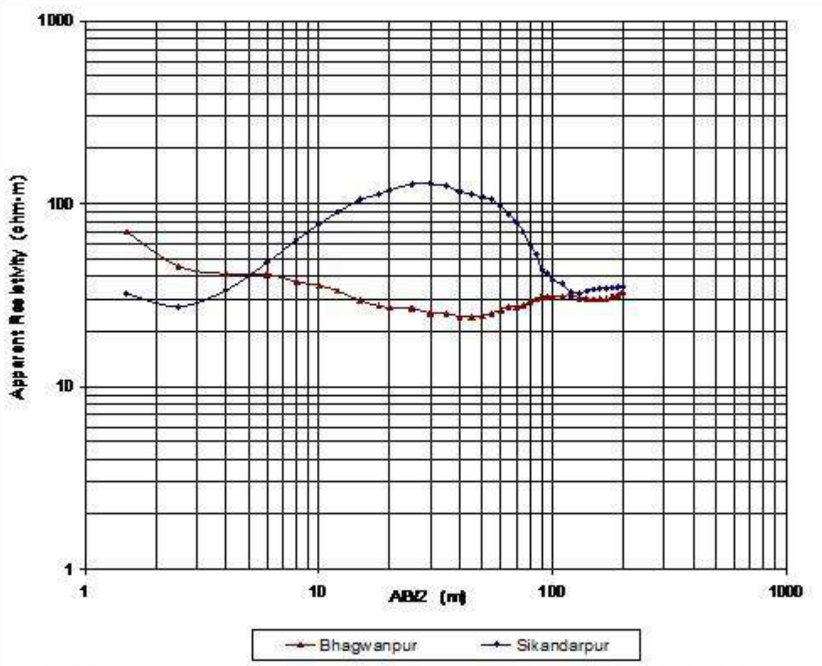


Fig 8: VES Curves of Bhagwanpur and Sikandarpur Sites in Haridwar District

Also, from the analysis of field curves (kinks & curve break) and interpreted layer parameters, the expected depth/s ranges at which there is possibility of encountering the boulder beds for the remaining Surveyed sites are summarized as below:

S. No.	Site Name	Depth in m bgl
1	Bhagwanpur	57 -66, 80 -94, 124- 156 and below 213 m bgl.
2	Sikandarpur	4-49 & 94-101.3 m bgl. Clay layer is also likely to be expected at the depth range of 50- 55 m bgl.
3	Latherdewa Sheikh	10-29,75,95,100-114,132-156,170,196-209 & 233-255 m bgl.
4	Nanhera Anandpur	9 – 23, 45, 60, 80, 90, 132 - 147 and 257 to 293 m bgl.
5	Chudiala	75, 110 and 160 and 194 - 224 m bgl.
6	Manakpur (Adampur)	35 & 100 m bgl.
7	Latherdewa Hun VES-1	26 to 29, 33 to 47, 59 to 62 and 98 to 118 m bgl
8	Latherdewa Hun VES-2	4 to 17, 25 – 35, 75 and 160 m bgl.
9	Mundlana	16 - 39, 52 - 57, 62 - 71, 80 – 136, 150 - 162 and 180 m bgl (90 - 95, 120 – 130 by curve break)
10	Ramnagar (Roorkee)	Resistivity survey not possible.

Aquifer 3-D disposition and Lithological Cross Section of Study Area

Two numbers of subsurface geological cross sections and an Aquifer 3-D disposition maps were prepared based on the lithologs of the tube wells drilled by tube well construction division, Roorkee as shown in the **Fig 9a & b and Fig 10.** One in the Indo Gangetic plain (Mohammadpur-Goverdhanpur-Raisi-Khanpur-Bhogpur) and second in bouldary formation (ManakpurAdampur-PadliGujjar-MahigramPadao-Patheri-Shyampur-Mithiberi). Preview of the subsurface lithological cross section shows that **nature of alluvial sediment is complex and there is alternation of fine to coarse sediments** and also three tier aquifer system exists in the indo-Gangetic belt of Hardwar district separated by clay layers.

The saturated aquifer system is comprised of fine to coarse-grained sand and gravels. In the bouldery formation (Bhabar belt) the aquifer group has been intervened by thin clay layers which at places are thick are mixed with boulders and cobble, pebble.

The Aquifer 3-D disposition map reveals that the first aquifer is encountered after sandy clay layer between 5-25 m. The 1st and the 2nd Aquifer are separated by 10-20m thick clay layer. In Bhabhar belt GW occurs under unconfined conditions. In Terai belt GW occurs under confined conditions. In Gangetic alluvium the GW occurs in Semi-Confined/ Confined conditions.

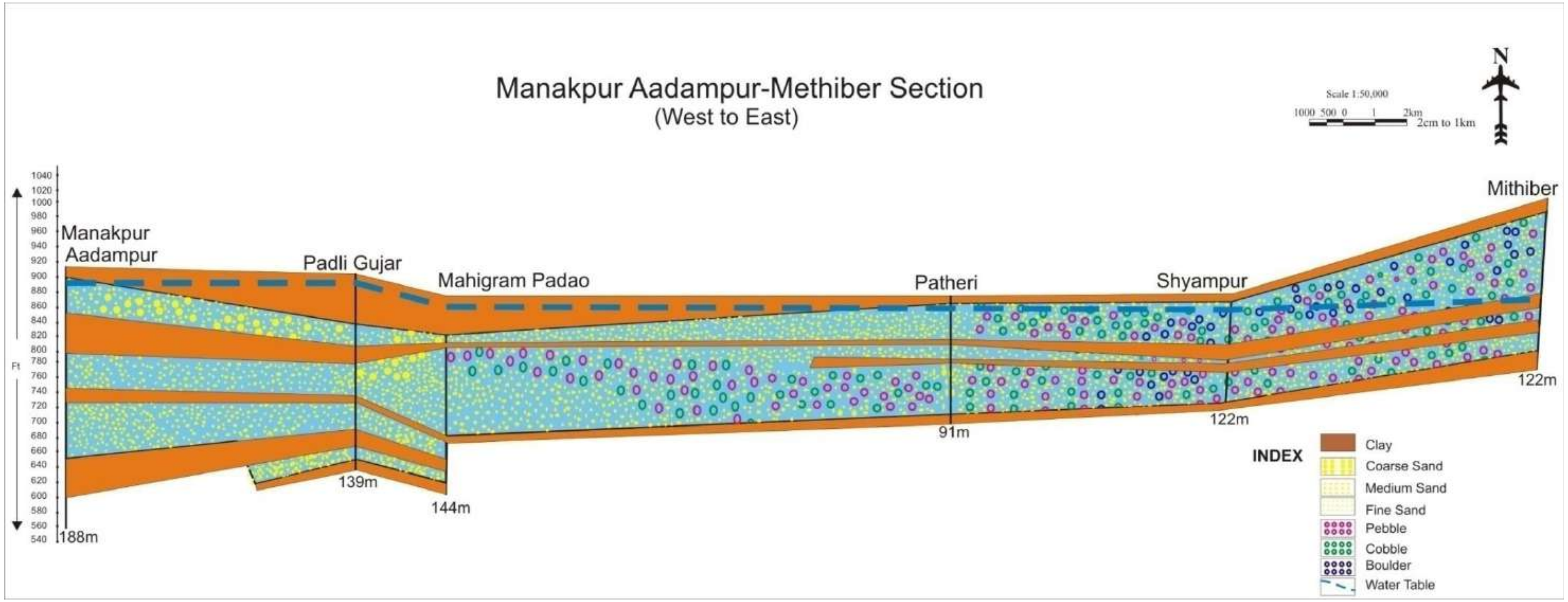


Fig 9a: Lithological Cross Section-1 of Haridwar District

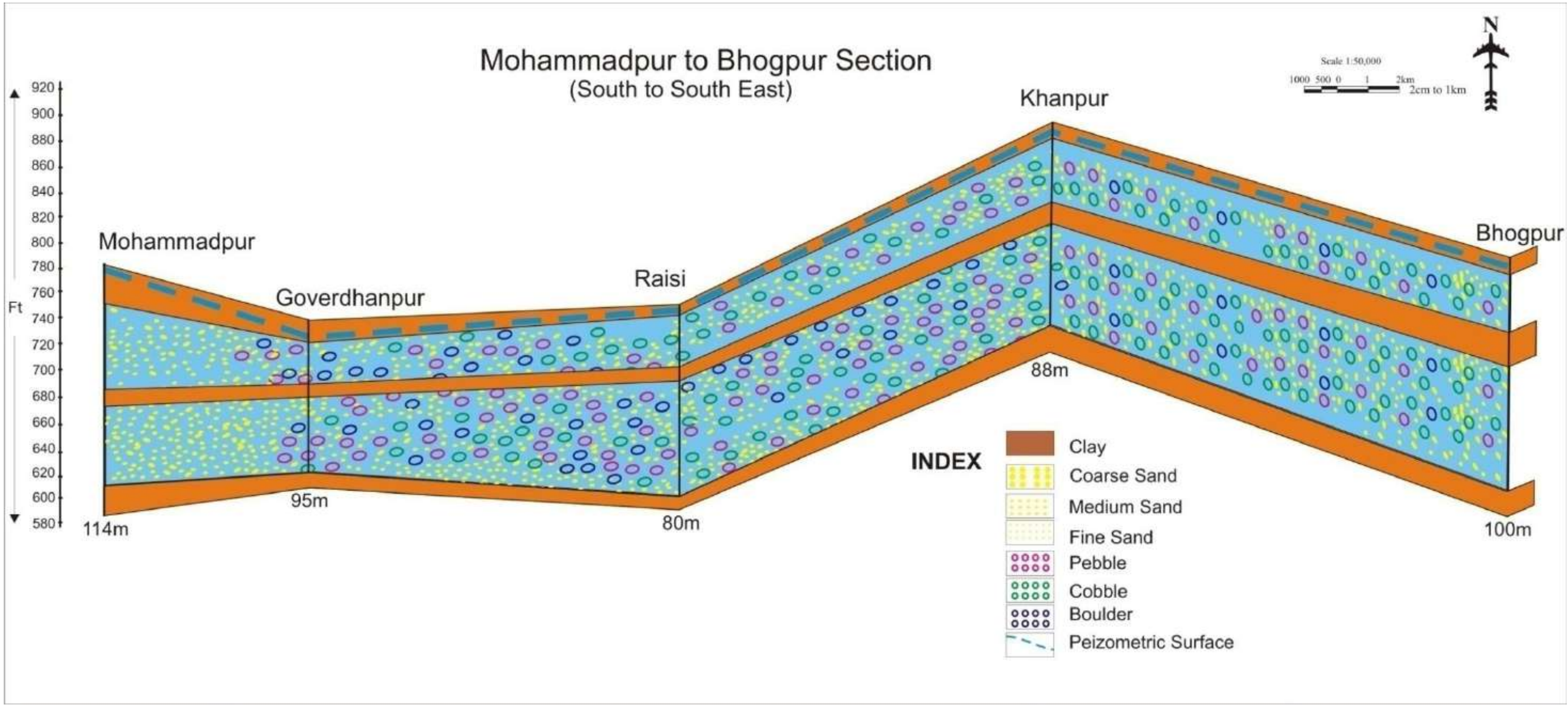


Fig 9b: Lithological Cross Section-2 of Haridwar District

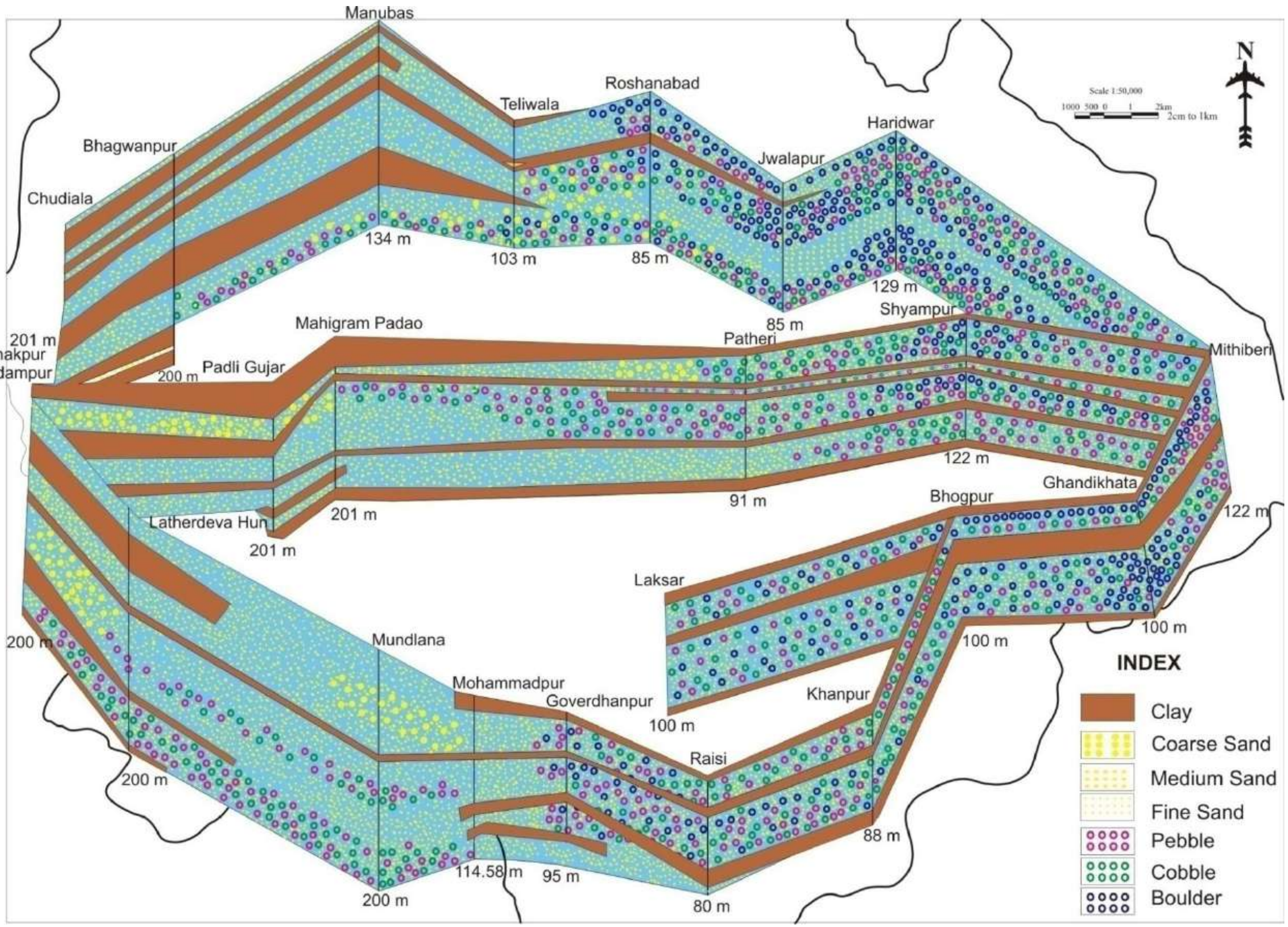


Fig 10: Aquifer 3-D disposition Map of Haridwar District

The ground water resource potential of Haridwar district has been done broadly within the guidelines and recommendations made by Ground Water Resource Estimation committee norms 1997 (GEC' 97). The principal source of recharge to aquifer is the rainfall. The return seepage from irrigated field, seepage from canals, water bodies and flood plains are the additional sources for recharge to an aquifer system. The gross annual ground water recharge estimates are made for monsoon and non-monsoon period separately.

Based on the GEC norms the block wise characterization of Ground Water Potential in district Haridwar, taking the database of 2011 has been calculated and given in the following **Table 17.**

Assessment of Ground Water Resource Potential of Unconfined and Confined Aquifer System

The groundwater available in the zone of water level fluctuation forms dynamic groundwater resource, which is annually replenishable. Below the zone of water table fluctuation, the groundwater which is available in the perennially saturated portion of the unconfined aquifer forms the in-storage or static groundwater resource of the unconfined aquifer. The thickness of the unconfined aquifer varies from place to place depending upon depositional history.

Computation of Static Ground Water Resource

The In-storage availability of groundwater resources in the unconfined aquifers below the zone of fluctuation is computed based on groundwater storage concept using specific yield of the aquifer, which is computed as per the equation 1;

Table 17: Block wise Ground Water Resource Potential of Haridwar (As on 31-03-2011)

S. No	Assessment Unit (Block)	Net Annual Ground Water Availability	Existing Gross Ground Water Draft for irrigation	Existing Gross Ground Water Draft for domestic and industrial water supply	Existing Gross Ground Water Draft for All uses	Provision for domestic, and industrial requirement supply to 2025	Net Ground Water Availability for future irrigation development	Stage of Ground Water Development (%)	Categorization
1	Bahadarabad	16036.61	7295.58	291.82	7587.40	454.59	7994.62	47.31	Safe
2	Bhagwanpur	8783.87	8202.84	328.11	8530.95	424.61	--	97.12	Semi Critical
3	Narsan	15475.10	4611.20	161.39	4772.59	311.11	10391.39	47.63	Safe
4	Khanpur	5913.08	4611.20	161.39	4772.59	239.85	900.64	80.71	Semi Critical
5	Laksar	9163.41	7066.40	247.32	7313.72	556.08	1293.61	79.81	Semi Critical
6	Roorkee	15731.15	6316.81	221.08	6537.89	307.46	8885.79	41.56	Safe
	Total	71103.22	38104.03	1411.11	39515.14	2293.7	29466.05	65.69	-

Equation 1. Estimation of In-storage Ground Water Resources of unconfined aquifer

In-storage Ground Water Resources	=	Total thickness of the granular zones in the aquifer below the zone of water level fluctuation of the aquifer down to exploitable limit.	X	Areal extent of the aquifer	X	Specific Yield of the aquifer

In the process of computing the In-storage (static) ground water resources, the volume of granular zones in the aquifer has been worked out on the basis of ground water exploration carried out by Central Ground Water Board.

Specific yield values adopted for assessment of in-storage resources of the unconfined aquifers have been multiplied by a factor of 0.6 in view of the inherent uncertainties associated with the degree of compaction/consolidation with increasing depth and the inherent nature of lithofacies variation within the aquifer.

Table 18: Parameter & Static Resources for Unconfined Aquifer- Haridwar

Name of District	Area (Sq. Km)			Av. RLGL (mamsl)	Predominent DTW (mbgl)	Av. Bottom depth (mbgl)	Thickness of Grainular Zones in Un-confinned Aquifer (m)	Adopted Specific Yield %	Static GW resources in unconfined aquifer (MCM)		
	Fresh	Saline	Total						Fresh	Saline	Total
1	2	3	4	5	6	7	8	9	10	11	12
Haridwar	1568	0	1568	274	12.77	45	32	0.108	5459	0	5459
TOTAL (MCM)	**1568**	**0**	**1568**					0	**5459**	**0**	**5459**
TOTAL (BCM)									**5.46**	**0**	**5.46**

Confined Resource

Methodology and Assumption

A confined aquifer is a porous and permeable geological unit, which is sandwiched between two relatively low permeability layers. The confined aquifers are generally extensive. The main source of recharge to any aquifer is rainfall. The recharge zone of a confined aquifer is located far apart and the ground water is under pressure. Under pre-development conditions within a confined aquifer, there is a dynamic equilibrium between recharge and the discharge or outflow from an aquifer. Water is under pressure and the total volume in storage remains relatively constant.

Assessment of development potential of confined aquifers assumes importance, since over-exploitation of these aquifers may lead to far more detrimental consequences that those of shallow unconfined aquifers. If the piezometric surface of the confined aquifer is lowered below the upper confining layer so that de-saturation of the aquifer occurs the coefficient of storage is no longer related to the elasticity of the aquifer but to its specific yield.

The most widely used analytical techniques are based on lumped approach using flow-rate concept and storage concepts. These methods are given below;

i. Ground water flow rate concept

The rate of flow of water through a confined area may be estimated by Darcy's law as follows:

Q = T I L

Where,

Q = Rate of flow through a cross of aquifer in m^3/day

T = Transmissivity in m^2/day

I = Hydraulic gradient m/km

L = Average width of Cross-section in km

Sample Calculation: Flow Rate concept
District: Haridwar, Uttarakhand

SECTION – 1

Q = T. I . L (m^2/ day.m/m.m) = m^3/day

Where T = Transmissivity (m^2/ day)
I = Hydraulic conductivity
L = length of the section across which water flows (m)
∂ h = 100 m
∂ l = 16.2 cm = 16.2 X 2.50 km = 40.5 km
= 40.5 X 1000 = 40500 m
∂ h / ∂ l = 100 / 40500
L = 6.3 cm = 6.3 X 2.5 = 15.75 km
= 15.75 X 1000 = 15750 m
Volume of water flowing across Section – I = T I L
= 2000 x 100 / 40500 x 15750
= 77777.0 m^3/day

= 0.78 MCM/day

Q_1 = 0.078 X 365 = 28.38 MCM/year

<u>SECTION – II</u>

T = 1985.0
∂ h = 100 m
∂ l = 18.3 cm = 18.3 X 2.5 X 1000 m = 45750 m

∂ h / ∂ l = 100 / 45750
L = 17 cm = 17 X 2.5 X 1000= 42500.0 m
Volume of water flowing across Section – II = T I L
Q_2 = 1985 x 100 / 45750 x 42500
= 184399.0 m^3/day
= 0.1844 MCM/day
~67.3 MCM/year

Total volume of water flowing across the district = Q
Q = Section – I + Section – II
= 28.38 + 67.3
= 95.68 MCM / Yr

Table 19: Ground Water Resources based on Flow Rate Concept- District Haridwar

Section	T (m^2/day)	Contour Interval of the Piezometric Surface (m) (∂ h)	Length of the Flow Line (m) (∂ l)	Length of the Section across which groundwater flows (km)	Hydraulic Gradient	Groundwater flow through the Section by maintaining confined conditions (m^3/day)	Groundwater flow per year (MCM)
I	2000	100	40.5x1000	15.75	100/40500	77777.0	28.38
II	1985	100	45.75x1000	42.50	100/45750	184399.0	67.30
Total groundwater flow (flux) across the area							**95.68**

Ground water storage concept

The co-efficient of storage or storativity of an aquifer is defined as the volume of water it releases or takes into storage per unit surface area of the aquifer per unit change in head.

Hence, the quantity of water added to or released from the aquifer (ΔV) can be calculated as follows:

$$\Delta V = S\, \Delta\, h$$

If the areal extent of the confined aquifer is A then the total quantity of water Q is

$$Q = S\, \Delta\, h\ X\ A$$

Where,

Q = Quantity of water the confined aquifer can release (m^3)

S= Storativity

A Areal extent of the confined aquifer (m^2)

Δh = Change in piezometric head

The quantity of water released in confined aquifer due to change in pressure can be computed between piezometric head (**h_1**) at any given time 't' and the bottom of the confining layer (**h_o**)by using the following equation

$$Q_p = S\, A\, \Delta\, h$$

$$= S\, A\, (h_o - h_1)$$

Where,

Q_p = Quantity of water under pressure (m^3)

S= Storativity

A Areal extent of the confined aquifer (m^2)

Δh = Change in piezometric head

H_t = Piezometric head at time 't'

h_o = Bottom of the confining layers

Table 20: Ground water Resources based on Storativity Concept-District Haridwar, Uttarakhand

District	Section	Area km^2	Storativity of the confined aquifer	Average thickness of the granular zone confined aquifer (m)	Average depth of the bottom of the confined layer	Time averaged Piezometric Head (mbgl)	Scenarios head loss (m)		Ground water resource released form storage of the confined aquifer MCM
							No.	Head loss (m)	
Haridwar	I	844.38	3.85×10^{-3}	27.0	45.0	10.0	1	1.0	3.25
							2	10.0	32.51
							3	35.0	113.78
	II	1350	3.85×10^{-3}	28.0	35.0	7.50	1	1.0	5.19
							2	10.0	51.90
							3	25.0	129.94
	Total volume of ground water that may be released from the storage of confined aquifer								243.72

Sample Calculation Using Storativity Concept
District: Haridwar

SECTION – I:

Area of the section (l) = 19.3 X 2.5 = 48.25 km^2

(b) = 7 X 2.5 = 17.25 km^2

Area = 48.25 X 17.5 = 844.38 km^2

Storativity = 3.85 X 10^{-3}

= 0.00385

Average depth of bottom of first confining layer = 45.0 m

Time averaged piezometric head (h_1) = 10.0 m

Scenario – I: If piezometric surface is lowered by 1.0 m through pumping

Pumping water level (h_0) = 11.0 m

Head loss ∂ h = $h_0 - h_1$

=11.0 – 10.0 = 1.0 m

Ground water Resources

Q = Area X Storativity X change in piezometric head (∂ h)

= 844.38X 3.85 X 10^{-3} X 1.0

= 3.25 MCM

Scenario – II: If piezometric surface is lowered by 10.0 m through pumping

Pumping water level (h_0) = 20.0 m

Head loss ∂ h = $h_0 - h_1$

= 20.0 – 10.0 = 10.0 m

Ground water Resources

Q = Area X Storativity X change in piezometric head (∂ h)

= 844.38X 3.85 X 10^{-3} X 10.0

= 32.51 MCM

Scenario – III: If piezometric surface is lowered up to the bottom of first confining layer

Head loss ∂ h = $h_0 - h_1$

= 45.0.0 – 10.0 = 35.0 m

Ground water Resources

Q = Area X Storativity X change in piezometric head (∂ h)

= 844.38X 3.85 X 10^{-3} X 35.0

Maximum Q_1 = 113.78 MCM

SECTION – II:

Area of the section (l) = 18 X 2.5X 1000= 45000

(b) = 7 X 2.5 X 1000= 30000

Area = 135 X 10^7 m^2= 1350 km^2

Storativity = 3.85 X 10^{-3}= 0.0038

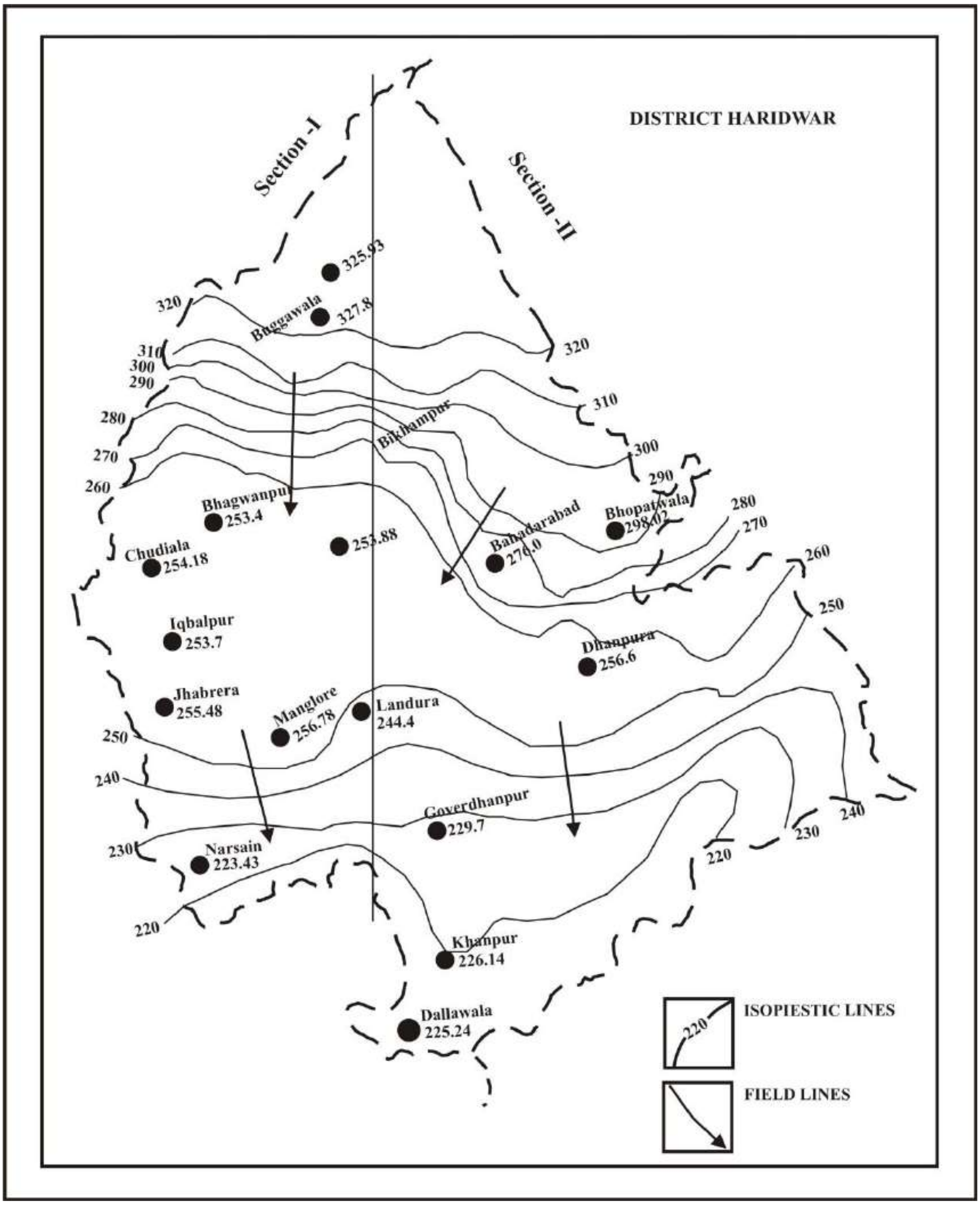


Fig 11: Groundwater Table Contour showing flow direction

Average depth of bottom of first confining layer = 35.0 m
Time averaged piezometric head (h_1) = 7.5 m

Scenario – I: If piezometric surface is lowered by 1.0 m through pumping
Pumping water level (h_0) = 11.0 m
Head loss $\partial h = h_0 - h_1$
$= 11.0 - 10.0 = 1.0$ m
Ground water Resources
Q = Area X Storativity X change in piezometric head (∂h)
= 1350 X 3.85 X 10^{-3} X 1.0
= 5.19 MCM

Scenario – II: If piezometric surface is lowered by 10.0 m through pumping

Pumping water level (h_0) = 20.0 m

Head loss ∂ h = $h_0 - h_1$

= 20.0 – 10.0 = 10.0 m

Ground water Resources

Q = Area X Storativity X change in piezometric head (∂ h)

= 1350 X 3.85 X 10^{-3} X 10.0

= 51.9 MCM

Scenario – III: If piezometric surface is lowered up to the bottom of first confining layer

Head loss ∂ h = $h_0 - h_1$

= 35.0.0 – 10.0 = 25.0 m

Ground water Resources

Q = Area X Storativity X change in piezometric head (∂ h)

= 1350 X 3.85 X 10^{-3} X 25.0

Maximum Q1 = 129.94 MCM

Maximum water available in District Haridwar in confined aquifer by maintaining confining conditions

= 113.78 MCM + 129.94 MCM

= 243.72 MCM

SUMMARISED AQUIFER WISE GROUNDWATER RESOURCES.

1. Unconfined Aquifer

a. Dynamic Zone

Net Groundwater Availability= **295 MCM**

b. In Storage

Fresh Groundwater Resources= **5459 MCM**

2. Confined Aquifer

a. Flow Rate Based Assessment= **95.68 MCM**

b. Storativity Based Assessment= **243.72 MCM**

Requirement of water are growing day by day due to increase in population, industrialization and urbanization. The dynamic groundwater resources are becoming scarce due to accelerated water demand and limited surface water availability in the unconfined aquifer. So far CGWB has been estimating the dynamic resources and static groundwater resources. The draft and water availability relationship indicate that many of the assessment units were categorized as critical and or over exploited.

Declining Ground water Level:

The Ganga Alluvium comparatively covers a large area in Hardwar district, where maximum agricultural activities are going on. The area has been extensively developed through shallow tube wells. Being non-command area, there is an immense pressure on ground water. The Ganga basin has deeper aquifers of large extension falling in Haridwar district. There is a stress on the unconfined aquifer in the parts of Bhagwanpur block of district Haridwar where declining water level trend are observed.

Groundwater Quality:

The chemical composition of natural water is affected by rock weathering and erosion. Chemical analysis of water samples helps indicate the nature and importance of some of the environmental factors to which water may be exposed in the hydrologic cycle. Hence, periodic monitoring of water quality is important for establishing its suitability for various purposes like drinking, domestic, agriculture and industrial and for deciphering the water quality trends in space and time. Analysis of hyrochemical data also help in evaluating the nature and extent of pollution, if any, and to ascertain the effectiveness of pollution control measures already in existence.

An overall view of the Chemical quality of ground water from phreatic aquifer as given in previous tables indicates that, the quality of water is very good and all the chemical constituents present in the water are well within the permissible limit. The heavy metals analysis in ground water at some places have shown higher concentration as given in the below **Table 21**. The major heavy metals that are found above permissible limits are Chromium (0.050 mg/l) and Lead (0.010 mg/l), also apart from these heavy metals Nitrate (45 mg/l) is also found in higher concentration at few locations.

Table 21: Summary of Heavy Metal Analysis from different location in Haridwar district.

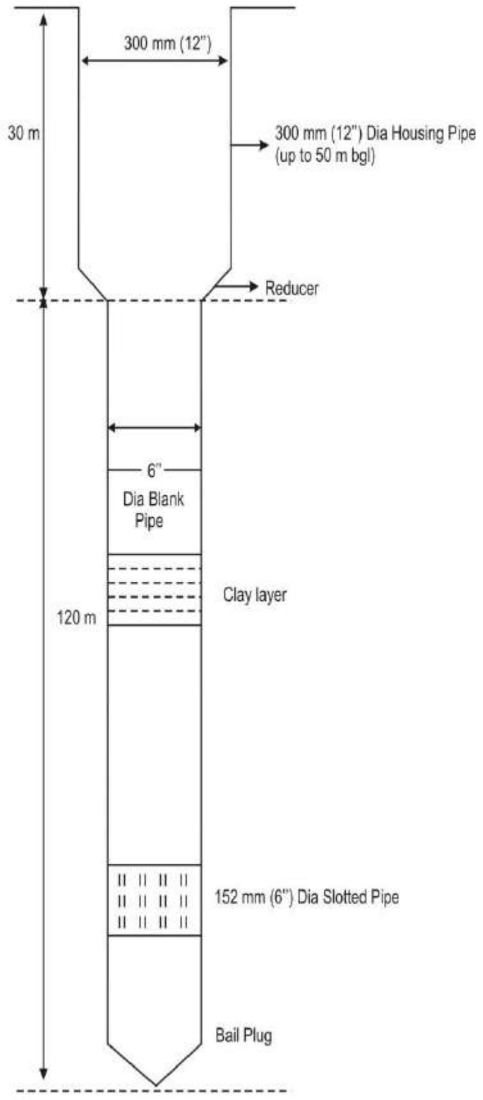
S. No	Location	Nitrate (mg/l)	Chromium (mg/l)	Lead (mg/l)
1	Sahidwala Grant	147	0.094	--
2	Banjarewala	--	0.085	--
3	Ibrahimpur	--	0.070	0.060
4	Lamagrant	--	0.089	0.060
5	Roshanabad	--	--	0.080
6	Gangdaspur	--	--	0.070
7	Rawali Mehdood	100	0.062	0.070
8	Jamalpur Khurd	119	0.056	0.080
	Permissible Limit	45	0.050	0.010

Remedial Measures

Apart from the decling groundwater level in the district the groundwater quality at few locations given in the above table shows higher concentration of Nitrate and heavy metals like chromium and Lead which makes the groundwater unfit for consumption. The main contribution of nitrate in groundwater comes from decay of organic matter, sewage wastes and application of nitrogeneous fertilizers. The mobile chromium in the groundwater could be removed by pump and treat methods. However, if the geochemical equibilium is upset and chromium is desorbed from the soil, then it would be very difficult to ever remove all of the chromium by pump and treat. Traces of Lead in water, usually is the result of solution of lead pipe through which the water has passed. Lead and the other metals are cation that can be expected to undergo cation exchange with clays. Hence, the mobility of lead in groundwater is limited. To remove the stress on the phreatic aquifer and to avoid the poor quality of groundwater it is recommended to construct deep tubewells in these locations for groundwater extraction and the well design for the deeper tubewells are given in the tables and figure.

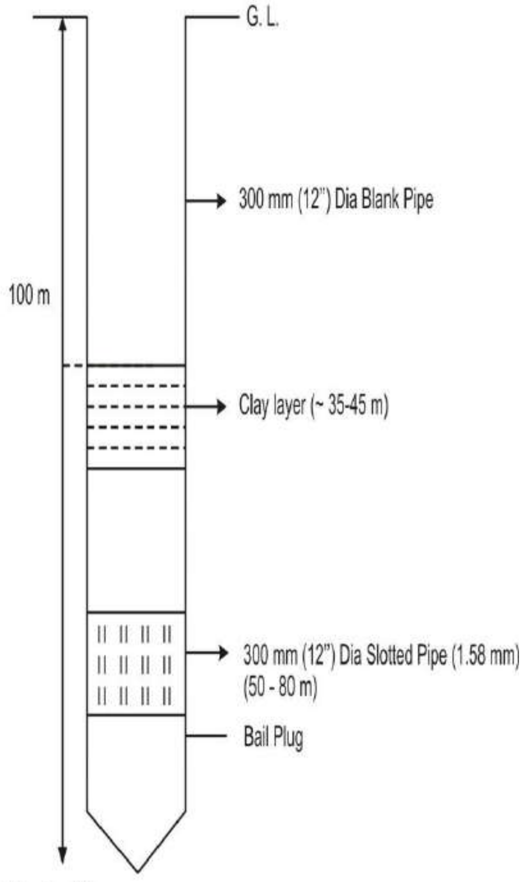
Well design for Zone 1	
Depth of Well	upto 140 m's
Aquifer Tapped	Sand along with pebbles/cobbles
Clay layer	40-50 m
Zonnes to be Tapped	B/W 60-100 m

Tentative Well Design for Soft Rock Formation



(Not to Scale)

Tentative well Design for Soft Bouldary Formation
(Straight Assembly)



(Not to Scale)

Well design for Zone 2	
Depth of Well	upto 100 m’s
Aquifer Tapped	Sand along with Boulders and pebbles/cobbles
Clay layer	35-45 m
Zonnes to be Tapped	B/W 50-80 m

Water Demand and Water Budgeting

Domestic Water Demand: Total population of Haridwar district is estimated to be 626313 (2015) which is projected to grow upto 701471 (2020) as per current population growth rate. The gross water demand is estimated as **0.0730** BCM for domestic use (**Table 22**).

Crop Water Demand: Rice and wheat being major irrigated crop of the district, the total crop water requirement is estimated as 1.2 m on hectare basis per year. Total sown area has been calculated as 131883 hectare which includes 126764 hectare of irrigated area. Total annual crop requirement has been estimated as 1.645 BCM while existing water potential is estimated to be 1.316 BCM which creates a demand gap of 0.329 BCM. Thus it justifies the strengthening of irrigation system in district through various interventions.

Livestock Water Demand As per Animal Census data , total livestock population of Haridwar is 513693 and their annual water requirement has been estimated to be **0.067499**BCM (2015) which is projected to increase upto 0.067 by 2020. Keeping in view the future demand of water for livestock, a water potential of 0.031 BCM need to be created (**Table 22**)

Industrial water requirement Industries are growing at a rapid pace in Haridwar especially in Roorkee and adjoining area and water demand from industries is going to rise in future. It has been estimated that current water requirement from industrial side is **0.013298**BCM which is projected to grow up to 0.013 BCM by 2020. This will also create further burden on existing water potential of Haridwar (**Table 22**)

Water Demand for Power Generation: Since Uttarakhand is Power Surplus state as it supplies power to various states, precise water requirement for power generation of Haridwar could not be estimated.

Total Water Demand of the District for Various sectors: Overall, total water requirement of Haridwar district for variety of stakeholders ranging from agricultural side to industrial use has been estimated to be 1.798 BCM. This requirement has been further distributed as 0.073 (DOMESTIC), 1.645 (Crop), 0.067 (Livestock) and 0.013 (Industrial). It clearly indicates that agricultural and related works are major sectors for water resource utilization.

Table 22 : Total Water Demand of the district for Various sectors

S.No.	Block	Components					Total,BCM
		Domestic	Crop	Livestock	Industrial	Power Generation	
1	**Bhagwanpur**	0.013	0.274	0.013	0.003	0	0.304
2	**Roorkee**	0.014	0.220	0.010	0.003	0	0.245
3	**Narsan**	0.013	0.323	0.010	0.0023	0	0.348
4	**Bahadrabad**	0.0193	0.309	0.017	0.0043	0	0.350
5	**Laksar**	0.011	0.336	0.011	0.0013	0	0.358
6	**Khanpur**	0.003	0.183	0.006	0.00033	0	0.192
	Total	**0.073**	**1.644**	**0.067**	**0.0132**	**0**	**1.798**

Water Budget Budgeting of water resources is an uphill task as it involves many static and variable factors. Nevertheless, they are important for Haridwar district as it will enable to formulate our water and irrigation schemes. Current water requirement of Haridwar district is estimated to be **1.776 BCM (Table 23)** which is projected to rise by **2.132 BCM** by 2020. Thus it would create a water gap of 0.426 BCM which need to be met to achieve our developmental goals.

Table 23 : Water Budget

Name of Blocks	Existing Water availability (BCM)		Total (BCM)	Water Demand (BCM)		Water Gap (BCM)	
	surface water	Ground water		Present	Projected (2020)	Present	Projected (2020)
Bhagwanpur	0.02	0.92	0.94	0.023	0.028	0.005	0.006
Roorkee				0.014	0.017	0.003	0.003
Narsan				0.007	0.008	0.001	0.002
Bahadrabad				0.088	0.106	0.018	0.021
Laksar				0.000	0.000	0.000	0.000
Khanpur				0.000	0.000	0.000	0.000
Total	**0.02**	**0.92**	**0.94**	**0.132**	**0.158**	**0.026**	**0.032**

Chapter-6
Management Strategies

To achieve above objectives, there should be focus on end-to end solution in irrigation supply chain, viz. water sources, distribution network, efficient farm level applications, extension services on new technologies & information etc. Broadly, the focus of should be on:-

a) Creation of new water sources; repair, restoration and renovation of defunct water sources; construction of water harvesting structures, secondary &micro storage, groundwater development, at village level.

b) Promotion of scientific moisture conservation and run off control measures to improve ground water recharge so as to create opportunities for farmer to access recharged water through shallow tube.

c) Promoting efficient water conveyance and field application devices within the farm viz, underground piping system, Drip & Sprinklers, pivots, rain-guns and other application devices etc.

d) Encouraging community irrigation through registered user groups/farmer producers' organizations/NGOs.

e) Farmer oriented activities like capacity building, training and exposure visits, demonstrations, farm schools, skill development in efficient water and crop management practices (crop alignment) including large scale awareness on more crop per drop of water through field days, and extension activities.

Conclusions

Haridwar district having a geographical area of 2360 km^2 lies in the southwestern part of the Uttarakhand state. It has three tehsils viz. Roorkee, Bhagwanpur and Laksar and six development blocks with a population of 1890422 (census 2011). The district forms a part of Indo-Gangetic alluvial plain having master slope towards south. The district is bounded by river Ganga in the east which forms the major drainage system of the district Solani river along with its tributaries are the other major drainage system of the area which drains the central part of the Haridwar district. The average normal annual rainfall in Haridwar district is 1174.3 mm. The district Haridwar can broadly be divided in to four geomorphologic units, the structural hills consisting of middle and upper Siwaliks, the foothills of Siwaliks forming the Bhabar formation. The Bhabar formation is characterized by boulders, cobbles, pebbles, sands of various grade and the clays. As the northern part receives copious amount of rainfall that give rise to seasonal nallas and they carry loads with them from middle and upper Siwaliks and depositing them in the forms in gradational fashion. This process has given rise to the Bhabar formation. These Bhabar are the recharging zone for the aquifer system of the indo gangetic plain. The water level in the entire district generally follows its topography. Bhabar being the recharge zone, here the water levels are very deep. The deepest water level measured here is around 69 meters below ground level in the tube wells drilled in this formation. This Bhabar further south of it is separated by swampy and marshy land where the water is oozing out in the nallas, called spring line, the later merging interceptibly in to the gangatic alluvium. The spring line is sporadic in the Haridwar district. The southern part can be called as older alluvial plain (upper piedmont plain PPU) and the younger alluvium plain (lower piedmont plain PPL). Ground water generally occurs under water table condition in the Bhabar belt although the deeper aquifer in the peripheral portions of this belt may occur under low confined condition due to intercalations of confining clay that usually taped off up with water table rests between 65.92 to 121.95 meters below ground level have yield ranging from 961 lpm to 2730 lpm of water at economic drawdown.

The ground water in the Bhabar belt has presently experiences acute water scarcity; can be developed by using latest techniques. The southern part of the district contains a good thickness of granular material sediments of older alluvium as well as younger alluvium. Science, the aquifer system has three-tier system, each of this aquifer group contains considerable thickness of sand. Sand percentage ranging from 50 to 60% can yield a good amount of water at economic drawdown. Tapping any of the aquifer group, it is quite safe to tap second and third aquifer below 150 meter for further development in the southern part. The upper most aquifer group should be left for shallow borings for the local farmers to use. Some of the areas like Bahadrabad and Roorkee blocks showing deep water level and decline in the water table, here ground water should be utilized precisely by tapping deeper aquifers and further development should be done under planned way and scientific manner.

In Bahadrabad and Bhagwanpur block, Roorkee and Landaura area where the water level is quite deep, rainwater harvesting practice should be adopted in a scientific and planned manner, As it has been observed that around Bhagwanpur township the industrial activities area going on and there are a number of sugar mills in Laksar and Chudiala areas the industrialist should be advised to adopt the root top rainwater harvesting system and waste sewerage treatment plant, so that it may not contaminate the ground water.