केन्द्रीय भूमि जल बोर्ड

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विभाग, जल शक्ति मंत्रालय

भारत सरकार

Central Ground Water Board

Department of Water Resources, River
Development and Ganga Rejuvenation,
Ministry of Jal Shakti
Government of India

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES

NAINITAL DISTRICT
UTTARAKHAND

उत्तरांचल क्षेत्र, देहरादून
Uttaranchal Region, Dehradun

REPORT ON

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES NAINITAL DISTRICT, UTTARAKHAND

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AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES, NAINITAL DISTRICT, UTTARAKHAND

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Executive Summary

- The study area (Nainital District) is situated in SE corner of Uttarakhand State bounded by Almora district in North, Udham Singh Nagar district in South, Champawat district in East and Pauri Garhwal district in West. It lies approximately in between 78º51′ 11.34″ and 79 º 58’ 23.06″ East longitude and 28º58’ 31.84″ and 29º36’ 45.19″ North latitude. The study area has been taken up for aquifer mapping study in AAP 2021-22.
- The total area of Nainital district is 4251 km^2 with an average altitude of 640 m above MSL. The present study area comprises of parts of Nainital district covering an area of 1107.77 sq. km. NAQUIM studies have been carried out in the Ramnagar block (995.00 sq.km), Haldwani Block (112.77 sq. km). The remaining blocks have slope greater than 20% and hence have not been included in the scope of NAQUIM studies.
- The study area receives an average annual rainfall of 1249 mm. Most of the rainfall is received during the period from June to September; July and August being the wettest months of the year.
- The study area may be divided into three geomorphological units namely the Lesser Himalayan Zone, the Himalayan Foot Hill Zone and the Piedmont Alluvial Tract
- Canals and tube wells are main means for the irrigation in the study area.
- Kosi river is the major river in the NAQUIM study area.
- The general flow direction of groundwater is NW- SE in the eastern part of the study area and NE- SW in the western part of the study area.
- There are 12 Number of NHS monitoring stations in the study area, which are being regularly monitored for ground water level and quality.
- To attempt the hydrogeological interpretation of aquifer disposition and its nature within the study area, the data from 12 Nos. of CGWB Exploratory Wells have been analyzed in detail.
- To know the water level and its behaviour with respect to time and space, 12 NHS monitoring wells comprising of dug wells and Handpumps were analyzed.
- For estimation of the quality of ground water, ground water samples from the 12 locations of NHS monitoring stations have been collected during pre-monsoon 2020. The ground water samples were analysed for major chemical constituents at Chemical Laboratory, CGWB, NR, Lucknow.
- The general chemical quality reveals that most of the wells contain low dissolved mineral contents and hence, groundwater in Nainital district is fresh and potable.

- Haldwani block comes under Semi-Critical category while Ramagar block falls under Safe Cateogry with an average Stage of GW Extraction as 59.41 % for the entire district(as per Dynamic Ground Water Resources Estimation 2020)
- Based upon the climatic conditions, topography, hydro-geology of the area, suitable structure for rain water harvesting and artificial recharge to ground water need to be planned and implemented.
- Farm ponds, chalkhal, efficient irrigation practices like drip irrigation and sprinklers can help in water conservation.

CHAPTER – 1

INTRODUCTION

1. Introduction

Central Ground Water Board, Ministry of Water Resources, River Development & Ganga Rejuvenation, Government of India, for mapping and managing the entire aquifer systems in the country has undertaken Micro Level Aquifer Mapping in entire country representing different hydro geological terrains of the country. In Uttarakhand 1107.77 sq km area of Nainital district comprising of Haldwani and Ramnagar blocks has been year marked for Aquifer Mapping during 2021-22 The present report embodies the above objective in parts of the Nainital district having area of 1107.77 Sq. Km, comprising of 2 blocks i.e., Ramnagar and Haldwani. The objective of this flagship project is to establish the methodology to identify and map the aquifers at the micro level in typical multi aquifer system of the alluvial area, to quantify the available groundwater resources, and to propose groundwater development plans appropriate to the scale of demand and aquifer characteristics, and the institutional arrangements for participatory management. The pilot study integrates multiple disciplinary and scientific approaches including remote sensing, hydrogeology, geophysics, hydrochemistry, drilling, ground water modeling and management plans.

1.1 Objectives & Scope

The objectives of the aquifer Mapping are -

i. To define the aquifer geometry, types of aquifer, ground water regime behaviour, and hydraulic characteristics of Multi-layered aquifer systems on 1:50,000 scale in parts of Nainital District.
ii. Finalizing the approach and methodology on which National Aquifer mapping Programme of the entire country can be implemented.
iii. The preparation of micro level aquifer mapping in the study area.

activities of the Aquifer Mapping can be envisaged as follows

Data Compilation & Data Gap Analysis: One of the important aspects 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, analysed, examined, synthesized and interpreted from available sources. These sources were predominantly non-computerized data, which was converted into computer editable formats. On the basis of available data, Data Gaps were identified.

1.2 **Data Generation:** There was also a strong need for generating additional data to fill the data gaps to achieve the task of aquifer mapping. This will be achieved by multiple activities such as exploratory drilling, geophysical techniques, hydro-geochemical analysis, remote sensing, besides detailed hydrogeological surveys.

1.3 **Aquifer Map Preparation:** On the basis of integration of data available from various studies of hydrogeology & state government, aquifers have been delineated and characterized in terms of quality and potential. Various maps have been prepared bringing out Characterization of Aquifers, which can be termed as Aquifer maps providing spatial variation (lateral & vertical) in reference aquifer extremities, quality, water level, potential and vulnerability (quality & quantity) on 1:50000 scale.

1.4 **Aquifer Management Plan Formulation:** On the basis of aquifer characterization, issues pertaining to sustainable aquifer management in the area have been identified. A suitable strategy for sustainable development of the aquifer in the area has been evolved based on the acquired data.

1.2 Approach and Methodology

i. The work plan for the aquifer mapping involved compilation, integration, validation and analysis of the entire existing database at one platform with a view to generate various thematic maps including administrative map, soil, rainfall, land use, geomorphology, geology, hydrogeology etc manually and also by using geo-scientific computer softwares. Data were collected from all concerned agencies for preparing the background information and thus the status of data gap. Greater attention was paid on activities that required generation of additional data to fill the identified gap. Refinements of aquifer disposition will be envisaged based on generation and integration of data. The overall approach and methodology of the aquifer mapping and management plans are presented as flow chart in Fig. 1.1.

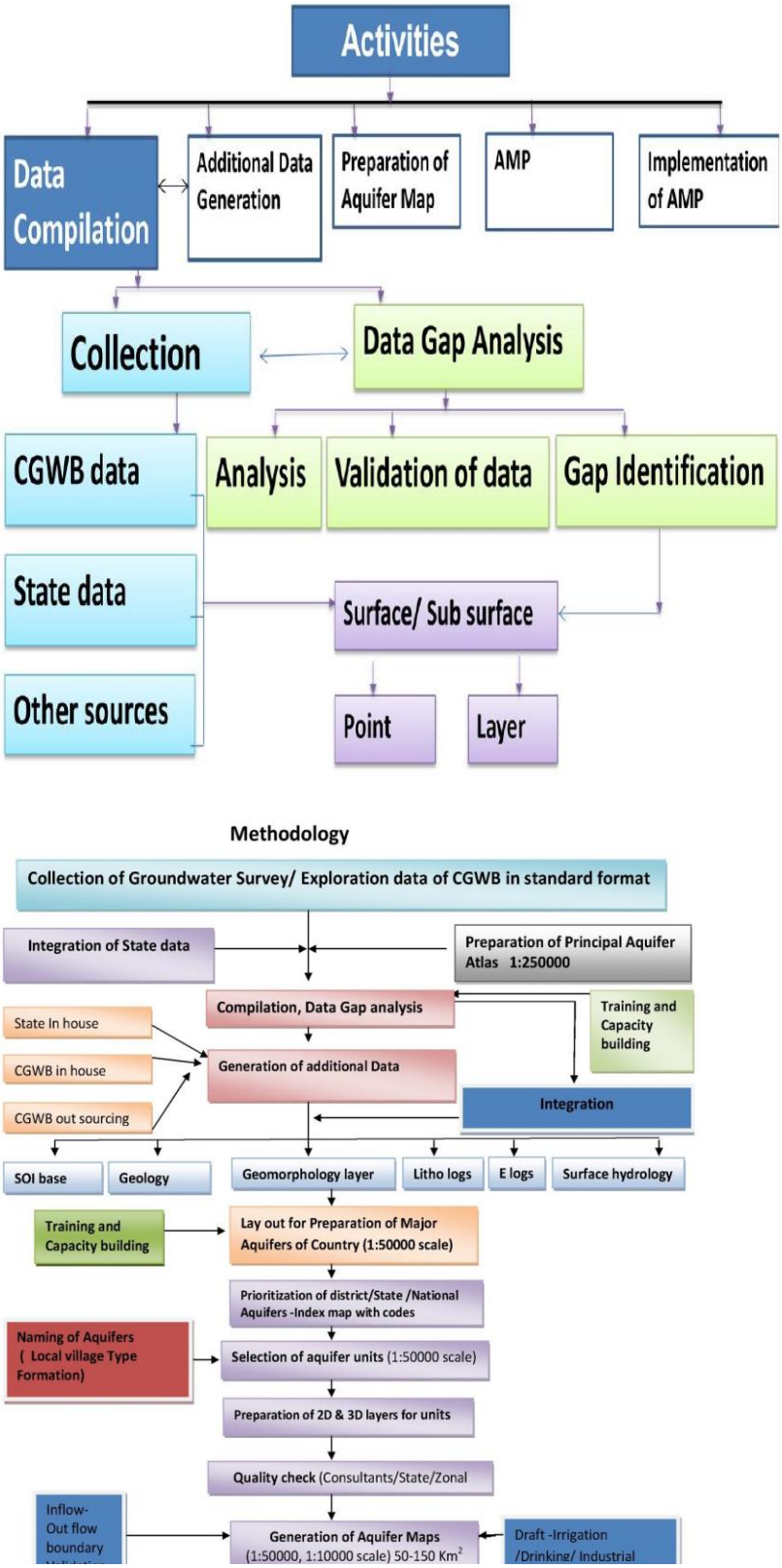


Fig. 1. 1 Methodology of Aquifer Mapping

1.3 Study Area

Nainital District is situated in SE corner of Uttarakhand State bounded by Almora district in North, Udham Singh Nagar district in South, Champawat district in East and Pauri Garhwal district in West. It lies approximately in between 28º58′31″ and 29º36′45″ North latitude and 78º51′11″ and 79º58′23″ East longitude.

Nainital district comprises of eight blocks viz. Ramnagar, Haldwani, Bhimtal , Kotabagh, Dhari, Betalghat, Ramgah, Okhalkanda. Since the major portion of Nainital district i.e., Bhimtal, Dhari, Kotabagh, Ramgarh, Betalghat , Okhalkanda and some parts of Ramnagar and Haldwani blocks falls under hilly category (where slope is more than 20%) so Aquifer management studies is not being carried out in those portion of the district. Ramnagar and Haldwani block of Nainital district and falls in parts of Survey of India toposheets 53K/15, 53O/3, 53O/7, 53O/8, 53O/11, 53O/12 & 53O/16.

The total geographical area of Nainital district is 4064.33 km^2 with an average altitude of 300 m above men sea level. The district comprises of nine tehsils, namely Nainital, Haldwani, Ramnagar, Kaladhungi, Lalkuan, Dhari, Khansayu, Kosiyakutoli and Betalghat. Further, it is divided into eight developmental blocks, viz: Haldwani, Bhimtal, Ramnagar, Kotabag, Dhari, Betalghat, Ramgarh and Okhalkanda. There are seventeen towns and 511 villages in this district. The administrative map of the district is shown in **Fig. 1.2.**

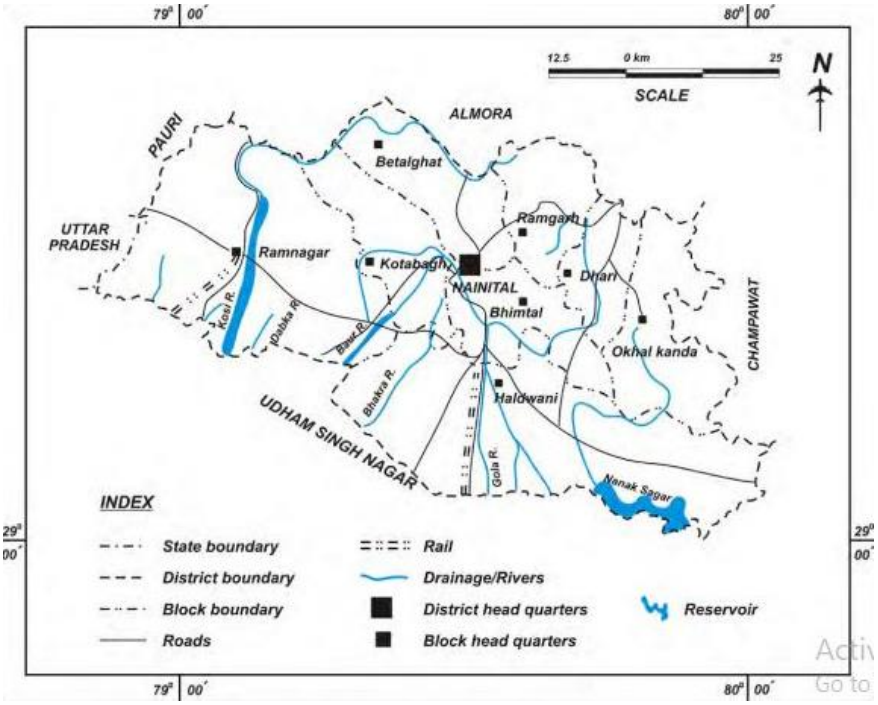


Fig. 1. 2 Administrative Map of Nainital District

1.3.1 Administrative Divisions

The administrative map of study area is shown in **Fig. 1.2.** There are 8 blocks, 9 Tehsils and 1 Municipal Corporation Board in the study area. There is well-distributed presence of villages in the study area (**Table 1.1**).

Table 1. 1 Administrative Division, Parts of Nainital District, Uttarakhand

Sl. No	Block	Villages		
		Inhabited	Uninhabited	Total
1	Haldwani	210	3	213
2	Ramnagar	136	0	136

(Source: Statistical Diary, Nainital, 2020)

1.3.2 Demography (Population since 2011)

The total population of the study area is 219432 (Census: 2011). The average decennial growth rate as per 2011 Census is estimated to be 14.75 %. The average population density is 401 persons/km^2. The block wise break up of total population is mentioned in the **Table 1.2**.

Table 1. 2 Block-wise Population, Haldwani & Ramnagar Block of Nainital District Uttarakhand

Sl. No	Block	Total Population			Present Population Density per Area (km^2)	Increase in Population/Area (km^2) from last decade
		Male	Female	Total		
1	Haldwani	50863	47000	97863	383	-12.45
2	Ramnagar	41487	40070	81557	420	15.13

1.3.3 Industries

The study area is well known for the industries in the Uttarakhand state, because of the topographical conditions and plenty of availability of resource like electricity, water, and transport communication etc. The number of small–medium scale industries being 902. Block wise list of industries is mentioned in the **Table 1.3.**

Table 1. 3 Block-wise list of Industries, part of Nainital District, Uttarakhand

S. No	Block	No of Small-Scale Industries	No of Workers Employed
1	Haldwani	462	2331
2	Ramnagar	440	2364
Total		**902**	4695

(Source: Statistical Diary, Nainital, 2020)

1.3.4 Irrigation

Water is a scarce resource in plenty. It can be utilized to the optimum level by adopting rational and prudent techniques of water conservations and management in this agricultural belt. Rainfall is characterized by variability in space and time, as most of it received in the three months of the year, while the use is spread over the entire year. The 90.86 Km^2 of Haldwani block and 85.19 Km^2 of Ramnagar block is irrigated by groundwater through Canals/Tubewells/handpumps/Wells. So, the main source for irrigation in the study area is Groundwater as per the data available.

Table 1. 4 Block wise sources of Irrigation and Irrigated Area (ha), part of Nainital District, Uttarakhand

S. No	Block	Area irrigated (in ha)						
		By Canals	By Tube wells		Wells	Ponds	Others	Total
			Govt.	Private				
1	Haldwani	5926	3160	160	2950	0	0	9086
2	Ramnagar	6702	1817	39	0	0	0	8519
		12638	4977	199	2950			17605

(Source: District Statistical Diary, Nainital, 2020)

1.3.5 Drinking Water Supply

The primary source of drinking water supply and domestic needs are met through hand pumps, tube wells, canals, and dug wells. The block-wise drinking water supply status, total number of structures installed and total population benefited in the study area given in **Table 5**.

Table 1. 5 Rural Drinking Water Supply Schemes, Ramnagar and Haldwani blocks of Nainital district, Uttarakhand

S. No	Block	Hand Pumps Indian Mark-II	
		Villages Covered Under Drinking Water Facility	Benefited Population
1	Haldwani	126	79695
2	Ramnagar	210	97985

(Source: District Statistical Diary, Nainital, 2020)

1.4 Climate and Rainfall

The district enjoys sub-tropical to sub-humid climate. The maximum temperature in the plain areas ranges from 42ºC to 46ºC and the minimum between 1°C and 9°C. In the hilly areas the minimum temperature falls below freezing point up to 0.9°C during winter. The annual normal rainfall in the district is 1285 mm and average annual rainfall is 1249 mm (as per Nainital District diary 2019-2020).

Climatically, Haldwani block has sub-tropic climate conditions. The maximum temperature in the Haldwani block ranges from 38ºC to 40ºC and the minimum between 5°C and 10°C. The average annual rainfall approximately 1505 mm. The intensity of rainfall generally increases from north to South.

Ramnagar block experiences sub-tropical climatic conditions. The mean annual rainfall is 205 cm and the mean annual temperature varies from 15°C to 35° C. Only the months of May and June are hot though they are seldom oppressive.

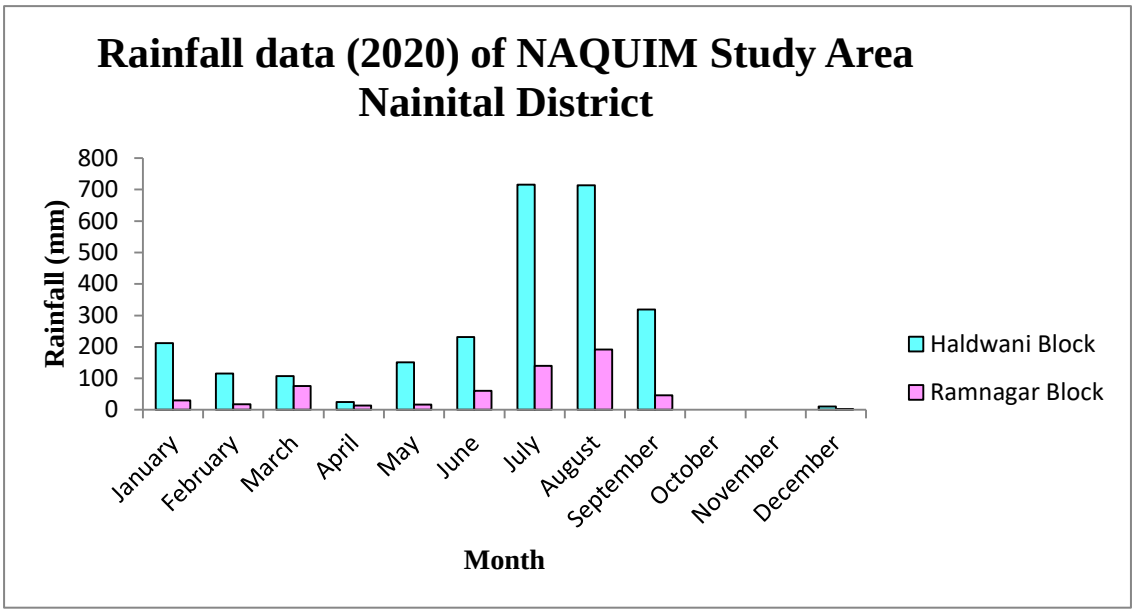


Fig. 1. 3 Bar Graph showing Annual Rainfall in Haldwani and Ramnagar block of Nainital district

1.5 Geomorphology

Nainital district comprises of three broad physiographic divisions, from north to south viz., the Lesser Himalayan Zone, the Himalayan Foot Hill Zone and the Piedmont Alluvial Tract corresponding to the major geo-tectonic sub-divisions of the Himalayas. The physiographic map of Nainital district is shown in Fig. 2.4.

1.5.1 Lesser Himalaya

This zone comprises of deep valleys and distinct terraces, both of alluvial and glacial origin. The terrain is overall rugged with sudden rise and/or fall in relief and slope with a maximum elevation of 2610 m above Mean Sea Level. The zone is extensively filled up by fluvial terrace deposits. The regional trend of major ridges is NNW-SSE.

1.5.2 The Himalayan Foothill Zone

This zone runs in NW-SE direction with a maximum elevation of 1677 m above Mean Sea Level. The lower Siwaliks are truncated towards south by major/minor structural discontinuities. The slopes are relatively moderate, with flat-topped hills.

1.5.3 Piedmont Alluvial Zone

At the Himalayan foothills, extensive zone of Recent sediments was deposited by the streams running downhill which can broadly be classified as Bhabar and Tarai. These zones extend in the NW-SE direction along the Himalayan foothill and are separated with each other by spring line. The slope of this belt gradually decreases towards south and becomes almost flat beyond the spring line. The gradients vary from 9.5 to 17 m/km. The soils are natural, dynamic, heterogeneous, non-renewable resource, which support plant and animal life. The tract of Nainital district consists of outward succession of ridges viz; Lesser Himalaya and Siwaliks of decreasing height. These hills possess very little leveled land. The soils have developed from rocks like granite, schist, gneiss, limestone, phyllites, shales, slate, sand stone etc. under cool and moist climate.

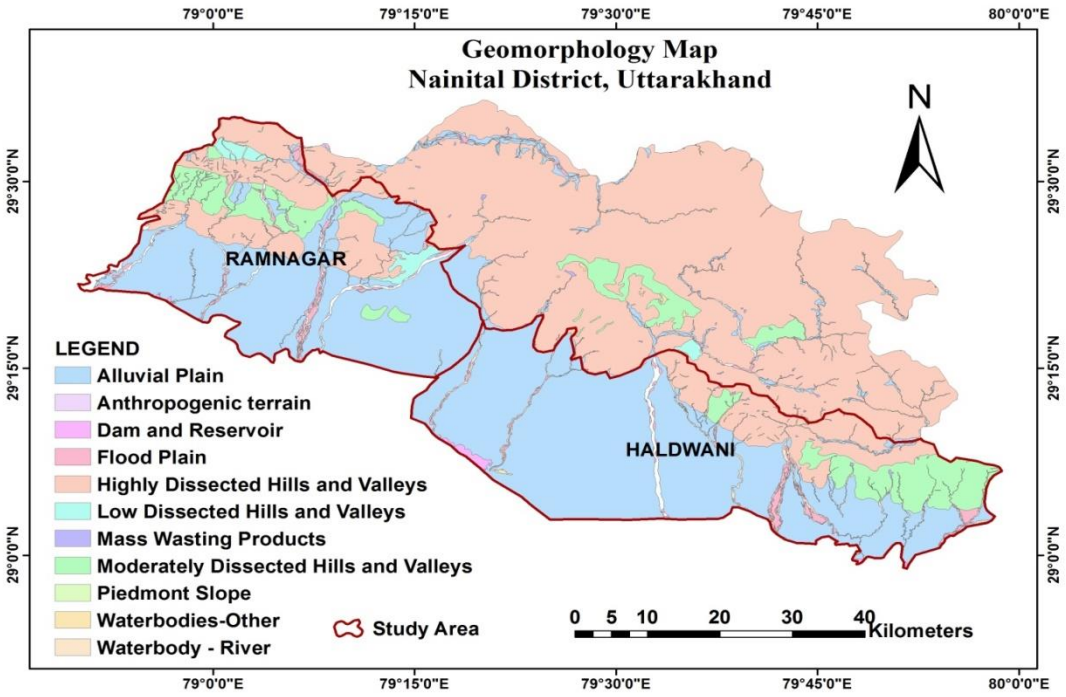


Fig. 1. 4 Geomorphology Map of Nainital district

1.6 Soil

Very steep to steep hills and Glacio-fluvial valleys are dominantly occupied by very shallow to moderately shallow excessively drained, sandy-skeletal to loamyskeletal, neutral to slightly acidic with low available water capacity soils. They have been classified as Lithic/Typic Cryorthents. These soils are in general under sparse vegetation. The Lesser Himalayan range is mainly composed of highly compressed and altered rocks like granite, phyllites, quartzite etc. and a major part of it, is under forest. Intermittent sparse patchy terraced cultivation is also practiced on fairly steep hill slopes whereas dry and wet cultivation are prevalent on the uplands and low-lying valleys respectively. The broader valley slopes dominantly have deep, well drained, fine-loamy, moderately acidic and slightly stony.

CHAPTER – 2

DATA AVAILABILITY & DATA GAP ANALYSIS

2 Data Availability & Data Gap Analysis

The primary data such as water levels, quality, and lithological inputs were available with CGWB, UR, Dehradun and utilised as baseline data. However, the ancillary data such as numbers of ground water abstraction structures, irrigation facilities, rainfall etc., have been collected from the various State govt. departments and compile

2.1 Data Collection and Compilation

The data collection and compilation for various components was carried out as given below.

i. Hydrogeological Data – Current and historical water levels along with water level trend data from 12 monitoring wells in Nainital district
ii. Hydrochemical Data – Ground water quality data from the 12 NHS monitoring stations of Pre-monsoon and Post-monsoon 2020 has been collected and compiled
iii. Exploratory Drilling – Ground water exploration data of twelve existing exploratory wells was complied.
iv. Geophysical Data – 54 nos. of Vertical Electrical Soundings (VES) were conducted in this area.
v. Hydrology Data – Data on various irrigation projects, their utilisation status, number of ground water abstraction structures and area irrigated from Irrigation department were compiled.
vi. Hydrometeorological Data - Rainfall data from IMD were complied.

2.2 Data availability and data gap analysis

After taking into consideration, the data available with CGWB on Ground Water Exploration, Geophysical survey, Ground Water Monitoring Wells (GWMW) and Ground Water Quality, the data adequacy were compiled. The requirement, availability and gap of major data inputs i.e., exploratory wells, geophysical data, GWMW and ground water quality data are detailed in the **Table 2.1.** Based on Data Gap Analysis, all the necessary data was generated as discussed below.

Table 2. 1 Data Gap Analysis in establishing Exploratory Wells & piezometer in the Study Area

Exploratory data available	Requirement of additional exploratory data	Monitoring data available
12	14	12

2.2.1 Ground Water Exploration

As seen from **Table 2.1**, exploratory data is required at 14 locations. However, lithology of 12 locations of the district is available with the CGWB, UR, Dehradun that has been used for the compilation of the report. (Annexure 1)

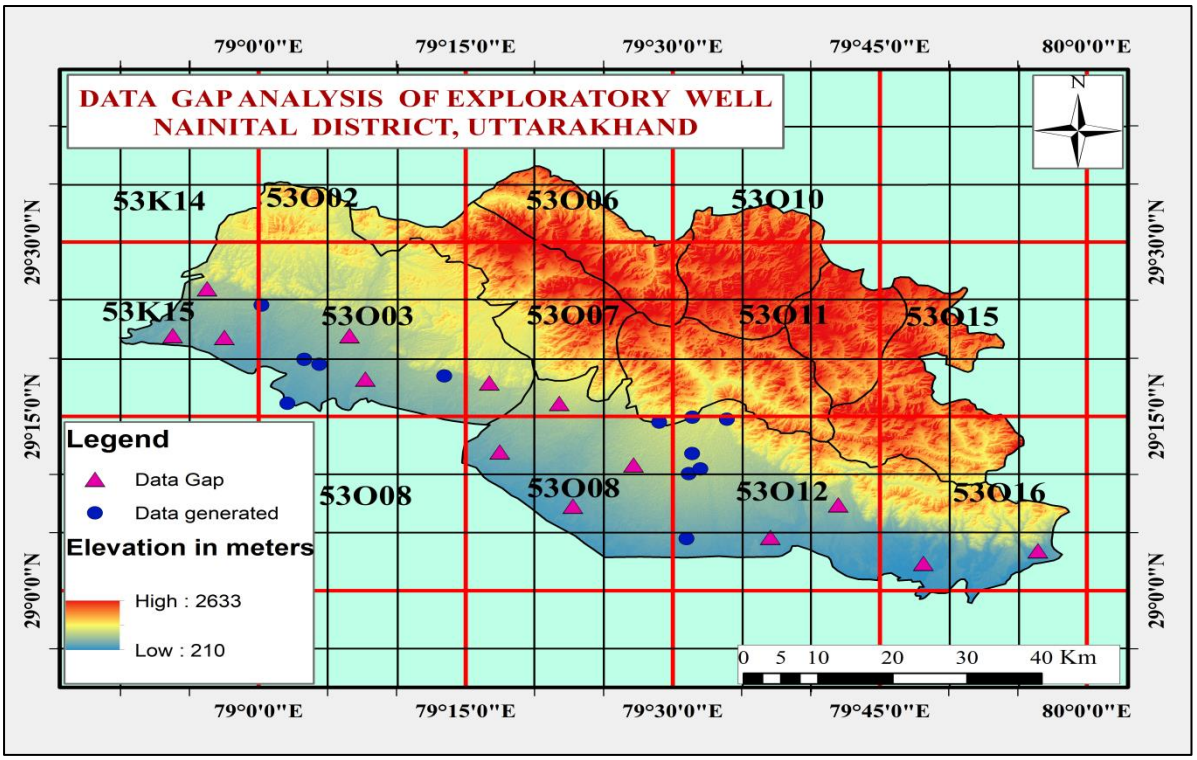


Fig. 2. 1 Data Gap Analysis of Exploratory Wells in Nainital district

2.2.2 Geophysical data

Total 54 (Haldwani block-38 nos., and Ram Nagar block -16 nos.) VES were conducted in Haldwani and Ram Nagar block of Nainital district. The surveyed area comprises of a horizontally layered sequence of clay, silt, sand, gravels, pebbles, boulders, fracture, weather, sandstone, quartzite, Granite, Geiness, phyllites and slate

2.2.3 Ground Water Quality

Ground Water Samples were collected from 12 NHS locations of the study area and the samples were analysed for the basic as well as heavy metals at the Chemical Laboratory of CGWB, NR, Lucknow.

2.2.4 Land Use

Land use and land cover have direct linkage to the water demand of any area. The most reliable land use statistics are available from Statistical Diary of Nainital (2020), which provides block wise information. The block wise land use pattern is given in the **Table 2.2.** Net sown area is 181.94 Km^2 and area sown more than once in the year is 150.63 Km^2. Area under Rabi and Kharif crops are 136.0 Km^2 and 169.91 Km^2, respectively. The principal source of assured irrigation is by wells and tube wells, which together account for about 76% of the total irrigation.

Table 2. 2 Block-wise Land Use Pattern, Parts of Udham Singh Nagar and Nainital District, Uttarakhand

S. No	Name of Block	Area (ha)	Forest	Present waste land	Other waste land	Infertile Non-agricultural land	Other uses	Gardens shrubs bushes	Net sown area	Area sown more than once	Gross Sown area		
											Rabi crops	Kharif crops	Zaid crops
		Hectare (Ha)											
1	Haldwani	22369	9933	473	503	68	1388	1	9404	8270	7139	8600	1934
2	Ramnagar	21245	9814	90	523	59	1281	10	8790	6793	6561	8391	630
	Total	43614	19747	563	1026	127	2669	11	18194	15063	13600	16991	2564

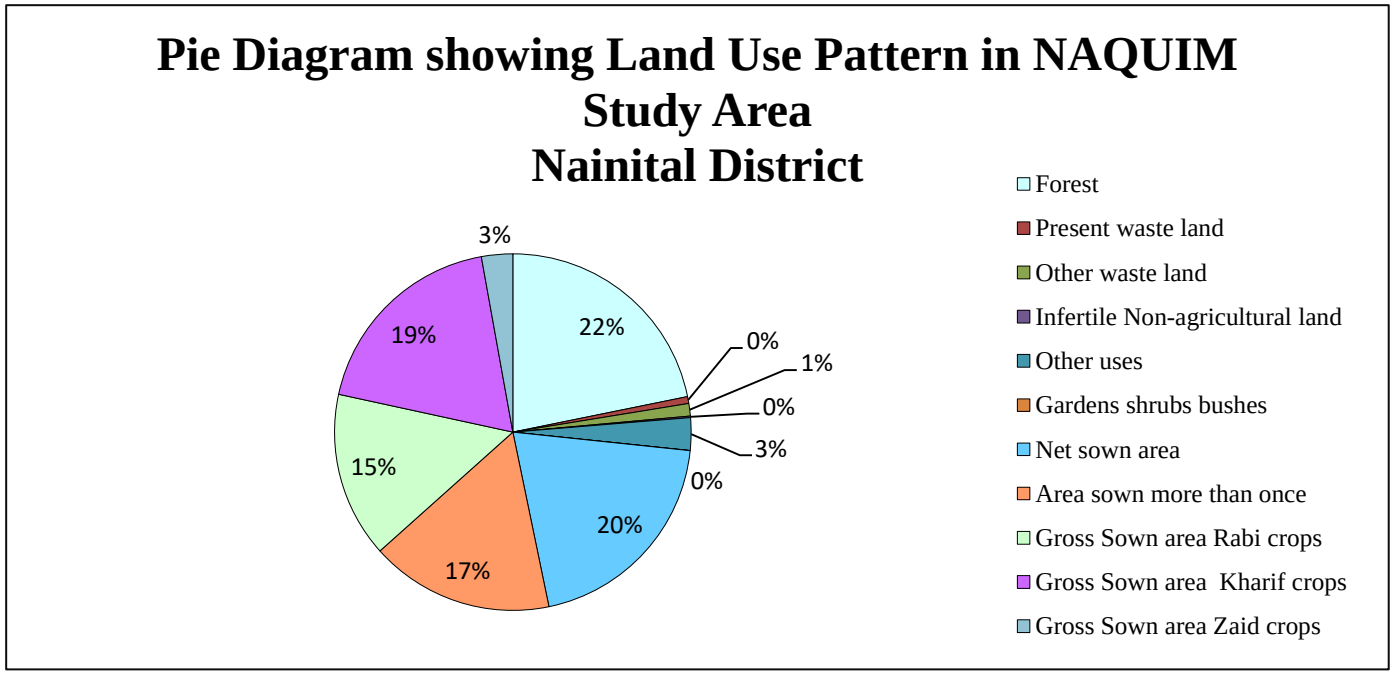


Fig. 2. 2 Pie Diagram showing Land Use pattern in NAQUIM study Area

CHAPTER – 3

DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

3 Data Interpretation, Integration and Aquifer Mapping

The data collected and generated on various parameters viz., water levels, water quality, exploration, aquifer parameters, geophysical, hydrology, hydrometeorology, irrigation was interpreted and integrated. Based on this the various aquifer characteristic maps on hydrogeology, current and long-term water level scenario, ground water quality, 2-D and 3-D sub surface disposition of aquifers by drawing fence and lithological sections, resource estimation, aquifer maps were generated and as discussed in details.

3.1 Geology

Nainital district can be classified into three broad geotectonic divisions namely, the Lesser Himalayas, the sub-Himalayas and the Piedmont alluvial plains. Each of these divisions is characterized by distinct rock types of varied geological age, structural trends, tectonic setting and geomorphic features.

3.1.1 Lesser Himalaya

The Lesser Himalayan formations occupy almost one third area of the district. These formations comprise dominantly of unfossiliferous metasedimentary sequences along with low to medium grade metamorphics ranging in age from Precambrian to Palaeogene. The main rock types are granite, granodiorite, phyllites, slates, quartzites, schists and gneiss. The Krol and Blaini formations comprise mainly of sandstones, limestones and quartzites.

3.1.2 Outer Himalayan Foothill Zone

This zone can be classified into the Lower Siwaliks, Middle Siwaliks and the Upper Siwaliks.

Lower Siwaliks: The lower Siwaliks are characterised by hard, massive, grey to brownish grey sandstones interbedded with grey to maroon clays. They form the outermost zone in the Nainital Himalayas and occasionally exhibit local structural discontinuities. The dip is usually northwards.

Middle Siwaliks: The middle Siwaliks are characterised by massive light grey micaceous sandstones. They exhibit sporadic patterns of cementation at different stratigraphic intervals.

Upper Siwaliks: The Upper Siwaliks are constituted of pebbles, cobbles, boulders, conglomerates and clay lenses. The pebbles and boulders are mostly quartzitic. Thin lenses of grey to light green colour clays are common. Outcrops of upper Siwaliks are exposed in the western part between Kaladhungi and Ramnagar. Intermontane Valleys: Small (~ 25 km long and 10 km wide) intermontane valleys locally known as "Kota Doon" occur within the Sub-Himalayan Siwaliks trending in NNW-SSE direction. The epispastics mainly comprise of boulders, pebbles, cobbles, granules, sands & clays of varied composition.

3.1.3 Piedmont Alluvial Plains

This zone is broadly classified into the Bhabar and Tarai formations, which are separated by the spring line. Bhabar Formation: The formation is mainly comprised of poorly sorted unconsolidated sediments viz, cobbles boulders, gravel, pebbles, sand and silt with intervening clay layers. The lithological constituents are of heterogeneous nature viz., basic, acid and intermediate along with epiclastics and metamorphiclasts. Clay lenses are of limited extent. The belt exhibits NW-SE elongation. Its northern boundary has an abrupt structural contact (Main Boundary Thrust) with lower Siwaliks. The width of the belt is quite variable. The maximum width (about 21km) is in Haldwani – Kichha (Udham Singh Nagar) section. Tarai Formation: Tarai formation consists of sand, clay, silt, sandy clays and occasionally gravel. Clay beds predominate over sand beds. The northern limit of the belts is the spring line, separating it from Bhabar. The Tarai deposits represent the finer washes out material brought by the streams from the hilly tracts and are evenly sorted.

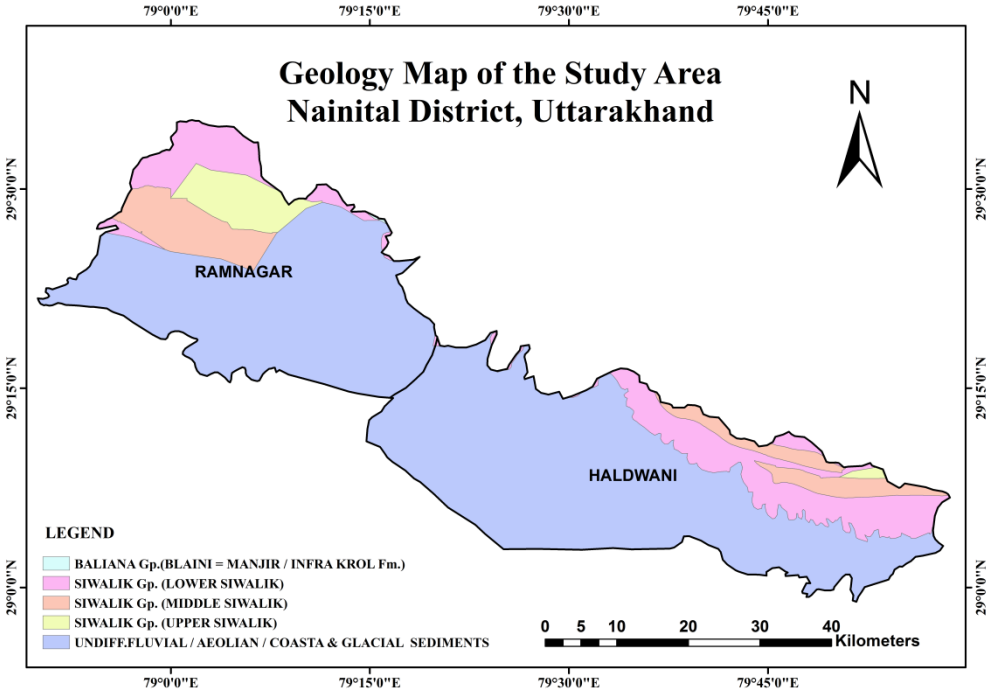


Fig. 3. 1 Geology Map of NAQUIM Study area in Nainital district

3.2 Hydrogeology

Information on hydrogeology of the study area is obtained from the district brochure of Nainital district. The geotectonic setup and physiography vary enormously within a limited geographical area controlling the occurrence, movement and behavior of ground water. On the basis of general morphology and geologic setting, the entire district can be broadly classified into two distinct parts viz.

1 Hard Rock Terrain and

2. Piedmount Alluvial Tract with reference to occurrence and yield of groundwater.

3.2.1 Groundwater conditions in hard rock terrain

More than 55% of the geographical area of Nainital district is underlain by the Outer Himalayan foot hill zone and Lesser Himalayan formations comprising mainly of sand stone, mudstone, shale, clay lenses, quartizites, slates, phyllites and gneisses. These rock masses have poor primary porosity. These rocks store and yield adequate volume of water only when secondary inter granular porosity develops on account of weathering and disintegration along planes of weakness. The occurrence and movement of ground water is primarily controlled by the presence of structural disjunction, geometry and spacing, disposition in space, interconnectivity, and depths to which they pervade the host rocks. The primary source of recharge, in this region, is precipitation. Substantial amount of rainwater

percolates down the exposed fractures, fissures, discontinuity planes and weathered mantle cover by infiltration and is stored as ground water. The various rock formations of this region are broadly grouped into three hydrogeological units, which are described below.

(i) High Potential Unit

The unconsolidated and semi consolidated fluvial and colluvial valley fill deposits along the major and minor rivers such as Kosi, Gola, Bhakra and Dabka are highly permeable which are capable of holding significant quantities of groundwater in unconfined condition. Highly weathered rock masses further add to a profound increase in the ground water potential in the area. Cavernous limestones and dolomites in the vicinity of Nainital Township are well recognized as high potential aquifers. Groundwater oozes out of these formations in the form of springs. This spring water may be harnessed for supplying water to some of the water scarcity areas. The Upper Siwaliks are the most permeable in the entire Siwalik succession.

(ii) Moderate Potential Unit

Highly fractured and jointed rocks with overlying weathered mantle of rock waste that overlie gentle to moderate slopes come under this category. These rocks are mainly slates, phyllites, schists etc. of Almora group, Ramnagar group and Bhimtal volcanics lying around Bhimtal, Bhowali and northeastern parts of the district. Permeable sandstones of middle Siwaliks may also be grouped in this category.

(iii) Low Potential Unit

This unit primarily consists of massive granitoids, gneisses, quartzites and shales at higher reaches with almost nil or little secondary interstices. Springs are the main source of drinking water in this unit where discharges are variable.

3.2.2 Groundwater conditions in the Piedmont Alluvial tract

The sediments belonging to the Quaternary age mainly consist of loose, poorly sorted, unconsolidated boulders, cobbles, pebbles, gravels, coarse to medium sand and clay. Composition of these sediments is heterogeneous in nature and cover around 40 – 45% of the geographical area of the Nainital district. The alluvial tract is divided into the Bhabar and Tarai zones.

(i) Bhabar zone

The Bhabar formation is essentially coalesced piedmont fans, which have resulted in the formation of piedmont alluvial plains. These are primarily the deposits from braided channel system. This highly permeable zone lies in an elongated trough in NW – SE direction with the

width ranging from 4 to 20 km. This unit gradually merges with the Tarai zone towards south. The general gradient of the Bhabar tract varies between 10m/km to 20m/km. Groundwater in this belt occurs under unconfined conditions. Depth to water levels generally varies between 40 and 75 m bgl during Pre-monsoon period 2007. The deepest water level, 173.71 m bgl, has been recorded in a tubewell at Paniyali (Haldwani). In the wells tapping the perched aquifers, water levels generally rest within the depth of 10 m bgl. The depth to water table gradually decreases towards south. The elevation of water table varies from 250 to 300m above MSL.

(ii) Tarai zone

The Tarai belt consists predominantly of fine sediments comprising of clay and silts with well-sorted granular material such as sand, gravels and occasional boulders and cobbles. The sand and gravel associated with fine materials constitute the principal aquifers, which are normally under confined condition. These aquifers upto a great extent are connected with the thick aquifers of the Bhabar tract, which serves as the recharge area for this zone. Groundwater occurs under unconfined to confined conditions. The depth to water in shallow unconfined aquifers ranges from 2 to 6 m bgl with average seasonal fluctuation of 2-4 m. The water table slopes towards south.

3.3 Hydrogeological Interpretation

To attempt the hydrogeological interpretation of aquifer disposition and its nature within the study area, the data from 12 Nos. of CGWB Exploratory Wells have been analysed in detail and the litholog data has been enclosed in Annexure 1.

In order to study the subsurface disposition of the aquifer system, fence diagram (**Fig. 3.2**) and three-dimensional stratigraphic model (**Fig. 3.3**) have been prepared using CGWB Exploration data keeping in mind the detailed lithological variations and overall stratigraphy encountered in the study area. Locations of these wells are shown in the Index Map (**Plate-I**).

3.3.1 Fence Diagram

To study the disposition of aquifers, 12 nos. of CGWB exploratory well data were considered. The entire lithological successions encountered in all the wells have been grouped into three major lithological types i.e., **Surface soil + Boulders**, **Sand + Gravels + Pebbles and Clay**. Review of the fence diagram (Fig 3.2) reveals that the lithological units are occurring in cyclic repetitions with varying proportions of clay. A detailed perusal of the Fence diagram indicated that the proportion of clay content is high in the Western part of the district. Sand, gravels and pebbles form the major aquifer system of the study area and are considered to be the potential zones which are separated by clay layers of varying thickness as shown in Fig 3.2.

Perusal of Fig 3.2 reveal that the nature of the aquifer system of Nainital district varies from unconfined aquifer to semi-confined aquifer.

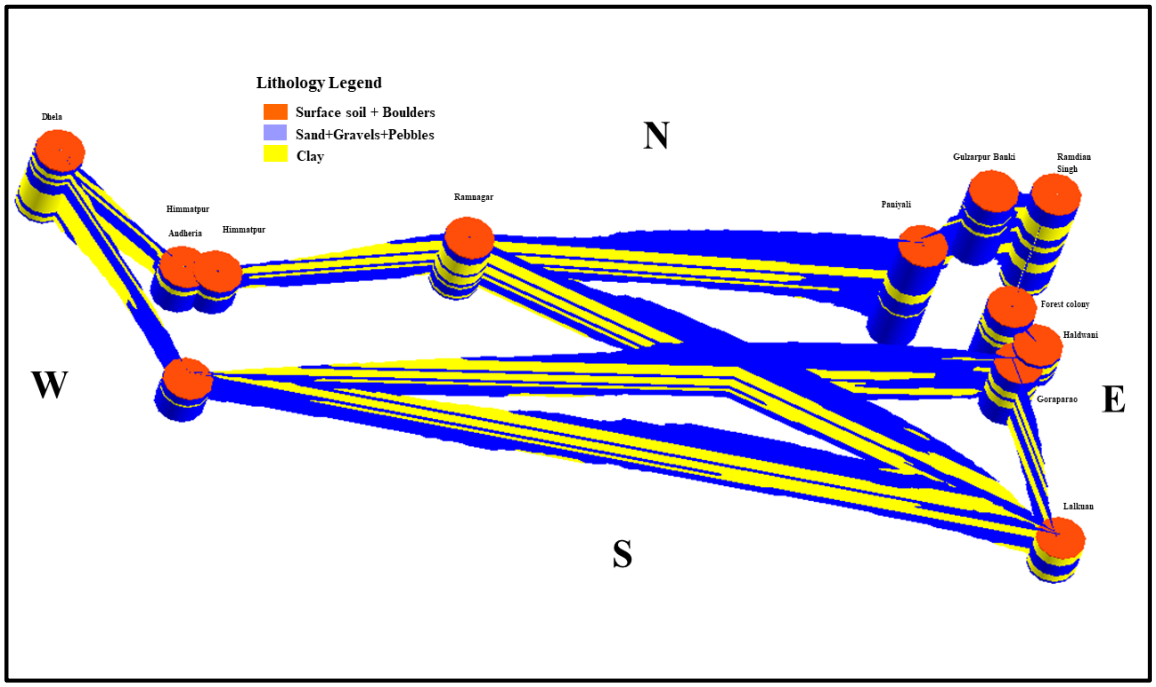


Fig. 3. 2 Fence diagram Depicting Sub-surface lithological variation in the Study area

In the SE part of the district (Ramnagar block) the aquifer system is mostly unconfined to semi confined in nature with thickness of clay layer as one moves westward. Variations of thickness of granular zones and clay layers have been interpreted through various lithological sections.

The stratigraphy model (Fig. 3.3) reveals the overall aquifer disposition of the district and its variation in lithology with respect to space.

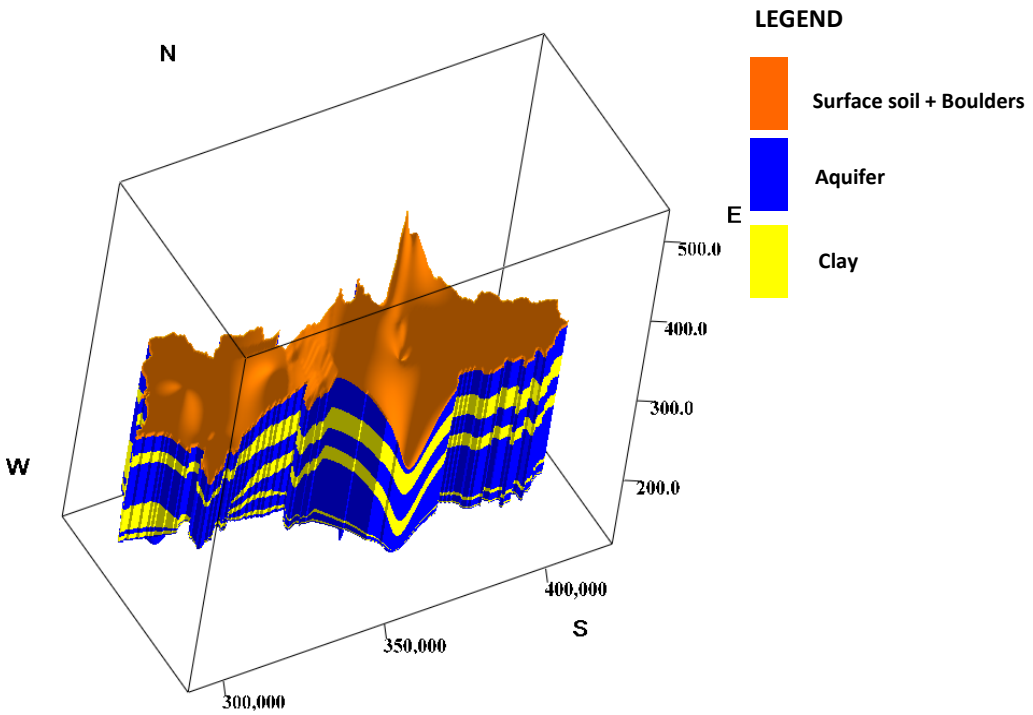


Fig. 3. 3 Stratigraphic model showing aquifer disposition of the study area

3.3.2 Geological Cross Section

Section-1 (Dhela - Himmatpur Andheria - Himmatpur – Paniyali - Gulzarpur Banki-Ramdian Singh)

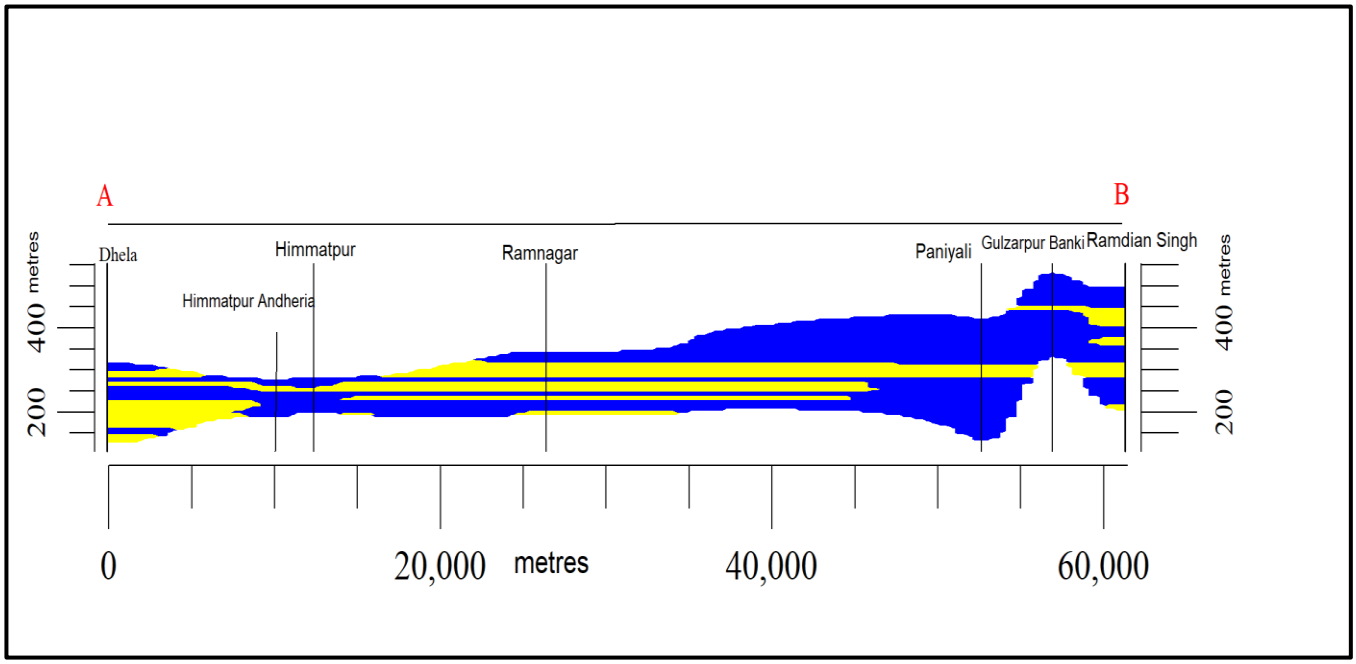


Fig. 3. 4 Section depicting sub-surface Lithological variation from Dhela to Ramdian Singh

This section stretching approximately 60 km in north west to south east direction of the study area (Ramnagar and Haldwani blocks of Nainital District) covering Dhela - Himmatpur Andheria - Himmatpur – Paniyali - Gulzarpur Banki-Ramdian Singh**. Fig. 3.4** clearly shows that the clay proportion gradually decreases as one moves from the East to West. The potential zones showing non uniform thickness varying from eastern to western part of the section.The groundwater quality is good and fit for drinking, domestic and irrigation purposes.

Section-2 (Pipalsana – Ramnagar – Paniyali – Gulzarpur Banki – Ramdian Singh)

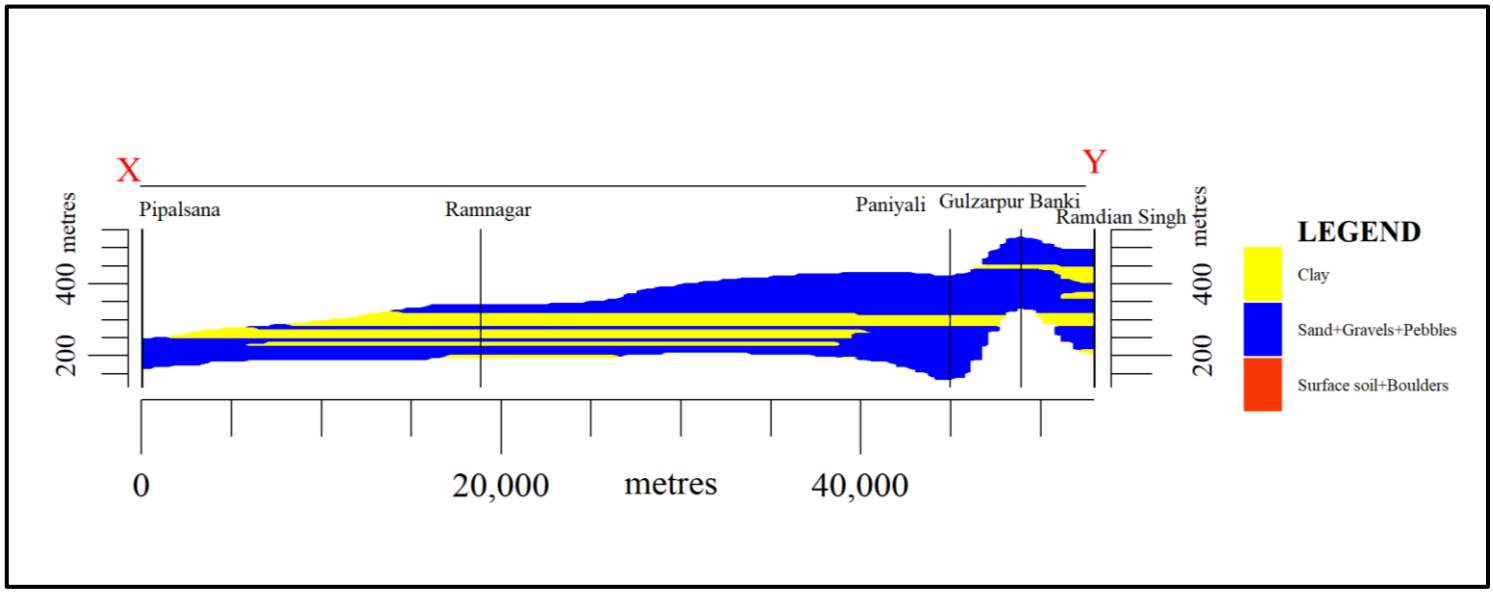


Fig. 3. 5 Section Depicting Sub-Surface Lithological variation from Piapalsana to Ramdian Singh

This section stretching approximately 50 km in north west to south east direction of the study area (Ramnagar and Haldwani blocks of Nainital District) covering Pipalsana Ramnagar – Paniyali - Gulzarpur Banki-Ramdian Singh**. Fig. 3.5** clearly shows that the clay proportion gradually decreases as one moves from the East to West. The potential zones encountered showing varying thickness. The groundwater quality is good and fit for drinking, domestic and irrigation purposes.

Section-3 (Ramdian Singh – Forest colony – Haldwani – Goraparao – Lalkuan)

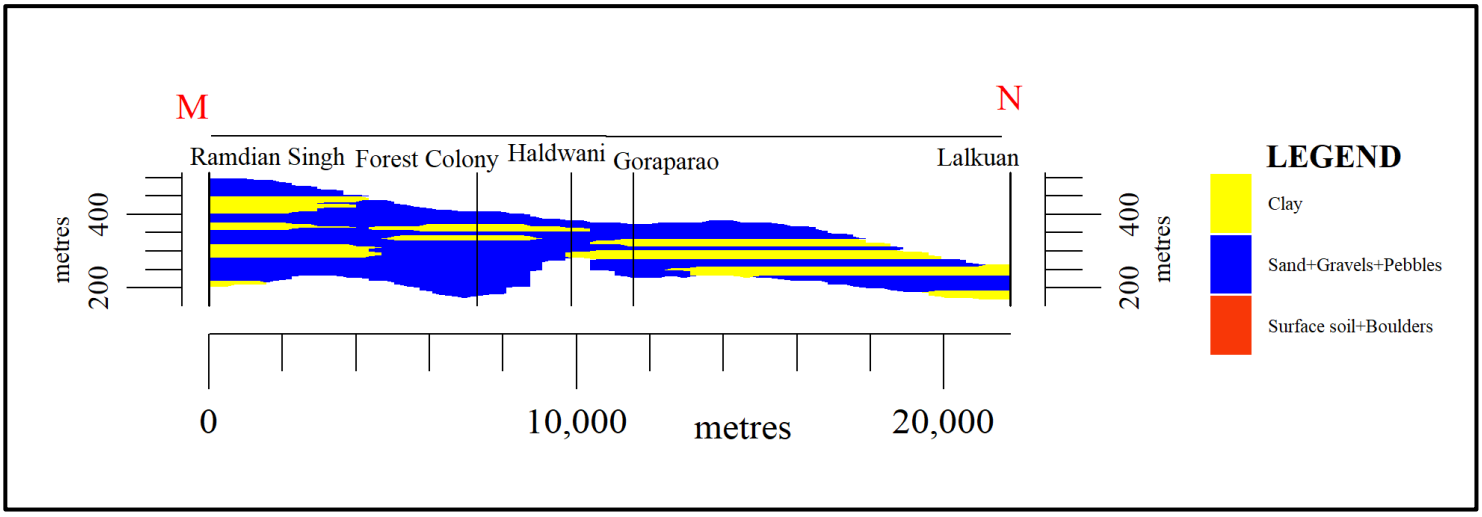


Fig. 3. 6 Section Depicting Sub-Surface Lithological variation from Ramdian Singh to Lalkuan

This section stretching approximately 60 km in north west to south east direction of the study area (Ramnagar and Haldwani blocks of Nainital District) covering Ramdian Singh Forest colony-Haldwani – Goraparao - Lalkuan**.** Fig. 3.6 clearly shows that the clay proportion gradually decreases as one moves from the North to South and the potential granular zones are of different thickness.The groundwater quality is good and fit for drinking, domestic and irrigation purposes.

3.3.3 Occurrence of Ground Water and Movement of Groundwater

Gravels are highly porous and they have a significant permeability. Groundwater occurs under unconfined and semiconfined conditions. The shallow aquifers occur under unconfined conditions, while deeper aquifers occur under semi-confined state of disposition. The confining layers are impermeable clay beds.

In a groundwater regime, equipotential lines i.e., the line joining points of equal head on the potentiometric surface are drawn based on the area of variation of the head of an aquifer. Water table contour map of the study has been prepared **(Fig. 3.7)** on the basis of ground water level data of already established NHS monitoring wells. Based on the Water table elevation, ground water flow directions are demarcated and are shown using arrow symbol. The altitude of water table in the area varies from 224 to 534 metres above mean sea level for aquifer system of the area.

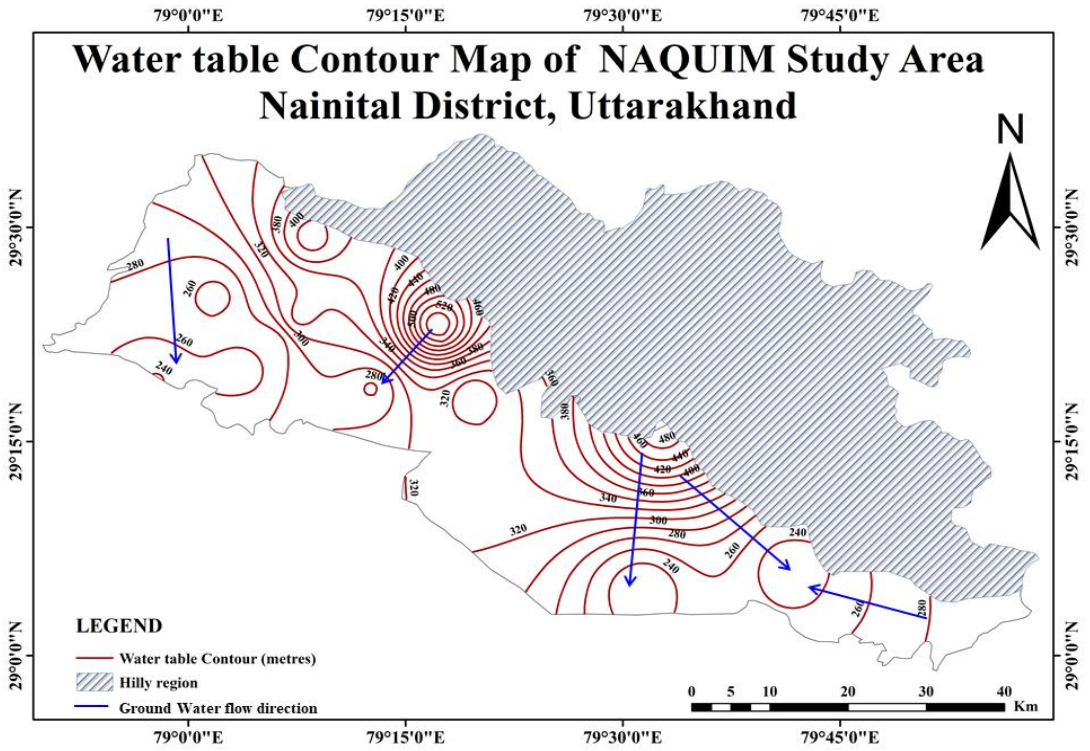


Fig. 3. 7 Water table Contour map of the Study area showing directional movement of groundwater

Sub-surface lithological information is obtained from the available reports in the office. The exploration detail of twelve nos. of well within the study area is available and attached in Annexure 1.

3.3.4 Depth to Water Level

The water levels are being monitored through the Groundwater Monitoring Stations (GWMS) 4 times a year i.e., May, August, November (2020) and January 2021. The Depth to Water Level (DTW) maps have been prepared based on 12 Ground Water Monitoring Stations (GWMS) (3 dug wells tapping the shallow aquifer and 9 Hand pumps tapping the deeper aquifers). The groundwater occurs under water table condition near surface and occurs under unconfined to semi-confined condition at deeper level. The block wise details of GWMS are given in **Table 3.1** and the location of the monitoring stations is plotted in **Fig. 3.8.**

Table 3. 1 Block-wise Ground Water Monitoring Stations (GWMS) in Haldwani and Ramnagar blocks of Nainital District, Uttarakhand

Sl. No	Block Name	Ground Water Monitoring Stations (GWMS)
1	Haldwani	NTL-03-DW (Lalkuan), NTL-HP-06 (lamachaur), NTL-HP-07 (Kaladungi), NTL-HP-08 (Kathgodam), NTL-HP-10 (Khatbans)
2	Ramnagar	NTL-HP-02 (Belparao), NTL-HP-04 (Peeru Madara), NTL-05-DW (Maldhan Colony), NTL-HP-03 (Dhela), NTL-HP-01 (Ramnagar), NTL-HP-09 (Garjiya), NTL-HP-05 (Dhoniya), NTL-HP-11 (Chilkiya)

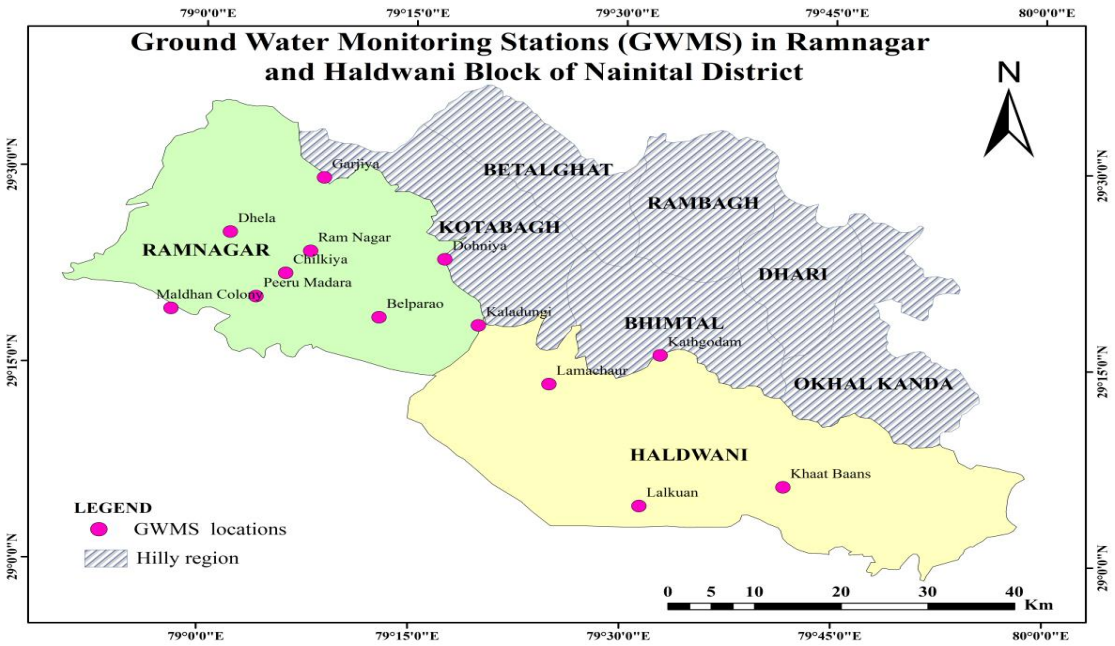


Fig. 3. 8 Ground Water Monitoring Stations in Haldwani and Ramnagar block of Nainital district, Uttarakhand

In the Study area, around 12 NHS well are monitored for water level and water quality analysis purpose. The depths to water level maps have been prepared for pre-monsoon and post monsoon season of the period 2020-2021 (**Figure 3.9, 3.10**). A study of pre-monsoon water level data reveals that the around 58 % NHS wells of the study area is having water level more than 20 m bgl. During Pre-monsoon 2020, deepest water level of 65.83 m bgl has been observed in Dhela of Ramnagar block of the district whereas shallowest water level of 3.68 m bgl has been observed in Garjiya of Ramnagar block of the district.

A study of Fig. **3.9** indicates that the major part of the the study area shows water level deeper than 20 m bgl. The water level in the depth range of 10-15 m bgl is observed in North West portion of the district i.e., in the Ramnagar block and rimming the water level of 5-10 m bgl and 0-5 m bgl water level in the Ramnagar block of Nainital district.

A study of post-monsoon water level data reveals that the around 58.33 % NHS wells of Nainital district is having water level more than 15 m bgl, around 16.67 % NHS wells are having water level in the range of 10-15 m bgl and around 8.33 % NHS wells of Nainital district are having water level in the range of 5-10 m bgl. During Post-monsoon 2020, deepest water level of 56.21 m bgl has been observed in Dhela of Ramnagar block of the district whereas shallowest water level of 2.83 m bgl has been observed in Maldhan Colony of Ramnagar block of the district.

A perusal of Fig. **3.10** indicates that the major part of the Nainital district shows water level deeper than 20 m bgl. The water level in the depth range of 10-15 m bgl rimming around the water level of 5-10 m bgl depth and 0-5 m bgl water level depth is observed in South East and Northern portion of the district i.e., in the Haldwani and Ramnagar block and in patches in South western part of Nainital district.

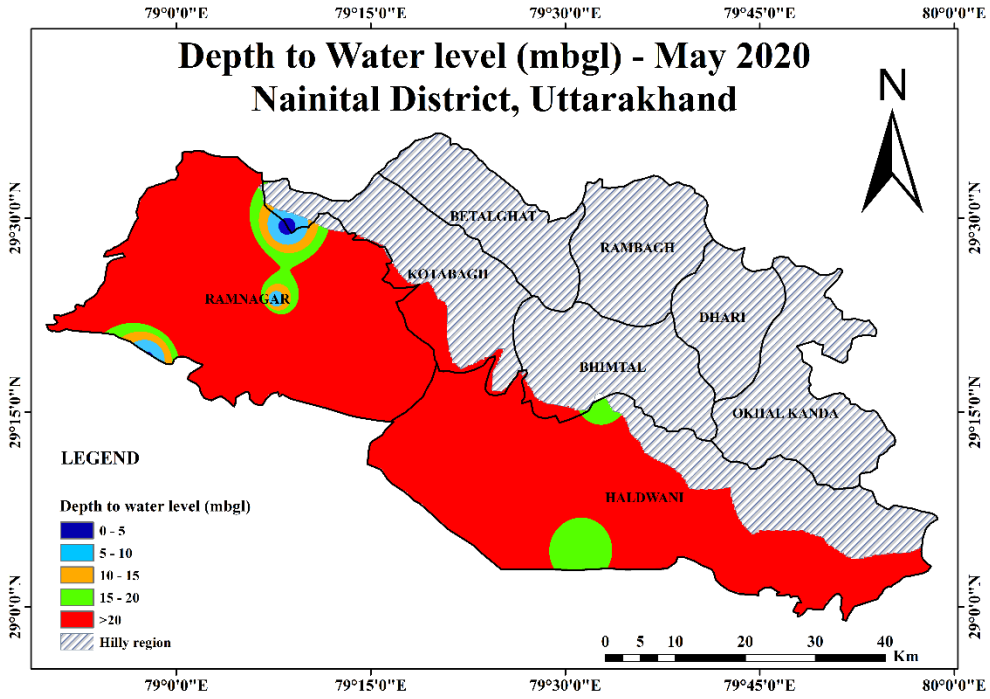


Fig. 3. 9 Map showing Depth to Water level during pre-monsoon period of the year 2020, Nainital District

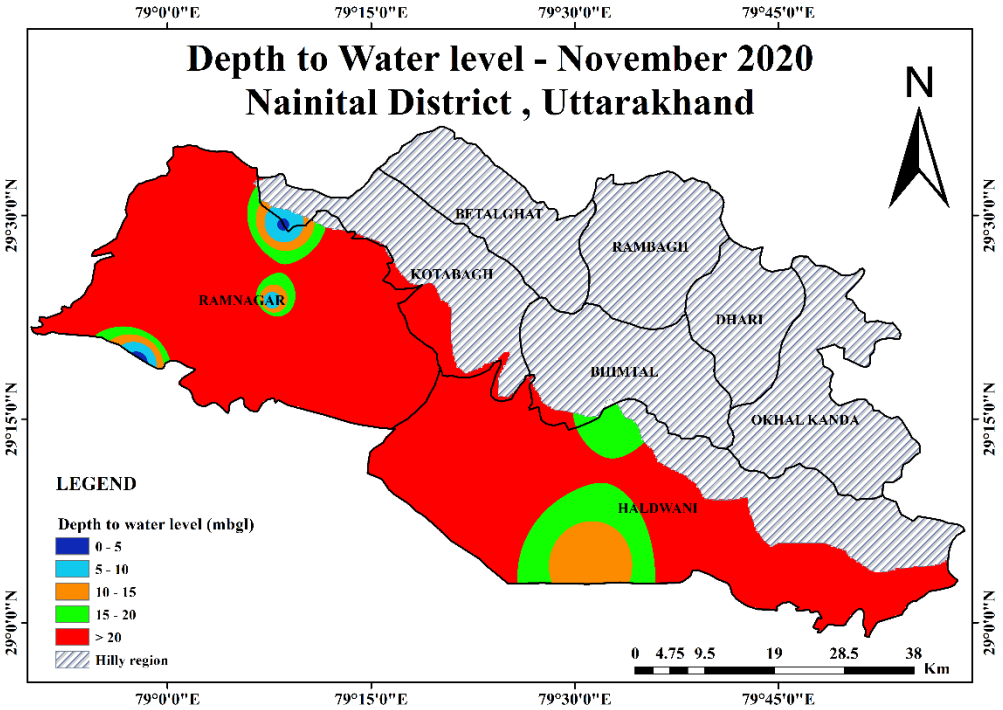


Fig. 3. 10 Map showing Depth to Water level during post-monsoon period of the year 2020, Nainital District

3.3.5 Water Level Fluctuation

Water Level fluctuates corresponding to recharge or withdrawal from phreatic aquifer. The quantum of fluctuation is a direct function of aforesaid components. Mainly recharge takes place during rainy season (June to September) and withdrawal during the rest of the period. The shallowest representative water table depth below ground is expected sometime at the end of monsoon season and it will be deepest just before the inception of rainy season. A part of rainfall infiltrating into soil is effective to rejuvenate the soil moisture deficiency (covered by ET losses and other localized factors) in the beginning of rainy season.

To study the seasonal fluctuation in the district, water level data of NHS wells were considered and a fluctuation map (**Fig: 3.11)** has been prepared by using the pre-monsoon and post monsoon data. Fig 3.11 shows that the higher seasonal rise of 2-4 m is observed in Haldwani block of the district.

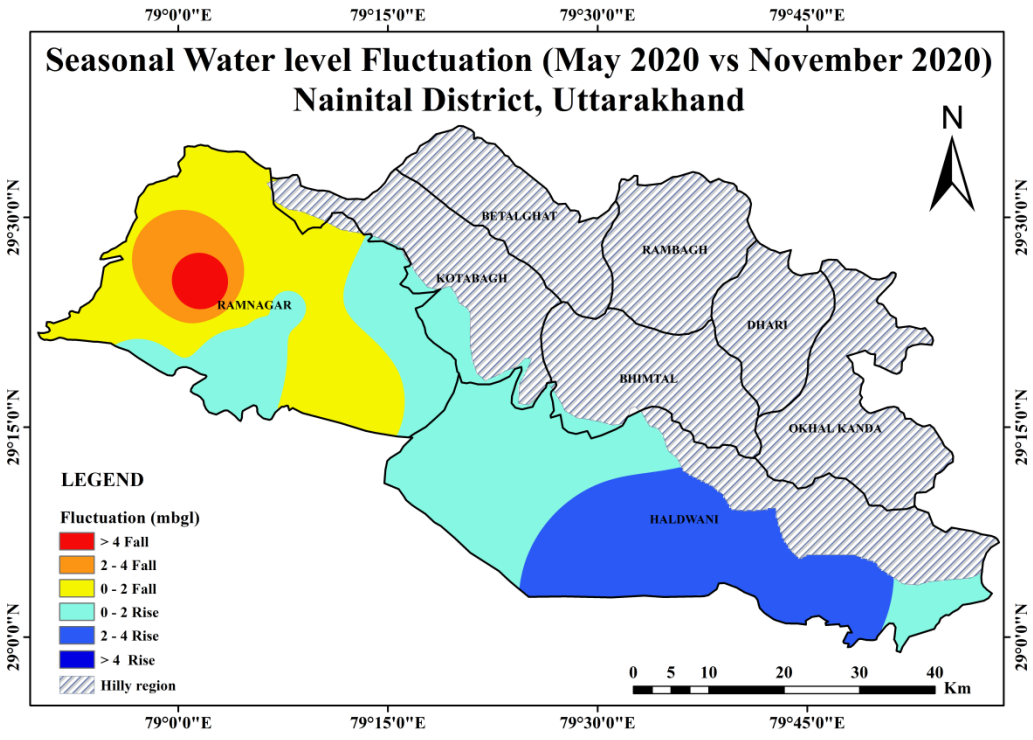


Fig. 3. 11 Map showing Water Level Fluctuation (May 2020 vs November 2020) in Nainital District

3.3.6 Long Term Water Level Trends

Long term water level trends from the existing 12 nos. of hydrograph stations were statistically analysed (2010-19). To study the pattern of water table fluctuation in space and time, the hydrographs of existing stations have been generated. It is observed that the long-term water level trends during pre- and post-monsoon seasons are rising in some parts while seen falling in major parts of the district **(Fig. 3.12).**

Rising trend of water level in Ramnagar block suggests that surface water irrigation not only compensates the withdrawal but puts additional recharge through return flow in the system and through direct seepage from running canal while declining trend in Haldwani block indicate excessive withdrawal of ground water because of urbanization and industrialization.

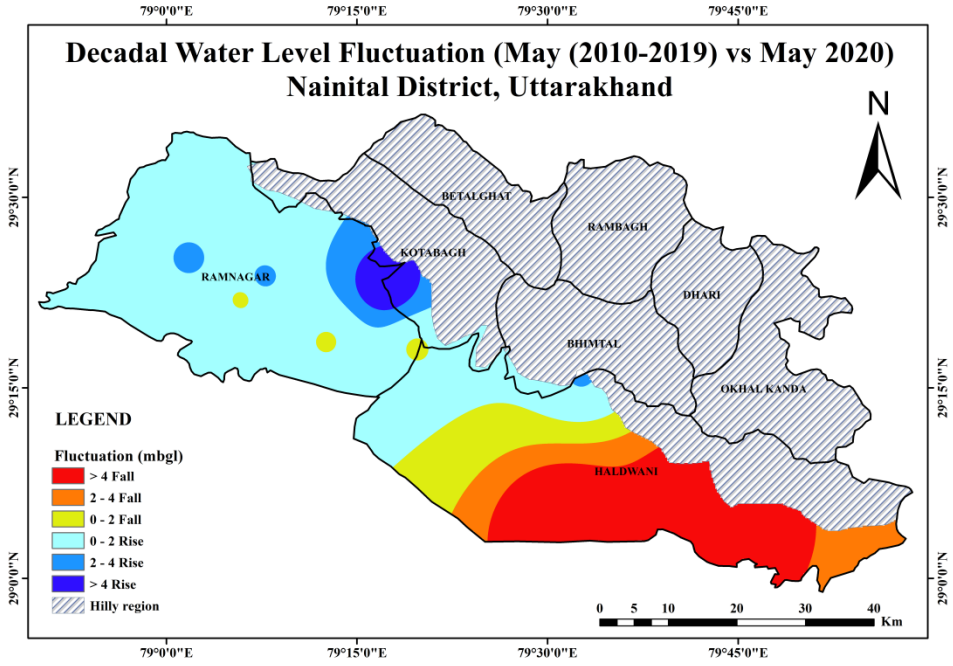


Fig. 3. 12 Map showing Decadal Water Level Fluctuation during Pre-monsoon in Nainital District

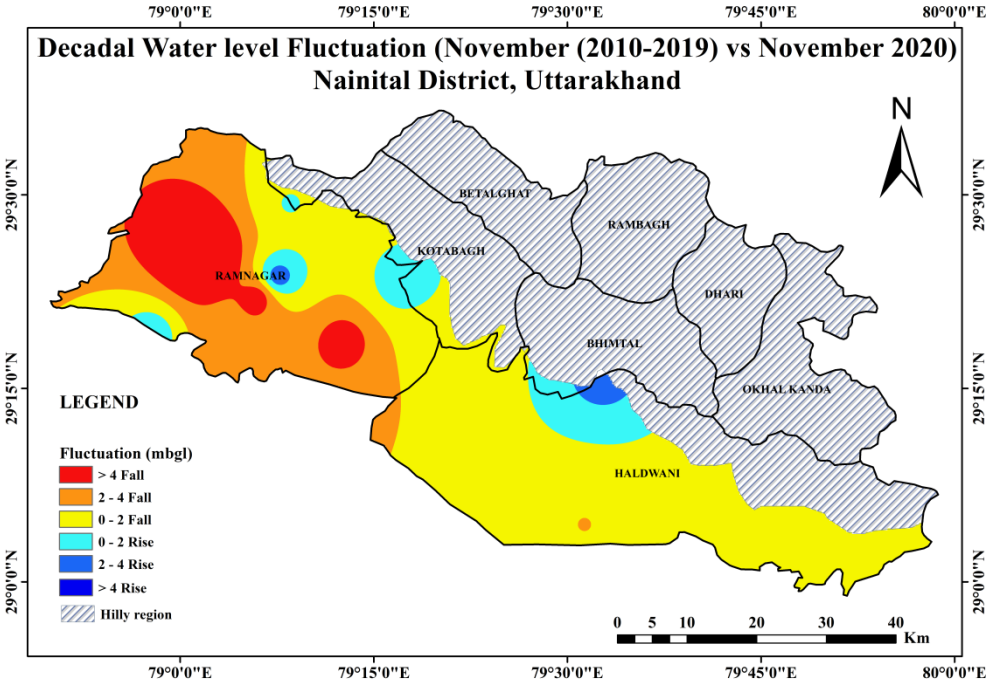
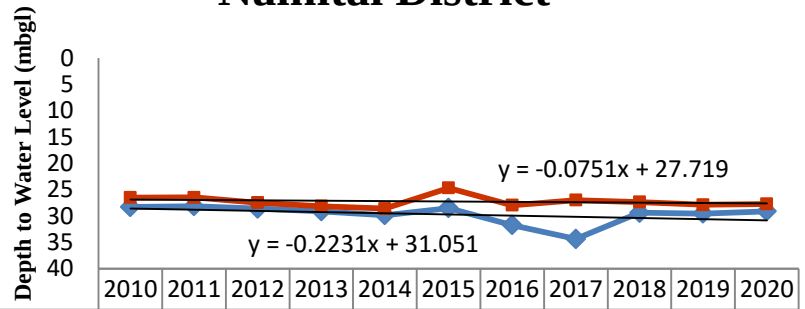


Fig. 3. 13 Map showing Decadal Water Level Fluctuation during Post-monsoon in Nainital District

Table 3. 2 Long term water level trend of Ground Water Monitoring Stations of Nainital District, Uttarakhand

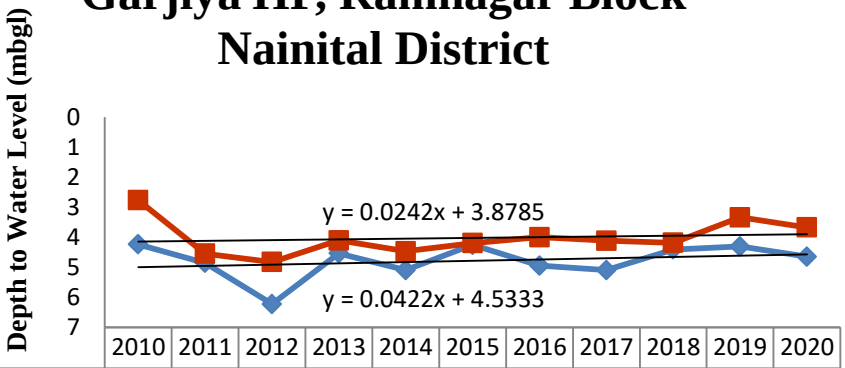
Location	Block	Data availability	Pre-monsoon long trend (m/yr.)	Post-monsoon long trend (m/yr.)
Kaladhungi	Haldwani	2010-2020	-0.2231	-0.0751
Garjiya	Ramnagar	2010-2020	0.0422	0.0242

Kaladhungi HP, Haldwani Block, Nainital District



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Pre-monsoon	28.32	28.15	28.62	29.12	29.85	28.52	31.75	34.4	29.42	29.57	29.12
Post-monsoon	26.53	26.5	27.48	28.16	28.62	24.7	27.97	27	27.37	27.89	27.73

Garjiya HP, Ramnagar Block Nainital District



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Pre-monsoon	4.24	4.86	6.23	4.54	5.1	4.26	4.95	5.1	4.41	4.31	4.65
Post-monsoon	2.77	4.55	4.83	4.11	4.47	4.2	4	4.12	4.19	3.34	3.68

3.4 Ground Water Quality

The suitability of ground water for drinking/irrigation/industrial purposes is determined keeping in view the effects of various chemical constituents present in water on the growth of human being, animals, and various plants and also on industrial requirement. Though many ions are very essential for the growth of plants and human body but when present in excess, have an adverse effect on health and growth. For estimation of the quality of ground water, ground water samples from the 12 locations of NHS monitoring stations have been collected during pre-monsoon 2020. The ground water samples were analysed for major chemical constituents at Chemical Laboratory, CGWB, NR, Lucknow.

Table 3. 3 Chemical constituents in Ground Water samples of the Study Area

Constituents	Min	Max	Average
pH	8.16	8.69	7.79
Electrical Conductivity (µS/cm)	307	748	527.5
Total Hardness (mg/l)	130	310	220
Calcium (mg/l)	24	100	62
Magnesium (mg/l)	9.6	34	21.7
Potassium (mg/l)	1	5.2	3.1
Sodium (mg/l)	5.6	44	24.8
Carbonate	Nil	48	
Chloride (mg/l)	7.1	43	25.05
Nitrate (mg/l)	5	18	11.5
Fluoride (mg/l)	BDL	0.29	

The average pH value of Nainital district is 8.43 indicating that the groundwater of the study area is neutral to alkaline in nature. Based on the permissible limit of pH in drinking water 6.5 to 8.5 (WHO, 2011; BIS, 2012), Value of pH observed from all water samples of shallow and deep aquifer are within the permissible range. The EC is defined as the measurement of the dissolved ions in groundwater, which is based on the conductivity of the aqueous solution. EC of the groundwater samples measured during this study ranges

from 307 to 748 µS/cm. The Electrical Conductivity measured from the ground water samples of Nainital district indicate that the ground water is fresh and potable.

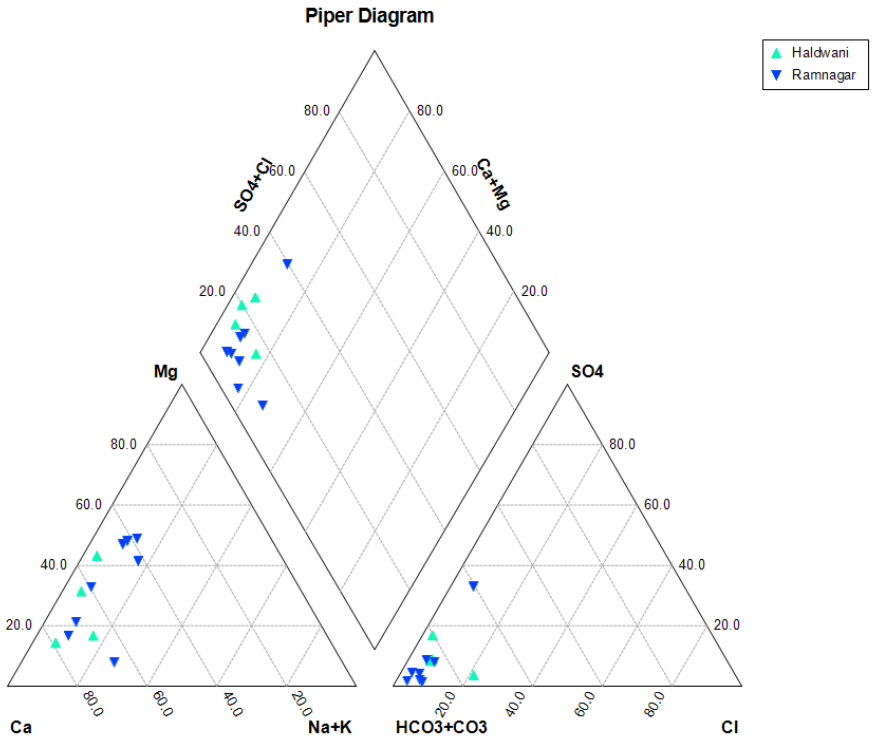


Fig. 3. 14 Groundwater samples of Haldwani and Ramnagar block plotted in Piper-Trilinear diagram

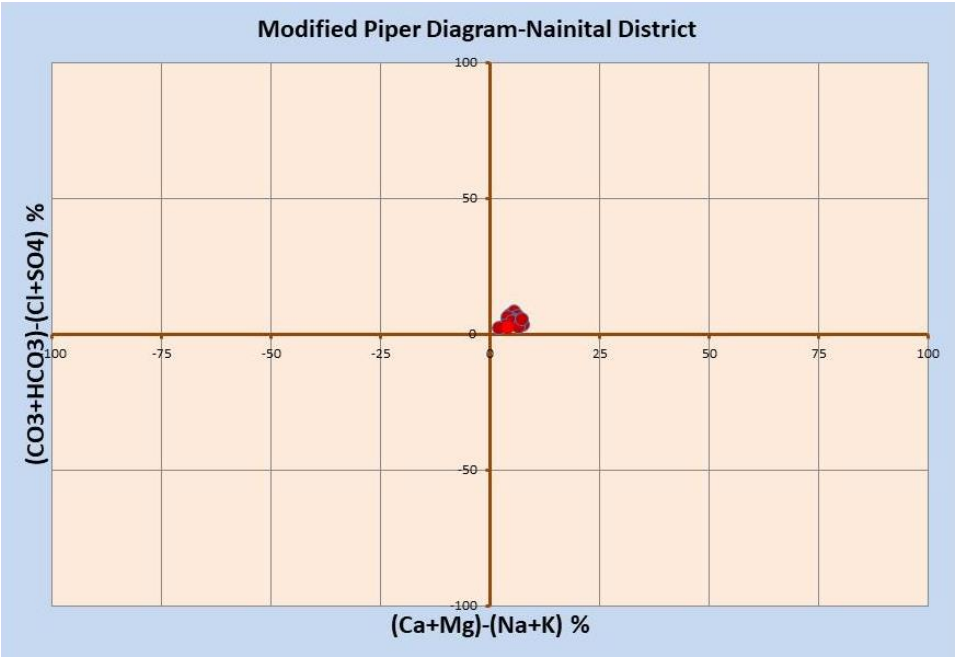


Fig. 3. 15 Modified Piper diagram of the Study area, Nainital district

The piper diagram is used to display the relative abundance of ions in groundwater samples and then to identify the hydrochemical facies. As interpreted from the Piper-Trilinear diagram and Modified Piper diagram **(Fig: 3.14 & 3.15)**, the aquifers are mostly dominated by Calcium sulphate and calcium bicarbonate types of groundwater. The general chemical quality reveals that most of the wells contain low dissolved mineral contents and hence, groundwater in Nainital district is fresh and potable.

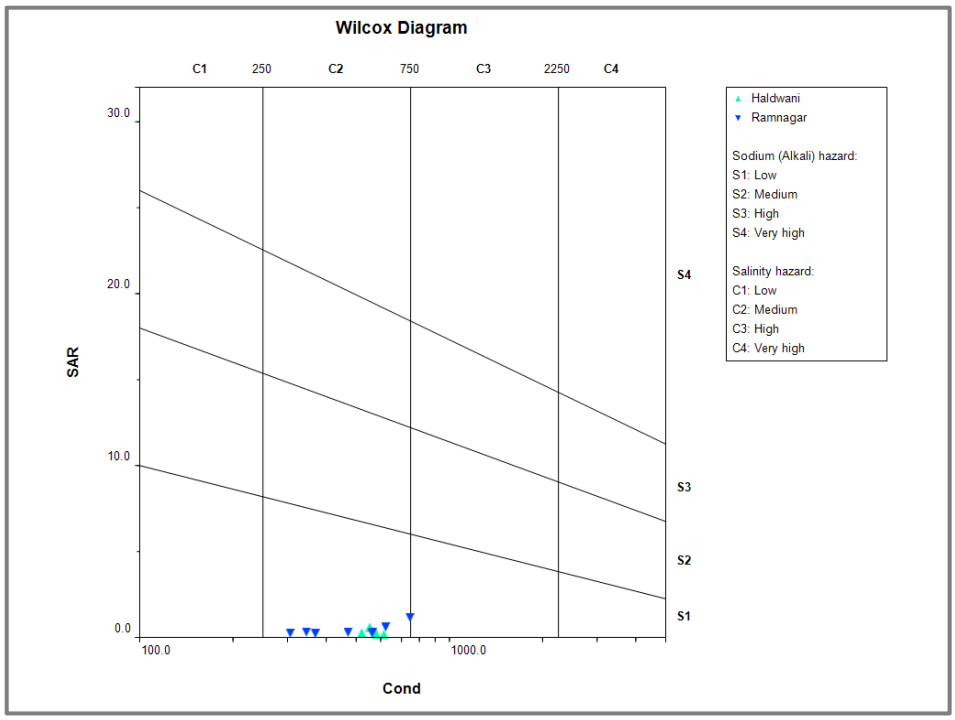


Fig. 3. 16 Groundwater samples of Haldwani and Ramnagar block plotted in Wilcox diagram

The alkali hazard is caused by high levels of sodium in soil. A high concentration of Na^+ in groundwater use for irrigation may create a tremendous concentration of sodium in soil and then lead to the destruction of soil structure. As per the U S salinity diagram (**Fig. 3.16)**, ground water samples of Nainital district is falling in the C2S1 region, which indicates its suitability for irrigation purposes on all types of soils. Ground waters that fall in C2-S1 region can be used for irrigation on all types of soil with little danger of the development of harmful levels of exchangeable sodium.

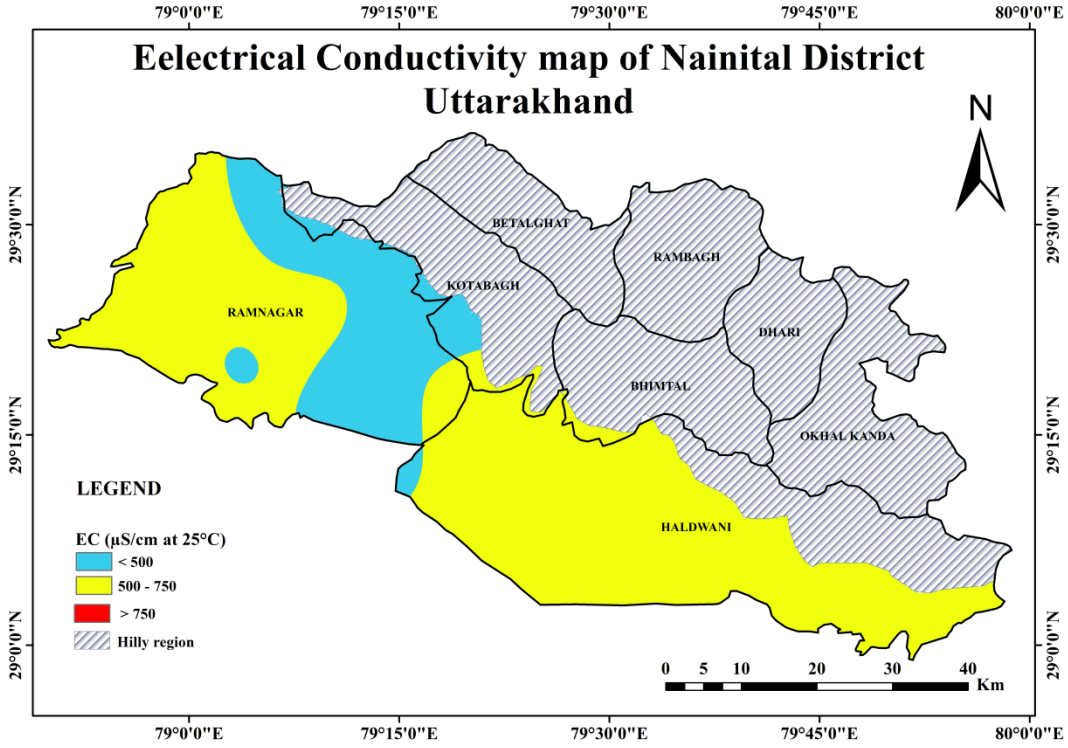


Fig. 3. 17 Electrical Conductivity Map of the Study area, Nainital District

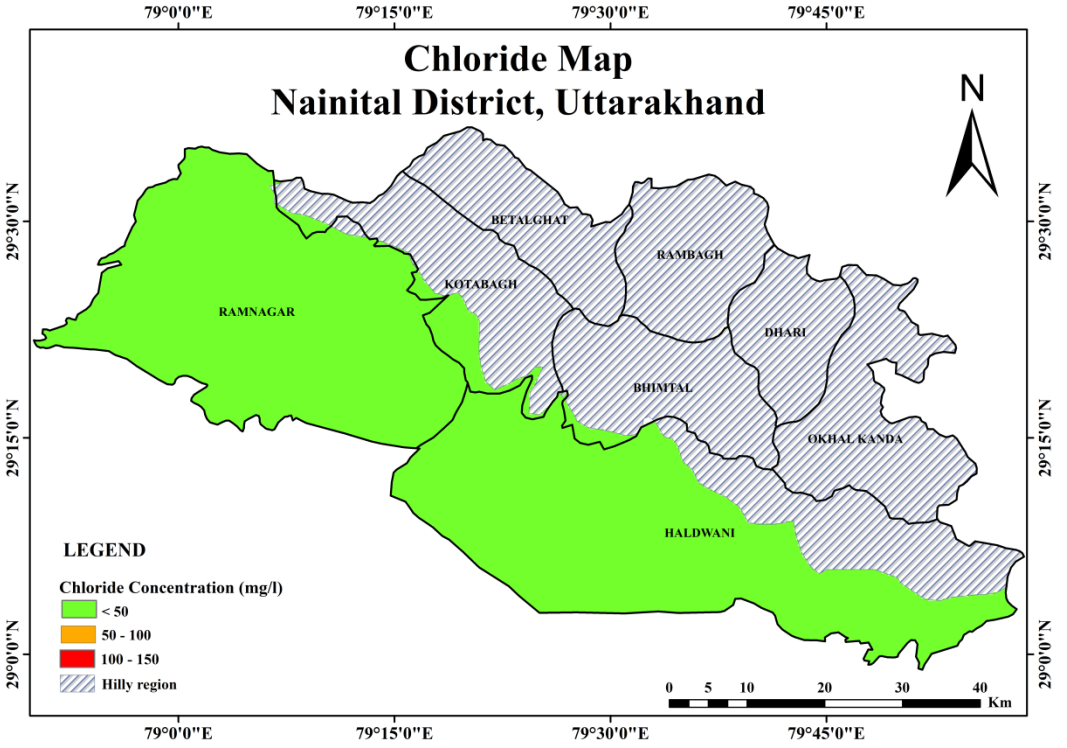


Fig. 3. 18 Chloride Concentration Map of the Study area, Nainital District

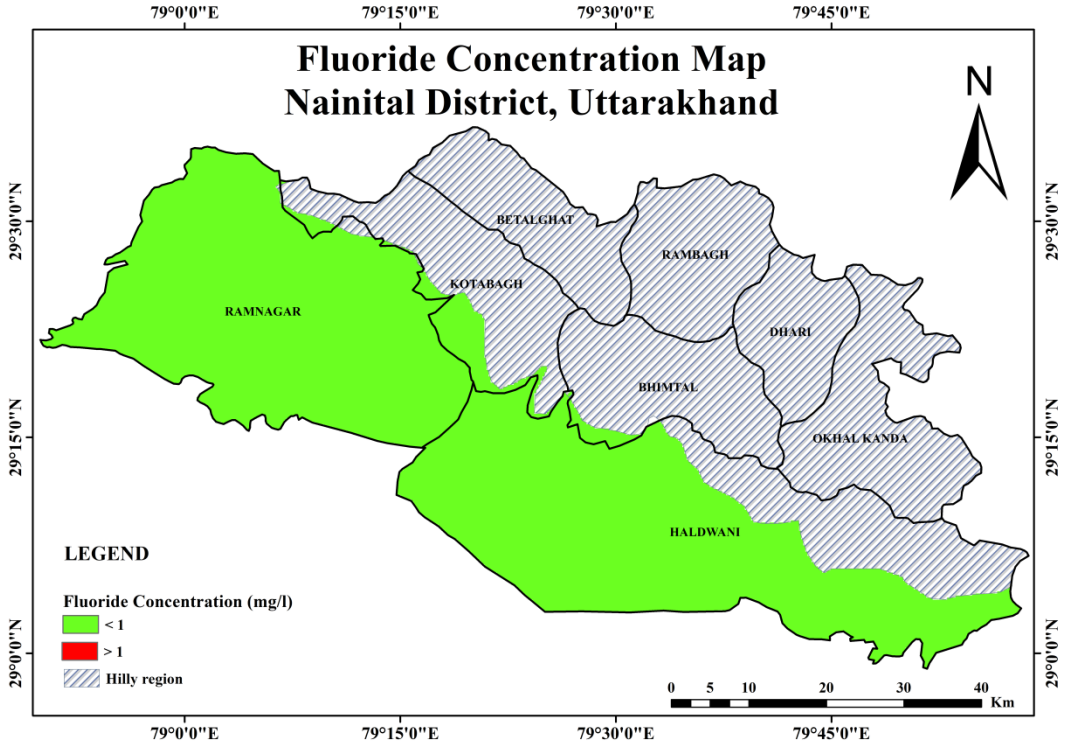


Fig. 3. 19 Fluoride Concentration Map of the Study area, Nainital District

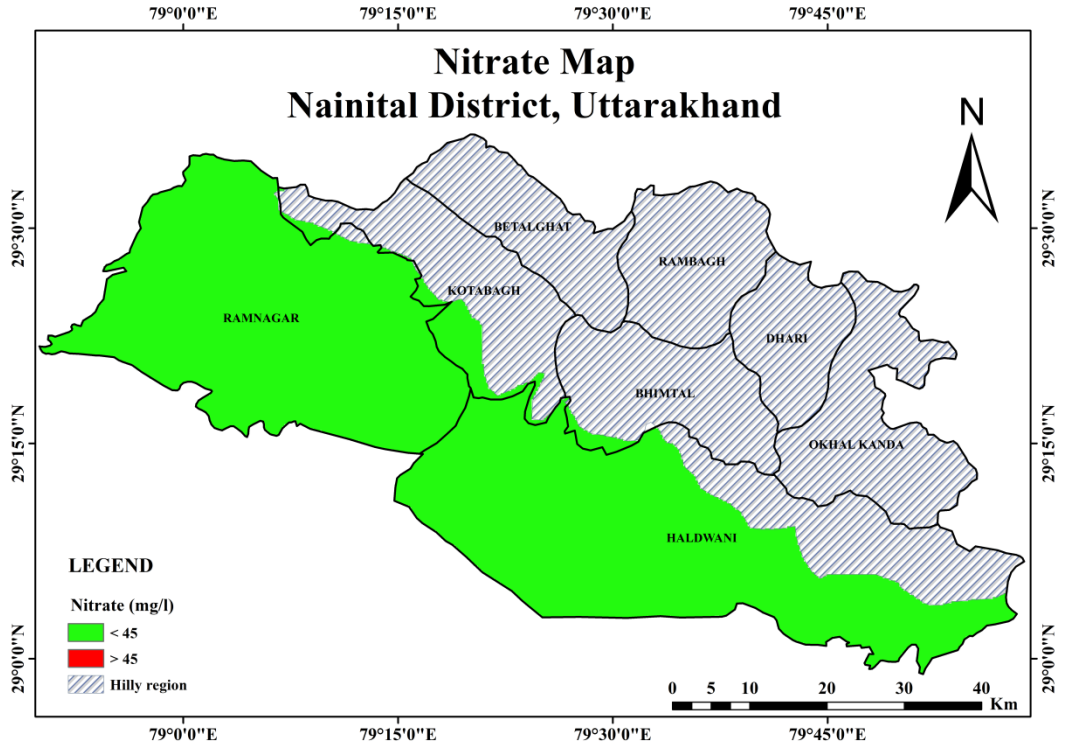


Fig. 3. 20 Nitrate Concentration Map of the Study area, Nainital District

CHAPTER - 4
GROUND WATER RESOURCES

4 Ground Water Resources

Dynamic Ground Water Resource Estimation for the year 2020 has been carried out for the two administrative blocks (Ramnagar and Haldwani) as ground water assessment units by CGWB. The precise estimation of ground water reserves and irrigation potential is prerequisite for proper planning and execution for socio-economic development in the area. The ground water recharge has been estimated on the basis of water level fluctuation method and Rainfall Infiltration Method. The dynamic ground water resource estimation is summarized as follows in **Table 4.1.**

Table 4. 1 Summary of Assessment of Dynamic Ground Water Resources of Nainital District (2020)

1.	Total Annual ground water recharge by all sources	**18,533.76 ham**
2.	Annual Extractable Ground Water Resource in the district	**16,680.38 ham**
3.	Existing gross ground water draft for all uses	**9556.8 ham**
4.	Annual GW Allocation for Domestic Use as on 2025	**3316.11 ham**
5.	Net ground water available for future use	**7123.58 ham**
6.	Stage of ground water development average of district	**59.41%**
7.	Number of Safe Blocks (Out of Total blocks assessed)	**1 (2)**
8.	Number of OCS blocks (Out of Total blocks assessed)	**1 (2)**

4.1 Recharge from Rainfall

Precipitation is the principal source of recharge to ground water in the district. The quantity of recharge depends upon the intensity and duration of rainfall, nature and texture of soil, vegetation cover and land use pattern of the area. Recharge from rainfall has been computed separately for monsoon and non-monsoon periods. Recharge from rainfall is mainly a function of geographical area of the district, normal monsoon rainfall and lithology of the area. The recharge from rainfall during monsoon season has been computed using mainly Water Level Fluctuation Method &Rainfall Infiltration Factor Method, whereas recharge from rainfall during non-monsoon

period has been computed using Rainfall Infiltration Factor Method. Block-wise recharge from rainfall is given in **Table: 4.2.**

Table 4. 2 Details of Recharge and Natural discharge (ham), Study Area, Nainital District (Uttarakhand)

Sl. No	Assessment Unit Name	Total Area of Assess-ment Unit (Ha)	Recharge from Rainfall-Monsoon Season	Recharge from Other Sources-Monsoon Season	Recharge from Rainfall-Non-Monsoon Season	Recharge from Other Sources-Non-Monsoon Season	Total Annual Ground Water (Ham) Recharge	Total Natural Discharges (Ham)	Annual Extractable Ground Water Resource (Ham)
1	**Haldwani**	11,277	3158.20	2008.13	764.08	2546.79	8477.21	847.72	7629.49
2	**Ramnagar**	12,366	3463.18	2663.49	837.87	3092.01	10,056.55	1005.66	9050.89

4.2 Recharge from Other Sources

Total Recharge to ground water has several components, rainfall being the major one. The other component include seepage from canals, return flow from surface water irrigation, return flow from ground water irrigation, seepage from Tanks and Ponds etc. for command area. Block wise recharge from other sources is also given in **Table 4.2.** The recharge from other sources during monsoon and non-monsoon period in Nainital district is 1601.95 ham and 5638.8 ham respectively.

4.3 Recharge from All Sources

Total replenishable ground water resources including rainfall recharge and recharge from other sources have been computed block- wise which is presented Table: 4.2. Total annual ground water recharge from all sources in Nainital district is of the order 59709.89 ham with Ramnagar block having the highest recharge of 10,056.55 ham whereas Haldwani block has the minimum recharge of 8477.21 ham.

4.4 Unaccounted Natural Discharge and Annual Extractable Groundwater Resource

The total annual ground water recharge of the area is the sum of monsoon and non-monsoon recharge. An allowance of 5-10 % of total annual ground water recharge has been kept for natural discharge in the non-monsoon season because WLF/RIF method respectively is employed to compute rainfall recharge during monsoon season.

The balance of ground water available accounts for existing net ground water availability for various uses and potential for future development. Block wise unaccounted natural discharge and net ground water availability is given in **Table 4.2**. Total unaccounted natural discharge in all the blocks is of the order of 1853.38 ham, with Ramnagar block having the highest discharge of 1005.66 ham and Haldwani block with lowest of 847.72 ham. Annual extractable groundwater resource in the district is 16680.38 ham with Ramnagar block having the highest Annual extractable groundwater resource of 9050.89 ham followed by Haldwani.

4.5 Ground Water Draft

The ground water draft is the quantity of water withdrawn from ground water reservoirs. The principal ground water development structures for utilization of ground water in the district are dug wells, private tubewells/ government tubewells/ government tubewells constructed under minor irrigation works and by other state government departments.

On the basis of statistical data available on the number of various ground water structures, the block wise annual gross draft has been computed by multiplying the average discharge of the wells and their annual operational hours. The total draft (extraction) for all the blocks of Nainital district is 9556.8 ham. From the **Table 4.3**, it is observed that ground water draft (extraction) of 6421.41 ham for all uses is maximum in Haldwani block ground water draft of 3135.39 ham for all uses is minimum in Ramnagar block.

4.6 Stage of Ground Water Extraction and Categorization of Blocks

The Stage of Ground Water Extraction in Nainital district has been worked out for each block as the ratio of existing gross ground water extraction for all uses to Annual Extractable Ground Water Resource.

The distributions of various categorized blocks in Nainital district are shown in the **Table 4.3 and Fig. 4.1.**

One out of two blocks in Nainital district falls under Safe category and another block comes under Semi-critical category with stage of GW Extraction as 59.41 % for the entire district.

Table 4. 3 Block-wise Groundwater Resources Potential, Parts of Udham Singh Nagar District, Uttarakhand as on 31/03/2020 (Ham)

S. No	Block	Total annual GW Availability	Gross GW Draft	Net GW Availability for Future	Stage of Development	Category
1	**Haldwani**	7629.49	6421.41	1208.08	84.17 %	Semi-Critical
2	**Ramnagar**	9050.89	3135.39	5915.5	34.64 %	Safe

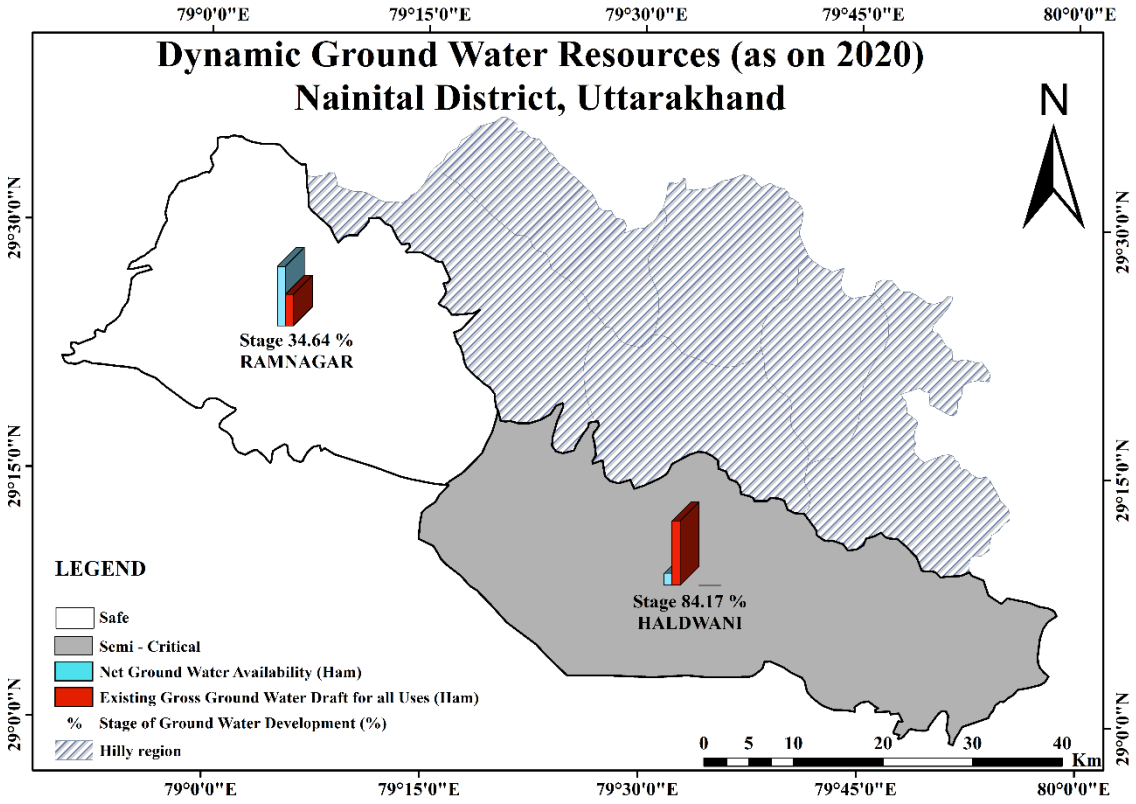


Fig. 4. 1 Dynamic Ground Water Resources Map of Nainital district

4.7 Present Groundwater Development

Groundwater in the study area is developed mainly through tube wells, dug wells, and hand pumps. Surface water bodies and canals are also in use for domestic, industrial and irrigational purposes. A large number of medium to heavy duty tube wells exist for the irrigation. Canals contribute about 6% of the net irrigated area and contribution of Tubewells and Handpumps are very significant as they are very much in use.

The stage of groundwater development is compared with the groundwater resource potential estimated in. Based on these groundwater development statistics, it reveals that the Haldwani block (15.30%) has the highest trend of groundwater

development due to growth industrial and agricultural activities. The details of the stage of groundwater development are mentioned in the Table 4.4**.**

Table 4. 4 Comparison of the Ground Water Development, Nainital District, Uttarakhand

S. No	Block	Stage of Groundwater Development 2020 (%)	Stage of Groundwater Development 2017 (%)	Percent of Rise / Fall (%)
1	Haldwani	84.17	73.00	-15.30 (Rise)
2	Ramnagar	34.64	39.0	11.18 (Fall)

The table shows that ground water extraction in Haldwani block has increased by 15.30% whereas ground water development in Ramnagar block has been reduced significantly.

CHAPTER – 5
MANAGEMENT STRATEGIES

5. Management Strategies

Ground water issues can be addressed by focusing on measures to increase recharge and reducing the draft. It can be managed by a mix of measures such as:

Supply Side management	Demand Side Management
• Water conservation and Artificial Recharge to ground water • On Farm Activities	• Adoption of techniques to enhance water Use Efficiency • Adoption of new irrigation practices in sugarcane cultivation area to save 35-40 % irrigation water • Diversification of Cropping pattern • Effective use of waste water

5.1 Status of Ground Water Development

Groundwater is developed mainly through tubewells and India mark-II hand pumps. Jal Sansthan, Jal Nigam and Irrigation departments have constructed a number of tubewells in Ramnagar and Haldwani blocks to meet the domestic and irrigational requirements. In hilly areas, springs form the main source of drinking water. The springs are developed for irrigation purpose also. India mark-II hand pump is common in hilly areas also. The depth of the tube wells, constructed in the district range from 50 to 150 m bgl whereas the discharge ranges from 500 to 1500 lpm.

5.2 Supply Side Management

5.2.1 Recharge / Water Conservation

- ❖ Water conservation structures such as check dams, farm ponds etc result in ground water recharge to the tune of about 50% of the storage capacity considering 3 annual fillings. Further construction of recharge trenches in the upstream side of the check dams is also proposed to enhance rate of infiltration by about 30 to 40%.
- ❖ The existing ponds and tanks lose their storage capacity as well as the natural ground water recharge due to siltation and encroachment by farmers for agriculture

purposes. Through desilting, coupled with providing proper waste weir, the village tanks can be converted into recharge structure.

5.2.2 On Farm Practices

Leveling of crop field is essential for uniform distribution of water. Laser leveling has been found very effective ensuring saving of 10 to 30% of applied irrigation. The in-situ farm activities such as contour bounding, land leveling, bench terracing, water harvesting structures, a forestation and diversification of cropping pattern are other measures to increase recharge in the block.

5.3 Demand Side Management

5.3.1 Water-efficient irrigation

- In flood irrigation method more than 50% of applied water is wasted through seepage to deeper level, localized inundation causes loss through evaporation and it leaches out the nutrients from the plant.
- Adoption of new irrigation practices in sugarcane cultivation area to save 35-40 % irrigation water
- While through drip & sprinkler irrigation wastage of irrigational water could be minimized. The conveyance losses (mainly seepage & evaporation) can be saved upto 25 to 40% through utilization of HDPE pipes.
- Agriculture department should promote to conserve the soil moisture by reducing ET losses through cultivation of ‘Green Manure’

5.3.2 Diversification of cropping pattern

- Horticulture department should promote Baghwani in the area. This will bring in money without high use of water. These will also help conserve soil moisture.
- Alternate cropping system having lower requirement of water are better option.
- Summer paddy and maize need to be avoided which are grown over substantial area in the Doiwala block.
- Large scale adoption of rice-wheat rotation system is the main reason of over exploitation of groundwater. Late sown wheat/peas are replaced by spring maize which consumes more water. Suggested cropping pattern are as under.
- Kharif- Maize, cotton, sorghum, pulses, groundnut
- Rabi- Mustard, gram, pulses, vegetable

- By adopting suggested cropping pattern 20 to 30% of irrigation water saving is possible.

5.3.3 Effective Use of Waste Water

The greywater generated from the industrial offices and buildings can be further treated in series of greywater treatment ponds which in turn will provide substantial benefits for water supply system by reducing the demand for fresh clean water and for wastewater system by reducing the amount of wastewater required to be conveyed and treated.

Water Management Training Program and IEC Activities

The target groups included MES Engineers, Uttarakhand Jal Sansthan, Jalagam, Uttarakhand Pey Jal Nigam, Degree college professors and students, NGOs, Irrigation, Mirror irrigation, Block Development Officers etc.

Public Interaction programmes have been conducted in villages in the district regarding local groundwater scenario, effective groundwater management and conservation techniques.

5.4 Conclusion and Recommendations

As it has been established that there is sufficient, exploitable, ground water resource available both in quantity and quality, it is recommended that:

- Artificial recharge is recommended only for those locations where water levels are deep and the aquifer has the potential to recharge.
- Tubewells should be constructed scientifically viz. suitable sites, distance between them, identifying aquifer parameters, recommended discharge and drawdown, recuperation time etc. should be strictly adhered to.
- Geophysical logging is recommended for deciphering the exact potential zones.
- Tubewell assemblies should be shrouded with a thick gravel pack, so as to avoid pumping of sand and silt and screen size and gravel pack size should be determined after carrying out proper grain size analysis of the aquifer to be tapped.
- Conjuctive use of surface and groundwater should be parctised in order to reduce the load on aquifers. Overpumping/Overdrawal from aquifer should not be allowed in any case.

- To arrest the decline in ground water levels and depletion of ground water resources, there is urgent need to implement both Supply side and Demand side measures which includes artificial recharge and water conservation, On-farm activities and adoption of water use efficiency measures.
- There is considerable scope for implementing Roof Top Rain Water Harvesting in the urban areas of the district. Check dams, nala bunds, renovation of ponds are ideal structures for rain water harvesting in rural areas. Water conservation structures such as check dams, farm ponds, nala bunds etc. result in ground water recharge to the tune of about 40% of the storage capacity considering 3 annual fillings.
- It is also proposed to adopt On Farm practices such as laser leveling, bench terracing, construction of farm ponds, afforestation, diversification of crops etc.
- Alternate cropping system having lower requirement of water should be encouraged in accordance to the irrigation water availability.
- Drip irrigation in sugarcane and other wide row crops should be practised with mulch in the area.
- Modern irrigation practices like drips and sprinklers, skip furrow method of irrigation, ring and pit method of sugarcane planting etc. should be adopted as these methods can effectively save 30-40% of irrigation water.
- A water budget should be formulated for the overall district in a blockwise or village wise manner and farmers should be encouraged to grow crops accordingly for that particular season/year.
- The prime necessity is to conduct participatory ground water management in the area for creating more and awareness among the common farmers and local people.
- All efforts should be taken to ensure treatment of waste disposal both solid and liquid from industries and urban areas to prevent pollution of ground water and surface water.

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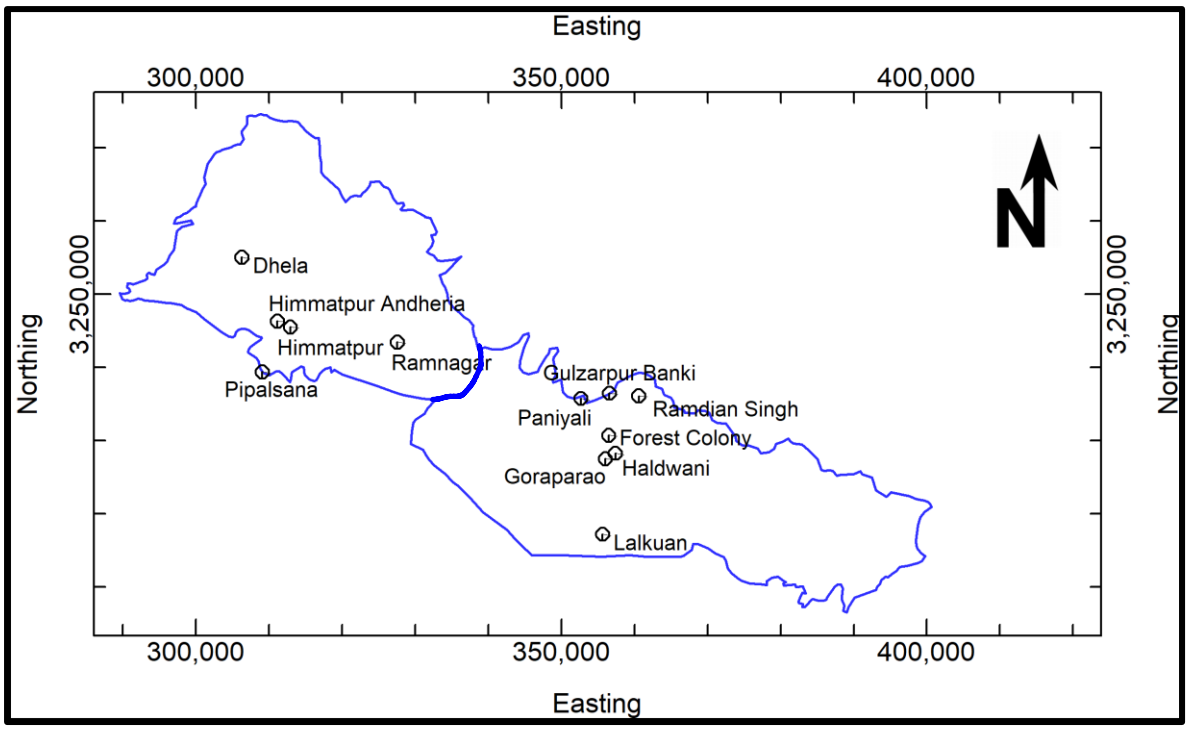
Plate I: Location Map of Exploratory wells constructed by CGWB in the Study Area



Annexure 1 Lithology of Exploratory wells in Nainital district

GULZARPUR BANKI

Depth Range (m bgl)		*Thickness (m)*	*Lithology*
From	***To***		
00.00	06.35	6.35	Surface cover- Boulder and Cobble of Sandstone with little clay.
06.35	08.35	2.00	Gravel and pebbles of sandstone quartzite rounded to sub-rounded.
08.35	14.00	6.65	Sandstone gravel, greenish colour (Crushed material)
14.00	39.30	25.30	Sand, medium to coarse, greyish, with clay intercalation, Rounded of sub-rounded sediments.
39.30	47.40	8.10	Sand, medium to coarse grained greyish, comprised of quartzite, sandstone and shale pieces.
47.40	51.00	3.60	Sand, medium to coarse grained, greyish with ferromagnesian minerals rounded to sub-rounded sediments with quartzite and sandstone
51.00	52.35	1.35	Clay, hard and plastic, yellowish in colour.
52.35	57.80	5.45	Sand, medium to coarse grained greyish, rounded to sub-rounded sediments.
57.80	58.20	0.40	Clay sticky, yellowish
58.20	63.25	5.05	Sand, medium to coarse grained, greyish, rounded to sub-rounded sediments of quartzitic sandstone.
63.25	65.60	3.35	Sandstone pieces angular to sub-angular with shale and schist.
65.60	84.30	18.70	Quartzitic sand stone pieces with shale (blackish) and schist.
84.30	86.65	2.36	Sand mixed with clay and angular pieces of sandstone and quartzite.
86.65	91.00	4.35	Clay sticky hard and yellowish
91.00	92.55	1.55	Sand, medium to fine, comprised of quartzitic sandstone, shale and schist
92.55	94.05	1.60	Clay yellowish
94.05	95.20	1.15	Sand, medium to coarse, greyish with gravel, quartzite & sandstone
95.20	101.80	6.60	Quartzite, sandstone pieces with shale and gneisses.
101.80	103.00	2.20	Sand medium to fine grained, brownish, mixed with quartzitic sandstone.
103.00	113.85	10.85	Quartzitic sandstone shale with little amount of fine-grained sand.
113.85	115.45	1.60	Sand, medium to fine grained greyish mixed with gravel.
115.45	117.30	1.85	Quartzitic sand stone mixed with weathered shale.
117.30	118.40	1.10	Clay sticky, hard and yellowish
118.40	119.20	0.80	Angular to sub-angular pieces of quartz, sandstone and shale.
119.20	120.95	1.75	Sand, coarse grained comprised of angular to sub-angular grains of quartz sandstone, shale ferromagnesian minerals.
120.95	123.75	2.80	Drill cuttings are in powder forms comprised of quartzite, sandstone and shale etc.
123.75	125.70	1.95	Sand mixed with gravel and powder of quartzitic sandstone and shale.

125.70	129.50	3.80	Sand, coarse mixed with gravel
129.50	131.60	2.10	Clay hard and plastic mixed with little amount of fine sand.
131.60	134.10	2.50	Cuttings are in powder form comprised of quartzitic sandstone cherty quartzite sand shale.
134.10	139.10	5.35	Sand, coarse grained comprised at angular to sub-angular pieces of quartzite sandstone, shale and ferromagnesian minerals.
139.45	143.55	4.10	Cuttings are in powder forms comprised of quartzite sandstone and shale.
143.55	148.15	3.70	Sand, medium to coarse grained, comprised of quartz, sandstone and shale.
148.15	150.15	2.00	Cuttings are in powder form comprised of quartzite, sandstone and shale.
150.15	151.75	1.60	Clay, yellowish in colour, hard and plastic in nature.
151.75	153.50	1.35	Sand, coarse grained, grains are angular to sub-angular (bluish in colour) comprised of quartz, sandstone and mafic rocks.
153.50	157.10	3.60	Sand, greyish, coarse grained mixed with pebbles of quartzite and minor angular chips of shale and sandstone.
157.10	159.45	2.35	Sand mixed with gravel of quartzite and angular chips of shale with little amount of clay.
159.45	160.30	0.85	Pebbles and cobbles of quartzite embedded with clay.
160.30	161.70	1.90	Sand, coarse grained, greyish mixed with gravel, pebbles and cobbles of quartzite and sandstone.
161.70	162.75	1.05	Clay yellowish, mixed with little amount of sand
162.75	171.65	8.90	Sand, medium to coarse rounded to sub-rounded, sand comprised of grains of quartz, feldspar sandstone, mica and ferromagnesian minerals
171.65	173.25	1.60	Clay, brownish yellow, hard and plastic in nature
173.25	175.90	2.65	Sand medium to coarse grained
175.90	176.70	0.80	Sand, medium to coarse grained comprised of quartz, mica and mafic minerals.
176.70	177.50	0.80	Pebbles and gravels of quartzite with angular chips of sandstone and shale.
177.50	180.35	2.85	Clay brownish, yellow and hard
180.35	181.25	0.90	Sand, fine grained mixed with gravel and little amount of clay.
181.25	188.50	7.25	Sand, medium to coarse grained with gravel and pebble of quartzite sandstone chips and sand comprised of quartz, feldspar, mica and mafic minerals.
188.50	189.95	1.45	Pebbles of quartzite with gravel and chips.
189.95	191.25	1.30	Sand, yellowish, medium to fine grained, comprised of quartz, mica and mafic minerals.
191.25	192.45	1.20	Sand, greyish, coarse grained mixed with gravel and pebbles of quartzite.
192.45	198.00	5.55	Sand medium to coarse grained, with pebbles and cobbles of quartzite and chips of sandstone angular to sub-angular with rounded to sub-rounded grains of sand.

RAMDIAN SINGH

Depth Range (m bgl)		*Thickness (m)*	*Lithology*
From	*To*		
0.00	1.80	1.80	Surface soil and sandy clay with boulders, cobbles, pebbles and gravel of sandstone, schist, granite gneiss quartzite. Boulder size range from 0.20 m to 0.40m.
1.80	28.50	26.70	Boulders, cobble and gravel with predominant coarse sand
28.50	32.50	4.00	Sand, coarse grained with pebble and gravel and clay
32.50	50.00	17.50	Sand, coarse to fine with some boulder and gravel
50.00	68.00	18.00	Sandy clay, sticky
68.00	86.50	18.50	Gravel with sand, coarse to fine and clay
86.50	91.00	4.50	Gravel with coarse sand
91.00	95.50	4.50	Clay with little gravel and cobbles
95.50	109.00	13.50	Gravel with sand, coarse to fine grained
109.00	116.00	7.00	Gravel with sand, coarse to fine grained and clay
116.00	123.00	7.00	Gravel with sand, coarse to fine grained
123.00	141.00	18.00	Clay, sticky with coarse to fine sand
141.00	183.00	42.00	Gravel with coarse sand
183.00	190.00	7.00	Sandy clay with little gravel
190.00	197.50	7.50	Sand, coarse to fine grained
197.50	209.00	11.50	Gravel with sand coarse to fine and little clay
209.00	215.00	6.00	Clay, sticky
215.00	252.00	37.00	Gravel with coarse to fine sand
252.00	257.00	5.00	Clay, sticky with fine sand
257.00	280.00	23.00	Gravel, with coarse to fine sand
280.00	295.00	15.00	Alternate bands of clay, sticky and gravel with coarse to fine sand
295.00	301.00	6.00	Gravel with coarse sand

LALKUAN

Depth Range (m bgl)		*Thickness (m)*	*Lithology*	
From	*To*			
0.0	1.5	1.5	Top soil	Clay with boulders and pebbles.
1.5	18.0	16.5	Boulders	Cobbles and pebbles composed of quartzite, granite, slate and some basic rock etc. in the matrix of grey, sticky clay.
18.0	26.8	8.8	Boulders	Cobbles and pebbles of quartzite, shale, sandstone and some basic rocks etc. in the matrix of brown clay.
26.8	27.7	0.9	Sand	Coarse-gravel and pebbles with clay, brownish, grey and sticky.
27.7	28.2	0.5	Clay	Brown, soft, sticky with a few pebbles and a little fine sand.
28.2	35.7	7.5	Sand	Very fine to coarse mixed with gravel of varying size, pebbles and few boulders composed of quartzite, granite, sandstone & basic rocks etc., with little brown clay.
35.7	39.0	3.3	Clay	Brown soft, plastic with a little fine sand, silk and few pebbles.
39.0	41.8	2.8	Clay	Brown, soft, plastic, alternating with coarse to medium sand and gravel.
41.8	42.7	0.9	Sand	Coarse to medium and assorted gravel with thin intercalations of clay, brown, soft and plastic.
42.7	46.0	3.3	Sand	Medium to
46.0	49.7	3.7	Clay	Brown soft, plastic, with a little sand and occasional gravel.
49.7	63.7	14.0	Sand	Medium to coarse with assorted gravel, pebbles, cobbles and boulders, with thin intercalations of clay, brown, soft and plastic.
63.7	68.0	4.3	Clay	Brown, soft, plastic, mixed occasionally with gravel and pebbles.
68.0	79.2	11.2	Gravel	Assorted, angular to sub-rounded, mixed with pebbles, cobbles and a few boulder; all composed of quartzite, sandstone and some dark basic rock and sand, with this intercalations or clay, brown soft and sticky.
79.2	82.3	3.1	Clay	Chocolate brown, plastic with a few pebbles alternating with coarse sand, gravel and pebbles etc.
82.3	86.7	4.4	Gravel	Assorted, sub-angular, with pebbles and a few boulders occasionally with a little brown plastic, clay.
86.7	91.4	4.7	Sand	Coarse, mixed with gravel, pebbles and a few boulders and clay, chocolate brown and plastic.

GORAPARAO

Depth Range (m bgl)		*Thickness (m)*	*Lithology*	
From	*To*			
0.0	0.9	0.9	Top soil	Clay with boulders and pebbles.
0.9	11.9	11.0	Boulders	Pebbles of variable sizes, and gravel angular to sub-angular, mainly composed of quartzite, granite shale and basic rock (all in matrix of clay and little sand).
11.9	18.3	6.4	Boulders	Pebbles as above, in a matrix of sand, very coarse, free of clay.
18.3	27.4	9.1	Boulders	Cobbles, pebbles etc. as above in a matrix of clay-light brown to grey with negligible quantity of sand.
27.4	36.6	9.2	Gravel and sand	Sand very coarse, mixed with pebbles, cobbles and boulders, mainly composed of quartzite granite, sandstone and some basic rock, with very little clay.
36.6	49.0	12.4	Gravel	With pebbles and boulders-all of quartzite (grey, pink and green) sandstone, granite and basic rock mostly sub-rounded, in a matrix of clay, brown, plastic.
49.0	53.9	4.9	Gravel	Crushed pebbles, cobbles and boulders (definite size not known, broken pieces) sub-rounded; composed of quartzite, trap and granite-in a matrix of sand with appreciable amount of clay.
53.9	55.5	1.6	Sand	Coarse to medium, mixed with gravel, rounded to sub-rounded, and pebbles-angular to sub-rounded and few angular chips of boulders.
55.5	57.9	2.4	Clay	Brown, plastic (crushed) pebbles of various size and boulders-composed of quartzite, sandstones and granite.
57.9	68.6	10.7	Sand and Gravel	Sand very coarse to medium; gravel of all sizes, changing to pebbles, cobbles and boulders, occasionally rounded to sub-rounded; mostly of quartzite, quartz and sandstone; very few pieces of granite and basic rocks; also with little clay in thin layers in patches.
68.6	80.8	12.2	Gravel	With pebbles of smaller size, and boulders, composed of quartzite in a matrix of clay of appreciable quantity and very little sand.
80.8	86.2	5.4	Gravel	Assorted, with sand and clay; also with pebbles of variable sizes and boulders of quartzite etc. as above.
86.2	93.0	6.8	Gravel	As above, but with negligible clay.
93.0	112.8	19.8	Gravel	With sand, coarse to medium, increasing with depth and less of pebbles and boulders.
112.8	132.6	19.8	Sand and Gravel	Sand, very coarse to medium; gravel pea size, with pebbles and cobbles and few boulders of quartzite, quartz and basic rock with variable quantity of clay-a thin layer at 125.9-126.2 m

132.6	134.1	1.5	Clay	Brown, sticky, with embedded gravel.
134.1	142.3	8.2	Sand	Very coarse, mixed with assorted gravel and pebbles, angular to sub-rounded-composed of quartzite of different shades and of basic rocks.
142.3	142.9	0.6	Pebbles and Cobbles	Pebbles and cobbles up to 76 mm size; with gravel, mostly angular to sub-rounded-composed of quartzite, sandstone and basic rocks also with little sand.
142.9	146.3	3.4	Sand	Very coarse to medium, (crushed) gravel and pebbles and occasional boulders up to 102 mm diameter; all composed of quartzite, quartz and sandstone.
146.3	152.2	4.9	Sand	Coarse to fine with gravel and few pebbles and clay, brown, sticky.

HALDWANI

Depth Range (m bgl)		***Thickness (m)***	***Lithology***
From	***To***		
0.0	0.6	0.6	Top soil :
0.6	6.0	5.4	Boulders and cobbles with a little clay.
6.0	11.6	5.6	Hard boulders and cobbles of quartzite (jasperoid).
11.6	13.7	2.1	Same as above with a little clay.
13.7	15.2	1.5	Boulders of phyllite with clay (earthy brown).
15.2	18.3	3.1	Quartz and quartzite gravel with a little clay and boulders of quartzite.
18.3	21.3	3.0	Clay, fawn to light pink with gravel and a few cobbles and boulders of quartzite.
21.3	24.4	3.1	Boulders and clay; boulders constituting of amygdaloidal basic rocks, grey and brown quartzite and quartz.
24.4	27.4	3.0	Gravel, boulders of hard shale and quartzite with some clay.
27.4	33.5	6.1	Clay, brown with boulders and gravel; boulders essentially of basic rock and quartzite.
33.5	36.6	3.1	Brown clay with gravel and chips of boulders and cobbles.
36.6	39.6	3.0	Sand, medium to very coarse with gravel, cobbles and a little clay.
39.6	42.7	3.1	Sand medium to coarse with boulders of sandstone and basic rock.
42.7	48.8	6.1	Sand as above with boulders of basic rock only.
48.8	52.7	3.9	Sand fine to medium with boulders of granite, quartzite and basic rock.
52.7	53.3	0.6	Sandy clay, brown with a few boulders.
53.3	54.9	1.6	Clay, brown, slightly sticky with a few boulders and cobbles of phyllite.
54.9	60.3	5.4	Clay, grey with gravel.
60.3	62.5	2.2	Sand, medium to very coarse, occasionally fine constituted partly of the basic rock above (trap) and quartzite.

62.5	64.0	1.5	Sand, with very little grey clay.
64.0	65.5	1.5	Sand, coarse with gravel and pebbles and cobbles of mainly quartzite, gneiss, and basic rock (trap).
65.5	70.1	4.6	Clay, sandy; with a few boulders and gravel; clay generally brown but with a few characteristic specks (mottled) of white, pink, olive and yellow (ochreous).
70.1	73.1	3.0	Sand - coarse with cobbles, pebbles, and very little clay between 65.5 and 76.1 m
73.1	76.2	3.1	Boulders, and pebbles with a little silt.
76.2	78.6	2.4	Boulder with less silt.

PIPALSANA

Depth Range (m bgl)		***Thickness (m)***	***Lithology***
From	***To***		
0.0	1.8	1.8	Top soil, silt, light brown and a little clay.
1.8	7.9	6.1	Sand, mostly medium to coarse consisting of quartz, mica and ferruginous matter.
7.9	10.8	2.9	Sand, very coarse to medium composed of quartz, mica, ferruginous matter and pebbles of quartzite.
10.8	14.3	3.5	Pebbles and boulders of quartzite and massive quartz, greyish pink in colour with a little very coarse sand.
14.3	27.4	13.1	Boulders and pebbles of quartzite and massive quartz as above and ferruginous matter with clay.
27.4	30.4	3.0	Boulders and pebbles as above with increasing amount of clay.
30.4	55.5	25.1	Sand, mostly medium and a little fine graineds, angular to sub-rounded, consisting of quartz, mica, and a few pebbles of quartz, quartzite and basic rock (may be from upper zone due to caving.)
55.5	58.5	3.0	Pebbles of quartz and quartzite (grey and pink in colour) with basic rock, clay and fine sand in small quantities.
58.5	60.7	2.2	Sand, coarse, consisting of quartz, mica and ferruginous matter, and pebbles of quartz, quartzite ad weathered basic rock.
60.7	64.3	3.6	Pebbles of quartzite, quartz and weathered basic rock with a little fine to medium sand.
64.3	71.3	7.0	Pebbles and boulders of grey and pink quartzite, quartz and weathered basic rock with a little clay.
71.3	84.4	13.1	Boulders and pebbles grey and pink in colour, of quartzite, quartz and weathered basic rock with a small quantity of medium to coarse sand.

DHELA

Depth Range (m bgl)		*Thickness (m)*	*Lithology*
From	*To*		
0.00	9.00	9.00	Surface soil, clay with boulders and gravels.
9.00	19.00	10.00	Angular chips, coming through boulders of quartzite.
19.00	21.00	2.00	Clay, yellowish and hard sand, fine to medium mixed
21.00	23.00	2.00	Sand, fine to medium mixed with loose clay and gravel, clay yellowish and hard
23.00	34.00	11.00	Clay, yellowish and hard
34.00	42.00	8.00	Sand, medium mixed with gravel and chips of quartzite boulders
42.00	45.00	3.00	Sand fine to medium mixed with gravel, cobbles and pebbles
45.00	55.00	10.00	Clay, yellowish and hard
55.00	65.00	10.00	Angular pieces of boulders, cobbles and pebbles
65.00	69.00	4.00	Sand, coarse, consisting of quart, feldspar pieces and chips of boulders
69.00	75.00	6.00	Sand, medium to coarse yellowish mixed with quartz
75.00	88.90	13.90	Pieces of cobbles, pebbles mixed with gravel
88.90	118.00	29.10	Clay, yellowish and hard
118.00	139.00	21.00	Clay, yellowish hard and mixed with silt
139.00	143.00	4.00	Angular to sub-angular pieces of quartz and sandstone
143.00	146.00	3.00	Clay, yellowish and hard
146.00	156.00	10.00	Clay mixed with fine sand, pieces of quartz and sandstone
156.00	170.00	14.00	Pieces of quartz and sandstone
170.00	181.00	11.00	Clay yellowish and hard
181.00	184.00	3.00	Clay mixed with fine sand
184.00	187.00	3.00	Clay, yellowish hard and plastic
187.00	192.00	5.00	Sand fine, rounded to sub-rounded mixed with quartz and feldspar pieces

HIMMATPUR

Depth Range (m bgl)		*Thickness (m)*	*Lithology*	
From	*To*			
0.0	1.2	1.2	Silt	Micaceous, brown.
1.2	1.5	0.3	Silt	As above with cobbles of quartzite, sub-rounded.
1.5	2.1	0.6	Sand	Fine to medium with cobbles of quartzite, sub-rounded.

2.1	5.2	3.1	Cobbles	Pebbles and coarse sand, essentially of quartzite, grey, pink and white, cobbles sub-rounded.
5.2	11.3	6.1	Cobbles	As above with little brown clay.
11.3	23.2	11.9	Sand	Coarse to very coarse with boulders mainly of quartzite, some of granite and granite gneisses, sub-rounded.
23.2	23.8	0.6	Clay	Sandy, light brown with pebbles and boulders.
23.8	28.3	4.5	Clay	As above, hard, micaceous.
28.3	29.0	0.7	Sand	Coarse to very coarse, dark grey, very angular, most of the grains tabular.
29.0	32.9	3.9	Clay	Sandy, light brown with pebbles and kankar.
32.9	48.7	15.8	Pebbles	Cobbles and boulders with sand, fine to coarse in varying quantities, composed mostly of quartzite, a little of sandstones, sub-rounded to rounded.
48.7	63.4	14.7	Sand	Fine to medium with a little gravel pebbles and cobbles and occasional boulders, mostly of quartzite sub-rounded.
63.4	82.3	18.9	Boulders	Cobbles, pebbles with a little sand sub-rounded to rounded mostly of quartzite, a few granite, quartzite, gneiss, phyllite and sandstone, quartzite between 67.1and 73.2 metre bgl with pitted surface.

RAMNAGAR

Depth Range (m bgl)		***Thickness (m)***	***Lithology***
From	***To***		
0.0	6.0	6.0	Boulders (> cobble size), granules and very coarse sand fraction, dark brown to dull grey colour
6.0	18.0	12.0	Admixture of pebbles, cobbles, very coarse sand, medium sand of varied shapes, angular, sub rounded to tabular fractions common, very poorly sorted, grey coloured
18.0	19.0	1.0	Coarse to medium sand, poorly sorted mixed with light brown clay
19.0	21.0	2.0	Very hard and compact clay, buff coloured
21.0	22.0	1.0	Very coarse to medium sand with clay (buff coloured)
22.0	26.0	4.0	Admixture of very coarse – medium – fine sand and granules with sporadic clay distribution, light brown to grey coloured, clay content of the zone increases towards the bottom
26.0	42.0	16.0	Clay, sticky, compact and hard
42.0	47.0	5.0	Admixture of clay, granules and coarse sand with a gradual decrease in clay proportion followed by a gradual increase in the finer fractions, light brown in colour
47.0	56.0	9.0	Clay, buff coloured, cohesive and compact (boulder horizon at a depth zone of 52.5 to 53.5 m)
56.0	62.0	6.0	Clay with fine to medium sand

62.0	64.0	2.0	Gravel, rounded to sub rounded, dull grey coloured, mixed with little calc matter.
64.0	65.0	1.0	Clay, sticky and plastic, pale yellow in colour
65.0	66.0	1.0	Sand and gravel mixed with little clay
66.0	67.0	1.0	1.0Sand and gravel, rounded to sub rounded and angular fragments
67.0	68.0	1.0	Clay, mixed with angular fragments of boulders
68.0	69.0	1.0	Fine grained sand
69.0	71.0	2.0	Coarse sand and gravel, rounded to sub rounded mixed with calc matter.
71.0	72.0	1.0	Clay, with little amounts of fine grained sand
72.0	74.0	2.0	Clay, hard and compact, greyish in colour
74.0	76.0	2.0	Clay, hard and compact, yellow in colour
76.0	77.0	1.0	Clay, hard and compact, mixed with gravel
77.0	78.0	1.0	Clay, hard and compact
78.0	80.0	2.0	Clay, mixed with calc nodules
80.0	84.0	4.0	Clay, hard and compact, sticky, yellow in colour
84.0	87.0	3.0	Clay, hard and compact, sticky, greyish in colour
87.0	88.0	1.0	Sand, medium to coarse grained, mixed with little gravel
88.0	93.0	5.0	Clay, with little sand, medium grained
93.0	94.0	1.0	Clay, greyish in colour
94.0	98.0	4.0	Clay hard and compact, yellow in colour
98.0	99.0	1.0	Sand, medium to coarse gained
99.0	108.0	9.0	Sand, medium to coarse gained, mixed with gravel, rounded to sub rounded
108.0	114.0	6.0	Clay, sticky and plastic, yellow in colour
114.0	115.0	1.0	Clay, sticky and plastic, yellow in colour, mixed with gravel
115.0	123.0	8.0	Sand, coarse grained mixed with gravel, rounded to sub rounded
123.0	124.0	1.0	Sand, coarse grained mixed with gravel, pebbles of dull grey ro brownish, sub angular to rounded
124.0	125.0	1.0	Sand, fine to medium grained
125.0	127.0	2.0	Clay, sticky, yellow, mixed with little sand and gravel
127.0	128.0	1.0	Sand fine to coarse grained, admixed with gravel
128.0	130.0	2.0	Clay, sticky and plastic
130.0	138.0	8.0	Sand, fine to coarse grained, mixed with gravel, rounded to sub rounded, greyish in colour
138.0	140.0	2.0	Sand, fine to medium grained
140.0	146.0	6.0	Clay, sticky and plastic in nature
146.0	148.0	2.0	Clay, mixed with little sand
148.0	154.0	6.0	Sand, coarse grained, mixed with gravel, pebble, rounded to sub rounded, grey to brown in colour.

HIMMATPUR ANDHERIA

Depth Range (m bgl)		*Thickness (m)*	**Lithology**
From (m)	*To (m)*		
0	3	3	Surface soil and gravels
3	5.15	2.15	Boulder cutting + V.Coarse to Medium Sand
5.85	8.85	3	Boulder cutting + Coarse to Medium Sand
8.85	11.95	3.1	Boulder cutting
11.95	14.95	3	Boulder cutting
14.95	18.05	3.1	Boulder cutting + fine sand
18.05	21.05	3	Gravels + clayey sand
21.05	24.15	3.1	Gravels + clayey sand
24.15	27.15	3	Clay+gravels
27.15	30.25	3.1	Sandy clay + gravels
30.25	33.1	2.85	Clayey sand + gravels
33.1	35.85	2.75	Medium to fine sand+ gravels
35.85	38.85	3	Coarse to medium sand + gravels
38.85	41.95	3.1	fine sand + gravels
41.95	44.95	3	Coarse to medium sand + gravels
44.95	50.05	5.1	Medium to fine sand+ gravels
50.05	52.15	2.1	Coarse to medium sand + gravels
52.15	55.15	3	Fine sand + gravels
55.15	56.2	1.05	Gravels + medium to fine sand
56.2	59.2	3	Coarse to medium sand + gravels
59.2	64.3	5.1	Medium to fine grained sand+ gravels(less in proportion)
64.3	65.3	1	Coarse to medium grained sand+ gravels
65.3	70.7	5.4	Coarse to medium grained sand+ gravels
70.7	72.7	2	Gravels + coarse grained sand
72.7	76	3.3	Medium to coarse sand + boulders

76	77.5	1.5	Medium to fine sand+ gravels
77.5	83.1	5.6	Boulders + coarse to medium sand
83.1	86.35	3.25	Boulders + coarse to medium sand
86.35	88.85	2.5	Boulder cutting + Coarse to medium sand
88.85	91.1	2.25	Boulder cutting + Coarse to medium sand
91.1	91.9	0.8	Boulder cutting + Coarse to medium sand

FOREST COLONY

Depth range (m bgl)		***Thickness (m)***	***Lithology***
From (m)	***To (m)***		
0	9.3	9.3	Surface soil & pebbles of rock fragments of variable colour and size.
9.3	12.4	3.1	Angular to sub-rounded pebbles & cobbles comprising phyllite & quartzite
12.4	15.4	3	Pebbles/cobbles of rock fragments with grayish brown clay
15.4	18.5	3.1	Sub-rounded to angular rock fragments
18.5	21.5	3	Sand, coarse grained, grey in colour
21.5	24.6	3.1	Coarse sand mixed with crushed rock fragments (quartzite)
24.6	30.7	6.1	Crushed rock fragments with angular to sub angular pebbles & cobbles
30.7	36.8	6.1	Coarse sand mixed with quartzite and occasional rock fragments (sub-angular & angular)
36.8	42.9	6.1	Crushed rock fragments of variable colour mixed with little clay (non-sticky)
42.9	49	6.1	Rock fragments of variable colour & size, mixed with clay
49	52	3	Coarse sand, brownish gray with occasional rock fragments
52	58.1	6.1	Rock fragments (angular to rounded) of quartzite & potassic granite(with K feldspar and quartz) mixed with clay
-58.1	7.3	65.4	Rock, fragment of none or less uniform size (pebbles mixed with coarse sand)
-67.3	9.5	76.8	Fine sand & silt mixed with clay, brownish grey in colour

79.5	85.6	6.1	Rock fragments(pebbles) of variable colour but generally uniform size, mixed with little find sand
85.6	88.6	3	Fine sand mixed with non-sticky clay, brownish grey in colour
88.6	100.8	12.2	Find sand, brownish grey with less amount of rock fragments (sub-angular to sub-rounded)
100.8	103.9	3.1	Predominately fine sand (brownish quartzite) with small angular rock fragments of quartzite.
103.9	116.1	12.2	Medium grained sand mixed with sub-rounded to rounded rock fragments of relatively uniform size
116.1	119.1	3	Medium to fine sand, yellowish brown coloured
119.1	122.2	3.1	Rock fragments of variable colour & size mixed with find sand of yellowish brown colour
122.2	131.3	9.1	Rock fragments of variable size & colour (size ranging from pebble to cobble)
131.3	137.4	6.1	Rock fragments of variable colour and size with find sand, greyish yellow in colour
137.4	165.4	28	Rock fragments (angular, sub-angular & sub-rounded pebbles) of variable colour
165.4	171.5	6.1	Yellowish brown clay, sticky & plastic, mixed with angular to sub-angular rock fragments of variable size
171.5	174.5	3	Fine rock fragments of variable colour but overall uniform size (pebbles)
174.5	177.6	3.1	Coarse sand, yellowish brown in colour, mixed with rock fragments of variable colour and size
177.6	183.7	6.1	Rounded to angular pebbles of sandstone (black sandstone with white vein quartz), variable in size & colour
183.7	195.4	11.7	Medium to coarse sand, brownish yellow in colour, mixed with sub-angular to sub-rounded rock fragments (quartzite pebbles) of variable colour
195.4	201.5	6.1	Sub-angular to rounded rock fragments (pebbles) of variable colour
201.5	205.6	4.1	Medium to coarse sand, yellowish brown in colour, mixed with rock fragments of variable colour and size (cobbles & pebbles)
205.6	207.36	1.76	Quartzite pebbles of variable colour and shape

207.36	225.6	18.24	Coarse & medium sand, yellowish brown in colour, mixed with pebbles and cobbles of quartzite and granite
225.6	228.72	3.12	Brown clay, non-sticky, mixed with sub-angular to rounded rock fragments (pebbles of quartzite)
228.72	240.96	12.24	Predominantly angular rock fragments (pebbles) of variable colour, mixed with gray coloured, medium to coarse sand
240.96	243.96	3	Fine to medium sand, brownish yellow in colour, with minor amount of sub-angular to rounded rock fragments (pebbles of quartzite) of variable colour

PANIYALI

Depth range (m bgl)		***Thickness (m)***	***Lithology***
From (m)	***To (m)***		
0	3	3	Fine grained yellowish coloured sand + pebbles
3	4.7	1.7	Fine grained yellowish coloured sand + pebbles
4.7	7.7	3	Sand with silt and clay + pebbles
7.7	10.8	3.1	sand yellowish in colour + pebbles
10.8	13.8	3	Fine grained yellowish coloured sand + pebbles
13.8	16.9	3.1	Fine grained yellowish coloured sand + pebbles
16.9	19.9	3	Fine grained Yellowish coloured Sand
19.9	23	3.1	Fine grained yellowish coloured sand + pebbles
23.0	26	3	Fine grained yellowish coloured sand + pebbles
26	29.1	3.1	Fine grained yellowish coloured sand + pebbles
29.1	32.1	3	Fine grained yellowish coloured sand + pebbles
32.1	35.2	3.1	Fine grained yellowish coloured sand + pebbles
35.	38.2	3	Fine yellowish coloured sand

38.2	41.3	3.1	Gravel with Silt and minor clay
41.3	44.3	3	Fine grained yellowish coloured sand + pebbles
44.3	47.4	3.1	Fine grained yellowish coloured sand + pebbles
47.4	50.4	3	Fine grained sand
50.4	53.5	3.1	Fine grained yellowish coloured sand + pebbles
53.5	56.5	3	Fine grained yellowish coloured sand + pebbles
56.5	59.6	3.1	Coarse grained sand + pebbles
59.6	62.6	3	Fine grained yellowish coloured sand + pebbles
62.6	65.7	3.1	Fine grained yellowish coloured sand + pebbles
65.7	68.7	3	Fine grained yellowish coloured sand + pebbles
68.7	71.8	3.1	Fine grained yellowish coloured sand + pebbles
71.8	74.8	3	Fine grained yellowish coloured sand + pebbles
74.8	77.9	3.1	Fine grained yellowish coloured sand + pebbles
77.9	80.9	3	Fine grained yellowish coloured sand + pebbles
80.9	84	3.1	Fine grained yellowish coloured sand + pebbles
84	87	3	Fine grained yellowish coloured sand + pebbles
87	90.1	3.1	Fine grained yellowish coloured sand + pebbles
90.1	93.1	3	Fine grained yellowish coloured sand + pebbles
93.1	96.2	3.1	Fine grained grey coloured Sand +pebbles
96.2	98.2	2	Fine grained grey coloured Sand +pebbles
98.2	99.2	1	Fine grained brownish yellow coloured sand
99.2	102.3	3.1	Fine grained yellowish coloured sand + pebbles
102.3	108.4	6.1	Fine grained yellowish coloured sand + pebbles
108.4	111.4	3	Clay +pebbles

111.4	114.5	3.1	Clay +Pebbles
114.5	117.5	3	Fine grained Sand+Pebbles+Clay
117.5	120.6	3.1	Fine grained Sand+Clay+Pebbles
120.6	123.6	3	Fine grained Sand+Pebbles
123.6	126.7	3.1	Fine grained Sand+Pebbles
126.7	129.7	3	Fine grained Sand+Pebbles
129.7	133.5	3.8	Pebbles
133.5	135.8	2.3	Fine grained grey coloured sand+Clay+Pebbles
135.8	138.9	3.1	Fine grainmed coloured sand+Clay+Pebbles
138.9	141.9	3	Coarse grained grey coloured sand+ Pebbles
141.9	145	3.1	Fine grained sand+Pebbles
145	148	3	Fine grained sand+Pebbles
148	151.1	3.1	Coarse grained sand + pebbles
151.1	154.1	3	Pebbles
154.1	157.2	3.1	Clay +pebbles
157.2	160.2	3	Fine grained sand+Pebbles
160.2	163.3	3.1	Fine Grained grey coloured sand+ pebbles
163.3	166.3	3	Fine Grained grey coloured sand+ pebbles
166.3	169.4	3.1	Fine Grained yellow coloured sand+ pebbles
169.4	172.4	3	Fine Grained yellow coloured sand+ pebbles
172.4	175.5	3.1	Fine Grained reddish yellow coloured sand+ pebbles
175.5	178.5	3	Fine to Coarse Grained yellow coloured sand+ pebbles
178.5	181.6	3.1	Fine Grained yellow coloured sand+ pebbles
181.6	184.6	3	Clay + pebbles

184.6	187.7	3.1	Clay + Sand + pebbles
187.7	190.7	3	Medium to Coarse grained Sand+Pebbles
190.7	193.8	3.1	Medium to Coarse grained Sand+Pebbles
193.8	196.8	3	Medium to Coarse grained Sand+Pebbles
196.8	199.9	3.1	Medium to Coarse grained Sand+Pebbles
199.9	202.9	3	Medium to Coarse grained Sand+Pebbles
202.9	206	3.1	Medium to Coarse grained Sand+Pebbles
206	209	3	Medium to Coarse grained Sand+Pebbles
209	212.1	3.1	Medium to Coarse grained Sand+Pebbles
212.1	215.1	3	Medium to Coarse grained Sand+ Clay + Pebbles
215.1	217	1.9	Medium grained sand+ Pebbles
217	220	3	Medium to Coarse grained Sand+Pebbles
220	223.1	3.1	Medium to Coarse grained Sand+Pebbles
223.1	226.1	3	Medium to Coarse grained Sand+Pebbles
226.1	229.2	3.1	Medium to Coarse grained Sand+Pebbles
229.2	232.2	3	Medium to Coarse grained Sand+Pebbles
232.2	235.3	3.1	Fine Grained sand + Pebbles
235.3	238.3	3	Medium Grained sand + Pebbles
238.3	240.9	2.6	Medium Grained sand + Pebbles
240.9	243.9	3	Medium Grained sand + Pebbles
243.9	247	3.1	Medium Grained sand + Clay+Pebbles
247	250	3	Coarse Grained Yellow coloured Sand + pebbles
250	253.1	3.1	Coarse Grained Yellow coloured Sand + pebbles
253.1	258.5	5.4	Coarse Grained Yellow coloured Sand + pebbles

258.5	259.2	0.7	Coarse Grained Yellow coloured Sand + pebbles
259.2	262.2	3	Coarse Grained Yellow coloured Sand + pebbles
262.2	265.3	3.1	Coarse Grained Yellow coloured Sand + pebbles
265.3	268.3	3	Coarse Grained Yellow coloured Sand + pebbles
268.3	271.4	3.1	Coarse Grained Yellow coloured Sand + pebbles
271.4	274.4	3	Medium to Coarse grained yellow coloured sand +Gravels
274.4	277.5	3.1	Medium to Coarse grained yellow coloured sand +Gravels
277.5	280.5	3	Medium to Coarse grained yellow coloured sand +Gravels
280.5	283.6	3.1	Medium to Coarse grained yellow coloured sand +Gravels
283.6	287.15	3.55	Medium to Coarse grained yellow coloured sand +Gravels
287.15	290.20	3.05	Sand (fine, yellow) pebbles
290.2	292.2	2	Medium to Coarse grained yellow coloured sand +Gravels
292.2	295.2	3	Medium to Coarse grained yellow coloured sand +Gravels
295.2	298.3	3.1	Medium to Coarse grained yellow coloured sand +Gravels
298.3	301.3 *	3	Medium to Coarse grained yellow coloured sand +Gravels
301.3	304.4	3.1	Medium to Coarse grained yellow coloured sand +Gravels
304.4	307.40	3	Medium Size grained sand+ Pebbles
307.4	310.5	3.1	Fine size grained Sand + Clay
310.5	313.5	3	Medium to Coarse grained yellow coloured sand + Pebbles
313.5	316.6	3.1	Medium to Coarse grained sand + Pebbles
316.6	319.6	3	Coarse Grained grey coloured sand + gravels
319.6	322.7	3.1	Coarse Grained grey coloured sand + gravels
322.7	325.7	3	Coarse Grained grey coloured sand + gravels
325.7	328.8	3.1	Coarse Grained grey coloured sand+ gravels

328.8	331.8	3	Coarse Grained grey coloured sand+ gravels
331.8	334.9	3.1	Coarse Grained grey coloured sand + gravels
334.9	337.9	3	Coarse Grained grey coloured sand + gravels
337.9	341	3.1	Coarse Grained grey coloured sand + gravels
341	34	3	Medium grained grey coloured Sand + gravel
344	347.1	3.1	Medium to coarse grained yellow coloured sand
347.1	350.1	3	Medium to coarse grained yellow coloured sand + Pebbles
350.1	353.2	3.1	Coarse Grained Yellow coloured Sand+ Pebbles
353.2	356.2	3	Medium to Coarse grained sand
356.2	359.3	3.1	Medium to Coarse grained sand
359.3	362.3	3	Medium to Coarse grained sand
362.3	365.4	3.1	Medium to fine grained brown coloured sand + Clay
365.4	368.4	3	Medium to Coarse grained yellow coloured sand + Pebbles
368.4	371.5	3.1	Coarse grained grey coloured Sand + Gravels
371.5	374.75	3.25	Coarse grained grey coloured Sand + Pebbles
374.75	380.85	6.1	Coarse grained grey coloured Sand + Pebbles
380.85	383.95	3.1	Coarse grained grey coloured Sand + Pebbles
383.95	386.95	3	Coarse grained grey coloured Sand + Pebbles
386.95	387.95	1	Coarse grained grey coloured Sand + Pebbles
387.95	390.05	2.1	Medium to Coarse grained yellow coloured sand + Pebbles
390.05	393.05	3	Coarse grained Yellow Sand + Pebbles
393.05	396.15	3.1	Medium to Coarse grained yellow coloured sand + Pebbles
396.15	399.15	3	Coarse grained Yellow Sand + Pebbles
399.15	402.25	3.1	Coarse grained Yellow Sand + Pebbles

*** Since the aim of NAQUIM programme is delineaton of aquifer information upto depth of 300 m bgl hence for exploratory well in Paniyali lithological information upto depth of 300 m bgl considered during preparation of fence diagram.**

Annexure 2 Depth to Water level data of Ground Water Monitoring stations in the study area of Nainital district

Sl.No.	Block	Location	Details	Latitude	Longitude	Type of Structure	Depth to water level (mbgl)		Fluctuation (mbgl)
							May-20	Nov-20	
1	Haldwani	**Khaat Baans**	On Chorgaliya-Sitarganj road, about 3 km from Chorgaliya, about 20 m SSW of missionary school/church, in front of Prabhat Tara Purva Madhyamik Vidyalaya.	29°06'00"	79°41'33"	Hand Pump	36.17	31.1	5.07
2		**Lalkuan**	Near Tahsil/PWD Store	29°04'28"	79°31'20"	Dug Well	17.82	10.55	7.27
3		**Kaladungi**	The hand pump is located E of Siddha Brahma Babu Mandir, about 1.8 km from Bazpur-Haldwani-Kotabagh/Aonlakot tiraha (culvert No. 35/1), Baur river bridge.	29°18'09"	79°19'41"	Hand Pump	29.12	28.73	0.39
4		**Kathgodam**	At Shani Dev Mandir/Peepal Tree, located behind Kathgodam sub-post office, about 50 m from Kathgodam railway station. LHS of road from Haldwani to Nainital.	29°16'00"	79°32'41"	Hand Pump	18.45	14.6	3.85
5	Ramnagar	**Belparao**	About 14km from Ramnagar, near tiraha crossing, towards Bhel Parao – Bazpur road, in front of Big mango trees, near Harish General store. Also 22km from Bazpur**.**	29°18'41"	79°12'36"	Hand Pump	57.71	60	-2.29

Sl.No.	Block	Location	Details	Latitude	Longitude	Type of Structure	Depth to water level (mbgl)		Fluctuation (mbgl)
							May-20	Nov-20	
6	Ramnagar	**Peeru Madara**	Located just in front of Peeru Madara bus shelter in Peeru Madara Chauraha. The village is located on Ramnagar-Kahsipur highway; after Kashipur 18 km distance stone	29°20'11"	79°03'48"	Hand Pump	26.49	23.43	3.06
7		**Maldhan Colony**	In the Forest check-post, the village is located in between Garhi Negi and Dhela and approached from Kunda Chauraha.	29°19'11"	78°57'46"	Dug Well	4.22	2.83	1.39
8		**Dhela**	About 500m from forest check-post and main road towards Dehela village. At Chauraha, right side of road. In front of a shop namely Corbett nature shop & Jungle Safari, near Atta Chakki and mobile tower.	29°25'05"	79°00'00"	Hand Pump	65.83	79.03	-13.2
9		**Ram Nagar**	Located in the premises of Pyarelal Navda Garhwal (PNG) Govt. Intermediate College. The college is approached Pyaralal Nanda Garhwal (PNB) from Ramnagar Chauraha on the way to Kosi bridge.	29°23'41"	79°07'38"	Hand Pump	6.06	5.74	0.32

Sl.No.	Block	Location	Details	Latitude	Longitude	Type of Structure	Depth to water level (mbgl)		Fluctuation (mbgl)
							May-20	Nov-20	
10	Ramnagar	**Garjiya**	About 400m from main road towards River edge restaurant at Corbett's river side retreat, about 30 m from River Edge restaurant in an open ground on the right bank of river	29°29'19"	79°08'31"	Dug Well	3.68	4.35	-0.67
11		**Dohniya**	About 11km from Bhel parao and 2 km before Kotabagh. At Dhoniya Tiraha crossing, right side of road in front of Shiv/Hanuman Temple towards Kotabagh	29°23'10"	79°17'13"	Hand Pump	60.7	56.7	4
12		**Chilkiya**	About 22 km from Kashipur, near K.G.N. Motors (Tata Authorized centre) and Bisht General Store, Ramnagar block	29°21'59"	79°05'53	Hand Pump	56.08	55.88	0.2

Annexure 3 Decadal Water level fluctuation 2010-2019 vs 2020 (Pre-monsoon)

Sl. No.	Block	Location	Latitude	Longitude	Pre-monsoon 2010-19 Average (m bgl)	Pre-monsoon 2020 (m bgl)	Fluctuation (m bgl)
1	Haldwani	Khaat Baans	29°06'00"	79°41'33"	29.57	36.17	-6.60
2		Lalkuan	29°04'28"	79°31'20"	9.98	17.82	-7.84
3		Kaladungi	29°18'09"	79°19'41"	29.77	29.12	-0.65
4		Kathgodam	29°16'00"	79°32'41"	20.58	18.45	2.13
5	Ramnagar	Belparao	29°18'41"	79°12'36"	57.58	57.71	-0.13
6		Peeru Madara	29°20'11"	79°03'48"	26.84	26.49	0.35
7		Maldhan Colony	29°19'11"	78°57'46"	4.90	4.22	0.68
8		Dhela	29°25'05"	79°00'00"	68.10	65.83	2.27
9		Ram Nagar	29°23'41"	79°07'38"	8.37	6.06	2.31
10		Garjiya	29°29'19"	79°08'31"	4.80	4.65	0.15
11		Dohniya	29°23'10"	79°17'13"	67.14	60.7	6.44
12		Chilkiya	29°21'59"	79°05'53	55.86	56.08	-0.23

Annexure 4 Decadal Water level fluctuation 2010-2019 vs 2020 (Post-monsoon)

Sl. No.	Block	Location	Latitude	Longitude	Post-monsoon 2010-19 Average	Post-monsoon 2020	Fluctuation
1	Haldwani	Khaat Baans	29°06'00"	79°41'33"	29.39	31.1	-1.71
2		Lalkuan	29°04'28"	79°31'20"	8.54	10.55	-2.01
3		Kaladungi	29°18'09"	79°19'41"	27.22	27.73	-0.61
4		Kathgodam	29°16'00"	79°32'41"	17.33	14.6	2.73
5	Ramnagar	Belparao	29°18'41"	79°12'36"	54.86	60	-5.14
6		Peeru Madara	29°20'11"	79°03'48"	19.95	23.43	-3.48
7		Maldhan Colony	29°19'11"	78°57'46"	4.19	2.83	1.36
8		Dhela	29°25'05"	79°00'00"	68.11	79.03	-10.92
9		Ram Nagar	29°23'41"	79°07'38"	8.83	5.74	3.09
10		Garjiya	29°29'19"	79°08'31"	4.06	3.68	0.38
11		Dohniya	29°23'10"	79°17'13"	58.08	56.7	1.38
12		Chilkiya	29°21'59"	79°05'53	50.7	55.88	-5.18

Annexure 5 Ground water quality data of Nainital district

Sample Location	pH	Conductivity µmho/cm at 25°C	CO_3	HCO_3	Cl	F	NO_3	SO_4	Hardness as CaCO3	Ca Hardness	Mg Hardness	Na	K	SiO_2	PO_4
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Khat Baans	8.32	522	12	232	43	BDL	8.8	9.3	260	88	9.6	7.9	1.4	27	nd
Lalkuan	8.47	582	24	268	14	BDL	14	24	300	80	24	6.5	2.9	40	nd
Kaladhungi	8.39	616	18	281	7.1	BDL	5	52	310	68	34	5.6	1.2	29	nd
Kathgodam	8.49	554	24	244	14	BDL	18	24	250	80	12	20	4.2	28	nd
Belparao	8.58	346	24	146	7.1	BDL	5	7	160	28	22	8.8	3.3	17	nd
Peeru Madara	8.51	472	24	207	14	BDL	13	19	230	44	29	9.9	2.4	28	nd
Maldhan Colony	8.58	748	36	354	21	0.29	10	5	280	100	7.2	44	5.2	33	nd
Dhela	8.16	566	nil	329	14	BDL	5	5.7	270	88	12	12	1	31	nd
Ramnagar	8.57	624	48	256	7.1	BDL	BDL	5	260	52	31	22	3.7	29	nd
Garjia	8.61	370	18	159	7.1	BDL	BDL	15.5	170	52	9.6	6.5	2.3	15	nd
Dhoniya	8.21	307	nil	110	7.1	BDL	BDL	47	130	24	17	6.3	1.1	14	nd
Chilkiya	8.69	564	48	244	7.1	BDL	BDL	13	280	72	24	9.3	2.4	23	nd

*BDL – Below Detectable Limit

*nd - not detected