केंद्रीय भूमि जल बोर्ड
जल संसाधन, नदी विकास और गंगा संरक्षण मंत्रालय
भारत सरकार
Central Ground Water Board
Ministry of Water Resources, River Development and Ganga Rejuvenation
Government of India

Report
on

AQUIFER MAPPING AND GROUND WATER MANAGEMENT PLAN

Udham Singh Nagar District, Uttarakhand

उत्तरांचल क्षेत्र, देहरादून
Uttaranchal Region, Dehradun

CENTRAL GROUND WATER BOARD
MINISTRY OF WATER RESOURCES
GOVERNMENT OF INDIA

AQUIFER MAPPING REPORT, PARTS OF UDHAM SINGH NAGAR DISTRICT, UTTARAKHAND

UTTARANCHAL REGION
DEHRADUN
OCTOBER – 2016

AQUIFER MAPPING REPORT, PARTS OF UDHAM SINGH NAGAR DISTRICT, UTTARAKHAND

By

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PREFACE

A study on Aquifer Mapping in Parts of Udham Singh Nagar District, Uttarakhand was taken up by Central Ground Water Board, Uttaranchal Regionduring AAP 2015-16 with an objective to identify and map the aquifers at micro level, quantify the availability of the ground water resource and suggest aquifer management plans compatible with the Ground Water demand, the aquifer characteristics and the basic issues of the area. The study area consists of 3 Blocks of Udham Singh Nagar district i.eJaspur, Kashipur & Bazpur covering an area of around 811 sq.km.

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

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

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

Place: Dehradun **(Anurag Khanna)**

Date: 05/10/2016 **Head of the Offfice**

EXECUTIVE SUMMARY

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

The total study area taken up for the aquifer mapping is about 811 sq.km. The area includes 3 blocks of Udham Singh Nagar District i.eJaspur, Kashipur & Bazpur, Uttarakhand. There exist multiple aquifers in the study area which are separated by thick clay layers of the thickness 17 to 35 m.The granular zones are composite in nature (Boulders mixed with pebbles, gravels, cobbles sand and clay), and are separated by the thick confining clay layers. The thickness of granular zone varies from 10 to 30 m. The First – second and second - third aquifer is separated by 17-21m and 14 to 39 m thick clay layer. The sand grains also show gradation from coarse to fine grain. The piezometeric levels in all wells is very shallow within the range of 1 to 4 mbgl and 7mbgl at Khempur. Geologically, the Tarai and Bhabhar formation of tertiary age exists in the area. Aquifers are encountered at the depths of 45 to 70 m and 125 to 160 m. These are unconfined to semiconfined in nature. The quality of the Ground Water is also suitable for drinking and irrigational purposes with EC values around 399 – 750 micromhos/cm. Ground water level in the study area is about 1.15 m bgl to 7 m bgl. The Groundwater is the main source of water for fulfilling the demands of irrigation, domestic and industrial purposes. The aquifer disposition and characteristics prevailing in the area has been studied based on exploratory drilling tapping different aquifers. Monitoring of Ground Water regime is done 4 times a year i.e May, August, November and January.

The main Ground Water related problem in the study area is shrinkage of the Auto Flow zone. The Possible causes for shrinkage of the Auto Flow Zones and reduction in discharges of the Artesian heads is 1) the Massive deforestation in the Bhabar zone which is the recharge area of the Tarai aquifers. 2) Rapid increase in the number of shallow tube wells in the region consequent upon increase in agricultural land. 3) No mechanism to control and regulate the flow of these Auto Flow wells. 4)General downward trend in the rainfall in the region. And 5) Increase in agricultural practices using Ground Water by constructing shallow tube wells.

Based on the present and past studies certain recommendations are made to augment the artesian wells for further future needs and development.1) It is recommended that to lessen the strain on artesian aquifers occurring in shallow depth range, the deeper artesian aquifers should be tapped. 2) Afforestation in Bhabar Zone will increase recharge in Tarai. 3) Artificial recharge in the Bhabar, which serves as the recharge zone, by building successively bigger bunds at suitable distance on the stream channels flowing through the Bhabar. This will check the rum off and allow the water to stay for a greater period of time leading to percolation downwards. 4) Change of cropping pattern also to be adopted, which helps to augment the groundwater.4) Battery of tube wells can be constructed at the flood plains of the river, instead of drilling cluster of tube wells in the different areas. 5) It is recommended that the free flowing wells be equipped with sluice valve so that the yield is fully controlled.

The study recommended development of holistic water management programme which involves controlled use of available fresh water resources and no new Ground Water based industry should be allowed in the study area as the Stage ofDynamic Groundwater Development in the study area already reaches 80 % and there exist 2 critical blocks also.

CHAPTER – 1
INTRODUCTION

1.1 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 7811sq km has been year marked for Aquifer Mapping during 2012-17. The present report embodies the above objective in parts of the Udham Singh Nagar district having area of 888 km sq, comprising of 3 blocks i.e Jaspur, Kashipur and Bazpur block. 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, type of aquifers, ground water regime behaviors, and hydraulic characteristics of Multi-layered aquifer systems on 1:50,000 scale in parts of Udham Singh Nagar 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.

The activities of the Aquifer Mapping can be envisaged as follows

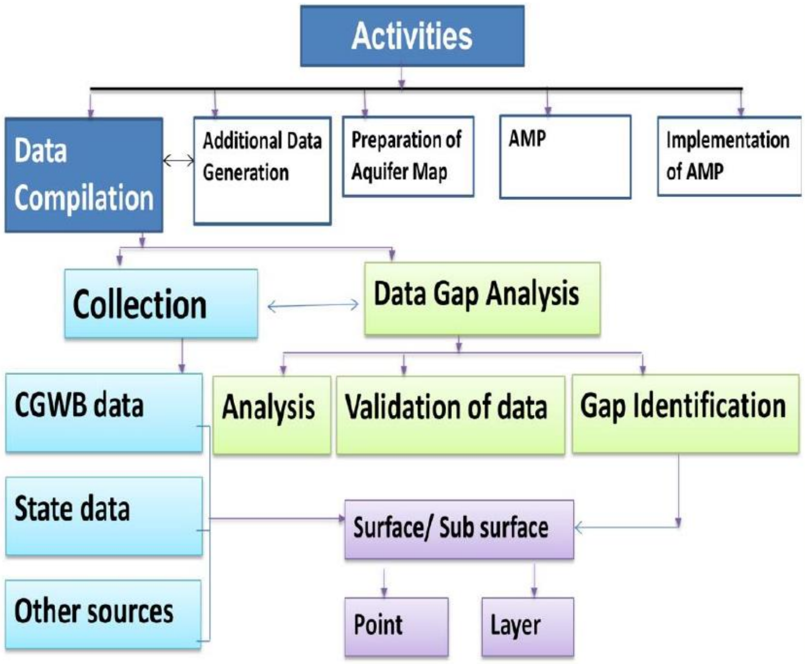
1. **Data Compilation & Data Gap Analysis:** One of the important aspect of the aquifer mapping programme was the synthesis of the large volume of data already collected during specific studies carried out by Central Ground Water Board and various Government organizations with a new data set generated that broadly describe an aquifer system. The data were assembled, 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.

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.
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.
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

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 and Fig 2.



Methodology

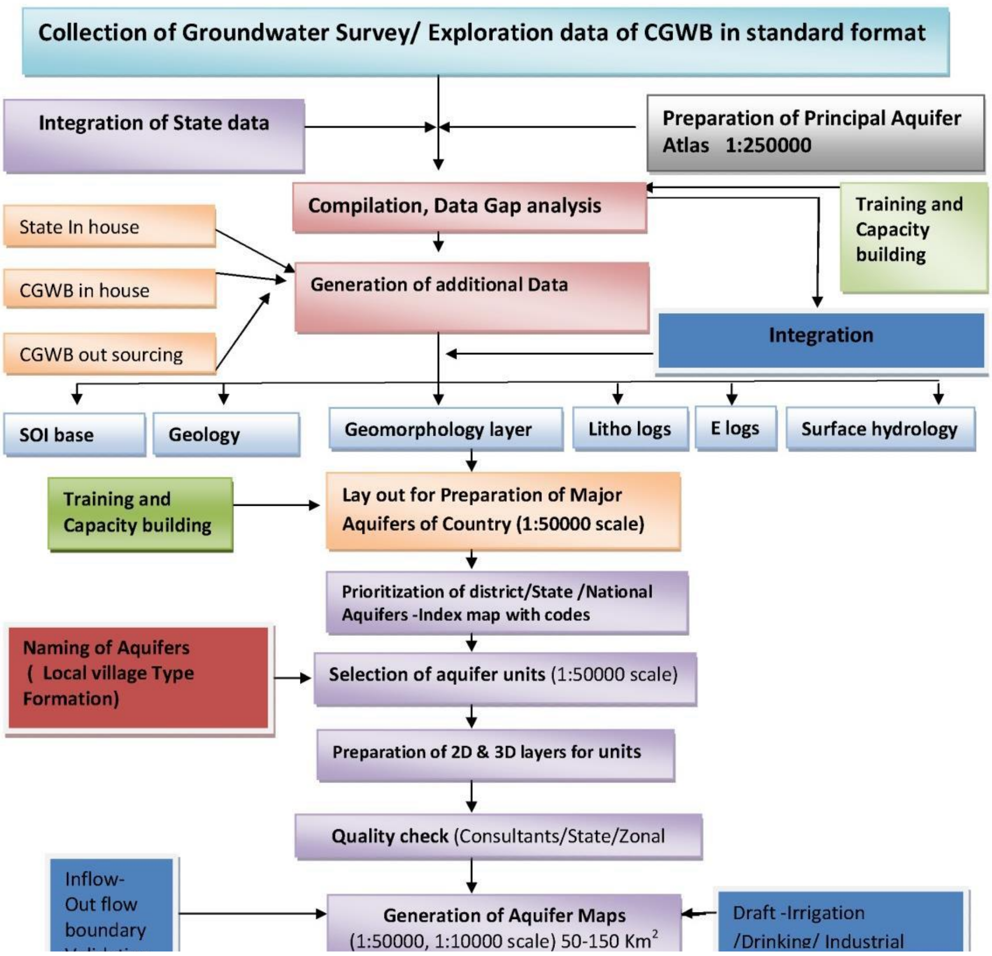


Fig 2 Methodology for Aquifer Mapping

1.4 Location

The study area occupies an area of 888 sq. km and is located in the western and central part of the Udham Singh Nagar district, Uttarakhand state. It lies between north latitudes 29°00′ and 29°20′ and east longitudes 78°45′ and 79°15′ and falls in parts of Survey of India toposheets 53 K/15, K/16& 53 O/ 4. The study area comprises 3 blocks i.eJaspur, Kashipur and Bazpur. It is bounded by Nainital district of Uttarakhand in the northern portion, Moradabad and Rampur districts of Uttar Pradesh in the southern portion, Bijnor district of Uttar Pradesh on western portion and Gadarpur block of the Udham Singh Nagar district on the eastern portion (Fig 3).

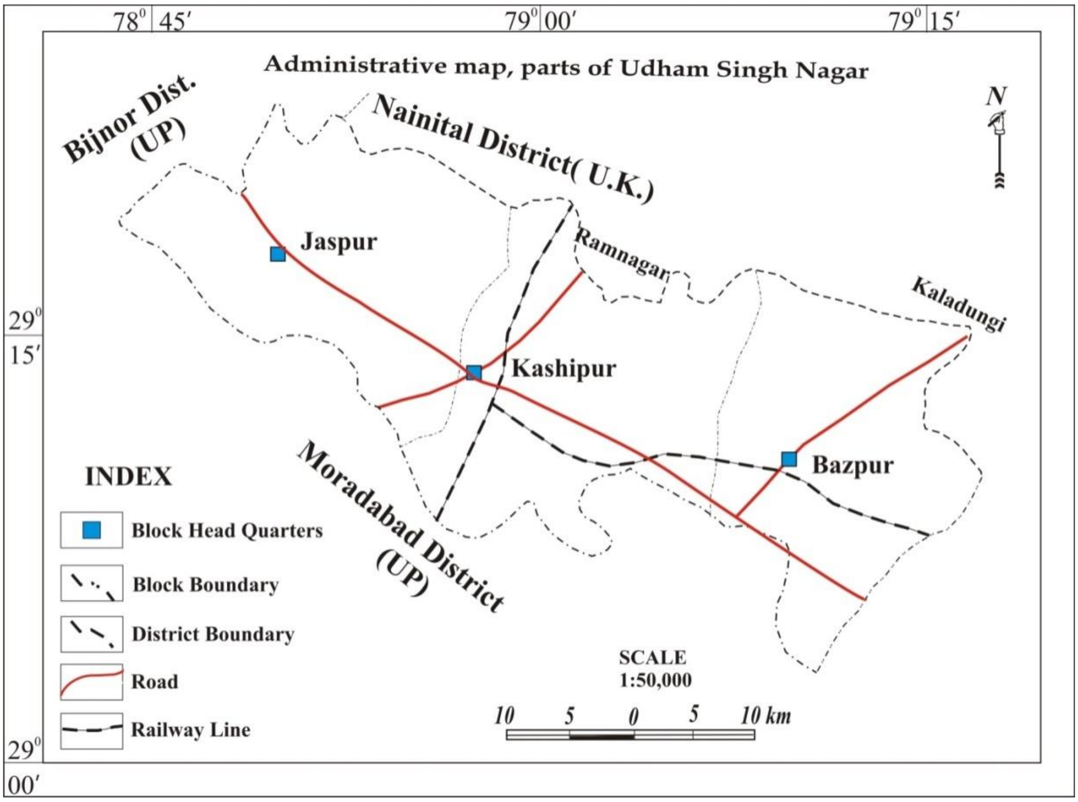


Fig. 3 Administrative Map, Parts of U S Nagar District, Uttarakhand

1.4.1Administrative Divisions

The administrative map of study area is shown in **Fig. 3.**There are 3 blocks, 3 Tehsils and 2 Municipal Corporation Board in the study area. There is well-distributed presence of 295 villages in the study area (**Table 1**). A perusal from the Table 1, it is clear that the maximum inhabited villages are recorded in Bazpur block and minimum (73) inhabited villages being in Kashipur block. Coincidently, Bazpur block occupies geographically large area 327 km^2 and smallest block being Jaspur 251 km^2.

Table 1. Administrative Division, Parts of Udham Singh Nagar District, Uttarakhand

S. No	Name of the Block	Area (Km^2)	Villages		
			Inhabited	Uninhabited	Total
1	Jaspur	251	96	4	100
2	Kashipur	310	73	0	73
3	Bazpur	327	120	2	122
	Total	**888**	**289**	**6**	**295**

(Source: Statistical Diary, US Nagar)

1.4.2 Demography (Population Since 2011)

The total population of the study areais 3,93,405 (Census: 2011). The decennial growth rate as per 2011 Census is estimated to be 38.07 %. The population density is 698 persons/km^2. The block wise break up of total population is mentioned in the **Table 2**.

Table 2. Block-wise Population, Parts of Udham Singh Nagar District, Uttarakhand

S. No	Block	Area	Total Population			Present Population Density per Area (km^2)	Increase in Density Population/Area (km^2) from last decade
			Male	Female	Total		
1	Jaspur	251	56634	51224	107858	559	9.75
2	Kashipur	310	75486	68811	144297	943	66.18
3	Bazpur	327	73441	67809	141250	593	38.29
	Total	**888**	**205561**	**187844**	**393405**		

(Source: Statistical Diary, US Nagar)

1.4.3 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 including Khadi & Village Industries being 326 (2014). Block wise list of industries is mentioned in the **Table 3.**

Table 3. Block-wise list of Industries, Parts of Udham Singh Nagar District, Uttarakhand

S. No	Block	No of Small Scale Industries	No of Workers Employed
1	Jaspur	95	476
2	Kashipur	19	5702
3	Bazpur	102	6024
	Total	**326**	12202

1.4.4 Agriculture

The study area is known as **"Chawal ki Nagari",** and primarily it is an agricultural belt, since it is lying in the Tarai region, which provides conditions for agricultural activities. Agriculture is the main source of employment and is also the main economic activity in this region, and paddy is the cash crop. Fertile land coupled with water availability marks the region an intensively cropped area. In addition to this, G.B.Pant University of Agriculture and Technology and Pradesh TaraiBeejVikas Nigam have contributed a lot in making this region a leader in agriculture.The study area mainly comprises of fertile soil, which yields high production, also boost up the agricultural activities. Khariff and Rabi are two major cropping seasons. Zaid crop, (part time crop) also under practice at some villages in the study area. The main Khariff crops are Rice, Maize, Soyabean, Cotton, Urd, Moong and till and the Rabi crops are wheat, Barley, Gram, Masoor, Mustard, Sunflower.

1.4.5 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 major rivers namely Phika, Kosi, Dhela and Dabka drain the study area. The 451.84 Km^2 of study area is irrigated by groundwater through Tubewells/handpumps/Wells, whereas the area irrigated by surface irrigation scheme like Kosi project is only 61.8 Km^2. The Tumaria Canal in the study area also caters the needs of irrigation. The block wise reservoirs are mentioned in Table 4. So, the main source for irrigation in the study area is Groundwater as per the data available. Sources of irrigation and irrigated area in Udham Singh Nagar is given in **Table 5.**

Table 5. Block wise reservoirs, Parts of Udham Singh Nagar District, Uttarakhand

S. No	Name of Block	Reservoir
1	Jaspur	Tumaria
2	Kashipur	NIL
3	Bazpur	NIL

Table 4.Block wise sources of Irrigation and Irrigated Area (ha),Parts of Udham Singh Nagar District, Uttarakhand

S. No	Block	Area irrigated (in ha)						
		By Canals	By Tube wells		Wells	Ponds	Others	Total
			Govt.	Private				
1	Jaspur	2110	2900	4300	3613	1	76	13,000
2	Kashipur	2225	3125	9421	4547	0	82	19,400
3	Bazpur	1845	5263	7600	4415	0	77	19,200
	Total area (ha)	6180	11,288	21,321	12,575	1	235	51,600
	Total area (Km^2)	61.80	112.88	213.21	125.752	0.01	2.35	516.00

(Source: District Statistical Diary, Udham Singh Nagar)

1.4.6 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 (295) installed and total population benefited (393405) in the study area given in **Table 6**. The maximum groundwater withdraw structures are deployed in Bazpur block. The entire study area is covered with the different drinking water schemes and projects.

Table 5. Block wise Rural Drinking Water Supply Schemes, Parts of Udham Singh Nagar District, Uttarakhand

S. No	Block	Hand Pumps Indian Mark-II		Villages Covered Under Drinking Water Facility
		Total no. of Structures Installed	Benefited Population	
1	Jaspur	96	107858	100
2	Kashipur	73	144297	75
3	Bazpur	120	141250	120
	Total	**289**	393405	295

CHAPTER – 2

DATA AVAILABILITY & DATA GAP ANALYSIS

The data on various attributes of the study like Geological, Hydrogeological and Hydrochemical data are collected from the available literatures of Central Ground Water Board, State Ground Water dealing Department of Uttarakhand and various Central and State Government agencies. The summarized table presenting the Data Requirement, Data Availability and Data Gap Analysis is presented in **Table 7**.

Table 7. Data Availability and Data Gap Analysis, Parts of Udham Singh Nagar District, Uttarakhand

S. No	Items	Data Requirement	Data Availability	Data Gap
1	Climate	Season-wise Rainfall pattern	Annual Rainfall of Meteorological Stations	Time series data Rainfall
2	Soil	Soil map and Soil infiltration rate	No data	Soil map and Soil infiltration rate
3	Land Use	Latest Land use pattern	Till 2012-13	Land use and data map. Latest updated data required
4	Geomorphology	Detailed information on geomorphology of the area	District level information on 1:25000	District level information on 1:50000
5	Geophysics	Geophysical data of the study area	No data	Entire area unexplored
6	Geology	Detailed information on geology of the area	Available on 1:25000	Map on 1:50000 to be provided by CHQ
7	Exploration data	Detailed information on sub surface of the area	8 EW of various depths is available	8 EW more required upto the depth of 300 m for complete exploration details.
8	Hydrogeology	Water Level	Long term and seasonal Water level	Hydraulic characters of individual aquifers not available
9	Monitoring Regime	Representative monitoring wells distributed all over the study area	Monitoring wells including Dug wells and Handpumps	Aquifer wise groundwater level data not available.
10	Water Quality	Aquifer wise groundwater quality and its suitability for Drinking, Irrigation & Industrial Purpose	Data available for shallow/ unconfined aquifers	Aquifer wise Groundwater quality data need to be collected

2.1 Climate

Data Availability

The climate of the study area is sub-tropical and sub-humid with three distinct climatic seasons i.e. summer, monsoon (rainy season) and winter. About 90% of rainfall is received during the southwest monsoon that is during the period of June to September. The winter rains are generally experienced in late December or early January, which brings down the temperature and that's how January is the coldest months in the study area. The average annual rainfall is 1282 mm. The summer season starts from March and it goes up to June. The hottest months of the year are May and June. The temperature goes up to 45ºC during the summers and the minimum temperature is around 1 to 4ºC in winter season.

Data Gap Analysis

Time series data on rainfall of the study area is required.

2.2 Soil

Date Availability

Information collected from various sources indicates that soils of study area are predominantly of two types Entisols and Mollisols with low to medium nutrient status. It is generally alkaline with pH values ranging from 6.3 to 8.5.

a. **Entoisols or Bhabhar soil**: Part of the alluvial fan deposits. Soils are shallow with sandy to loamy texture, poorly sorted, comprising mainly of gravel, sand, silt, clay, in transpired with pebbles etc. Soils are deficient in N_2 and H_3PO_4 (Phosphoric acid) but usually rich in lime and potash.

b. **Mollisols or Tarai Soils**: Soil is calcareous, moderately productive and suitable for extensive cultivation of high yielding crops like rice and sugar cane. Soils typify marshy and swampy environment. Soils are rich in N_2 and H_3PO_4 (Phosphoric acid) but usually deficient in potash.

Data Gap Analysis

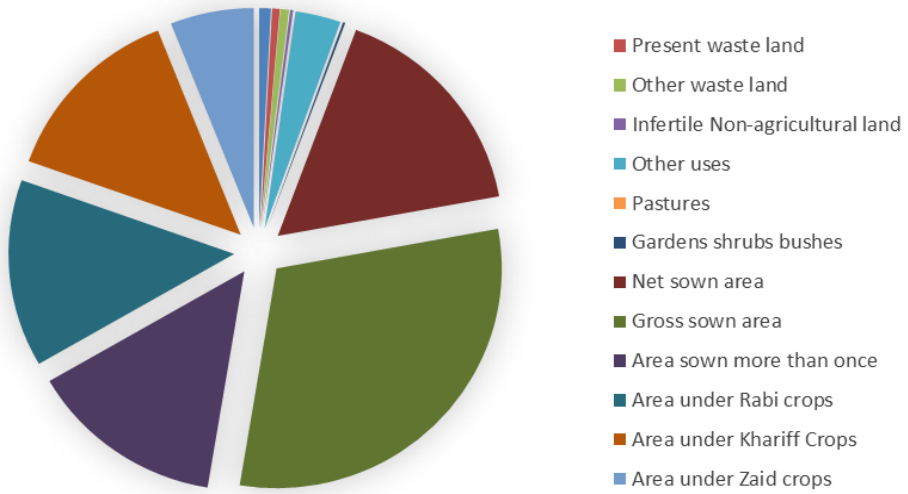
Data on soil infiltration rate for various types of soils existing in the project area needs to generated in order to analyses the impact of the soil cover on the ground water regime of the area.

2.3 Land Use

Data Availability

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 Udham Singh Nagar, Government of Uttarakhand (2014), which provides block wise information. The block wise land use pattern is given in the **Table 8.**Out of the total geographical area of 888 Km^2 of study, the Net sown area is 523.33 Km^2 andarea sown more than once in the year is 446.4 Km^2. Area under Rabi and Khariff crops are 438.39 Km^2 and 430.75 Km^2, respectively. The highest net sown area, the gross cropped areas is in Kashipur block. The principal source of assured irrigation is by wells and tube wells, which together account for about 90% of the total irrigation. Only 61.8 Km^2 (6%) of the studyarea is irrigated by canal irrigation.

Fig 4. Land Use Pattern, Parts of Udham Singh Nagar District, Uttarakhand



Data Gap Analysis

Landuse and Land cover maps. Updated land use statistics needs to be collected

Table 8 Block-wise Land Use Pattern, Parts of Udham Singh Nagar District, Uttarakhand

S. No	Name of Block	Area (ha)	Forest	Present waste land	Other waste land	Infertile Non-agricultural land	Other uses	Pastures	Gardens shrubs bushes	Net sown area	Gross sown area	Area sown more than once	Area under Rabi crops	Area under Khariff Crops	Area under Zaid crops
1	Jaspur	19691	550	490	405	175	3850	13	146	13560	29120	15560	13200	13322	2596
2	Kashipur	25585	632	666	700	225	3150	9	199	19422	35002	15580	18000	13501	3500
3	Bazpur	26971	1656	624	855	265	3385	22	164	19350	32850	13500	12639	16252	3956
	Total	**72247**	**2634**	**1720**	**1960**	**665**	**10385**	**44**	**509**	**52332**	**96972**	**44640**	**43839**	**43075**	**19052**

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2.4 Geomorphology

Data Availability

The study area is divided into two physiographic units from north to south viz., Bhabar and Tarai respectively. Since the area is located in the Himalyan foothills, a very thick of alluvial column is deposited, which can be classified into two distinct divisions:

a) **The piedmont fan deposits known as Bhabar**

b) **The Tarai Alluvium**

These zones spread in NW-SE direction all along the foothills of the Siwalik formation having a maximum width about ~20km. The general gradient towards south varies from 9 to 17 m/km. The slope gradually decreases towards south in the Tarai region and becomes almost flat close to the boundary between Tarai and CentralGanga plains, which exists few km south of the southern boundary of the study area.The area is drained by the mighty river Kosi (which is perennial) and other rivers are Phika, Dhela andDabka. Most of the rivers drain the area in a north-south or northeast-southwest direction. The Fig 5 & 6 shows the geomorphology and drainage Map of the study area.

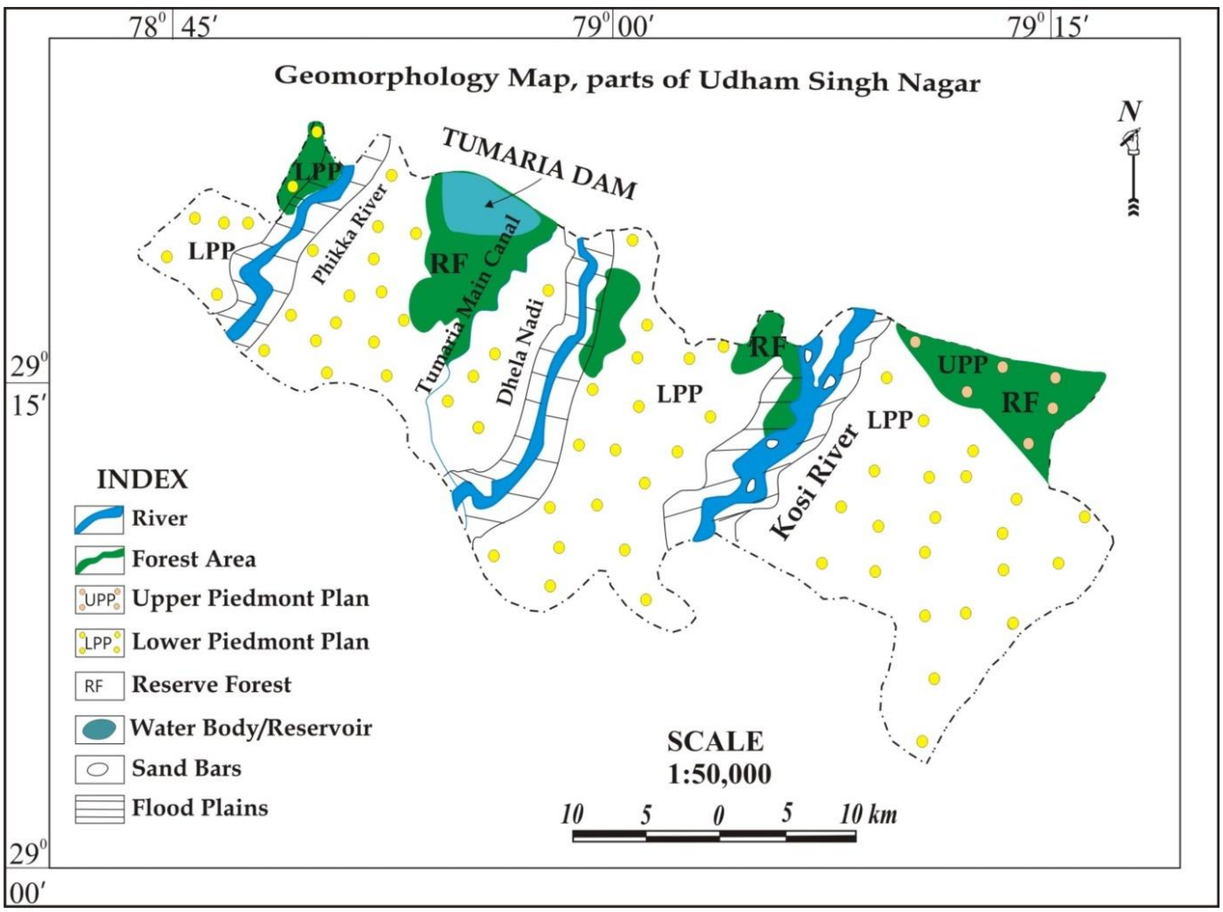


Fig 5. Geomorphology Map, Parts of U S Nagar District, Uttarakhand Fig 1:

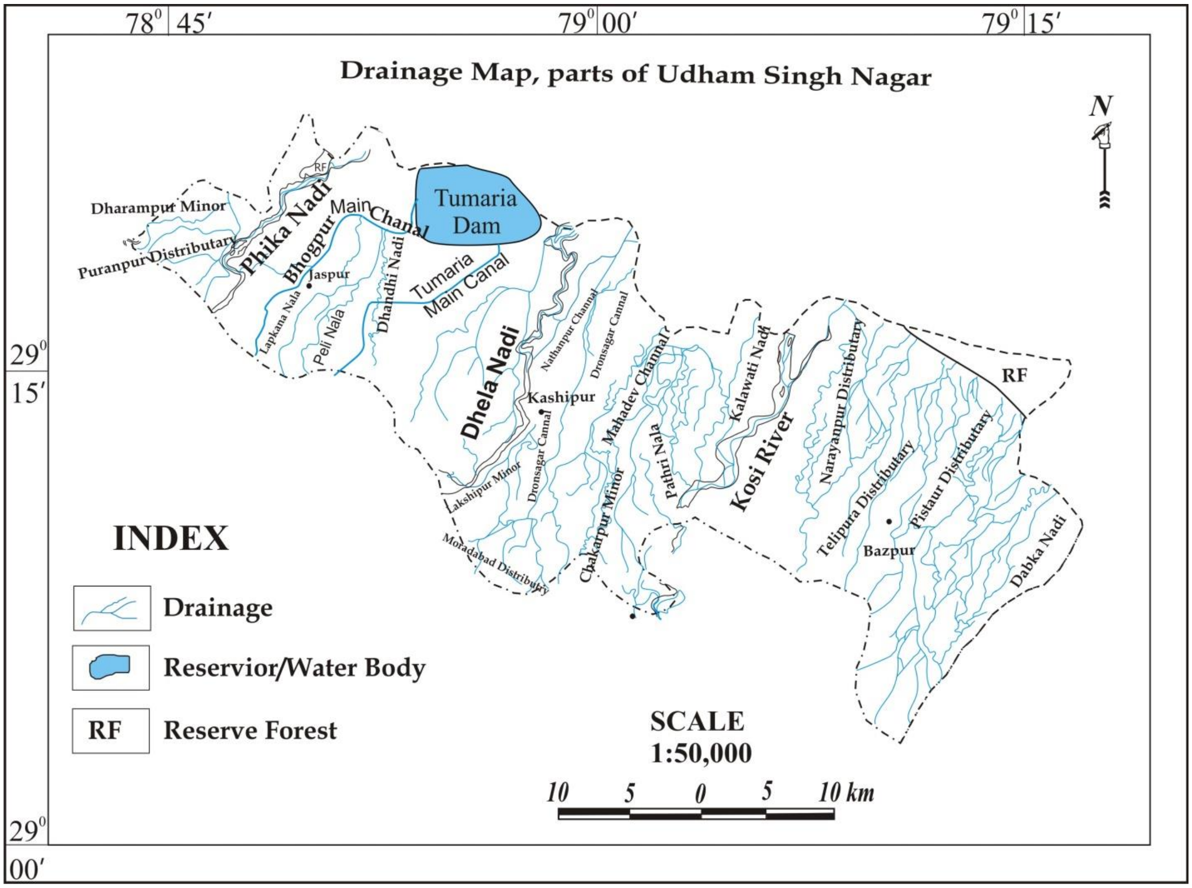


Fig 6. Drainage Map, Parts of U S Nagar District, Uttarakhand

Data Gap Analysis

Additional information need to be collected, so that the same can be used in hydrogeological interpretations and formulation of ground water management plan.

2.5 Geophysics

Data Availability

No geophysical study was carried out within project area.

Data Gap Analysis

The entire area is un-explored as far as geophysical investigations are concerned.

2.6 Geology

Data Availability

Geology plays an important role in shaping the groundwater scenario of an area. It becomes imperative to know the geology of the area. Piedmont alluvial deposits represent the geology of the study area. Broadly, it can be divided into two formations viz. Bhabar and Tarai. which are characterized by distinct lithology, grain size distribution; variation of degree of sorting etc. A generalized geological succession, of the study area is shown in table 9 and Ge

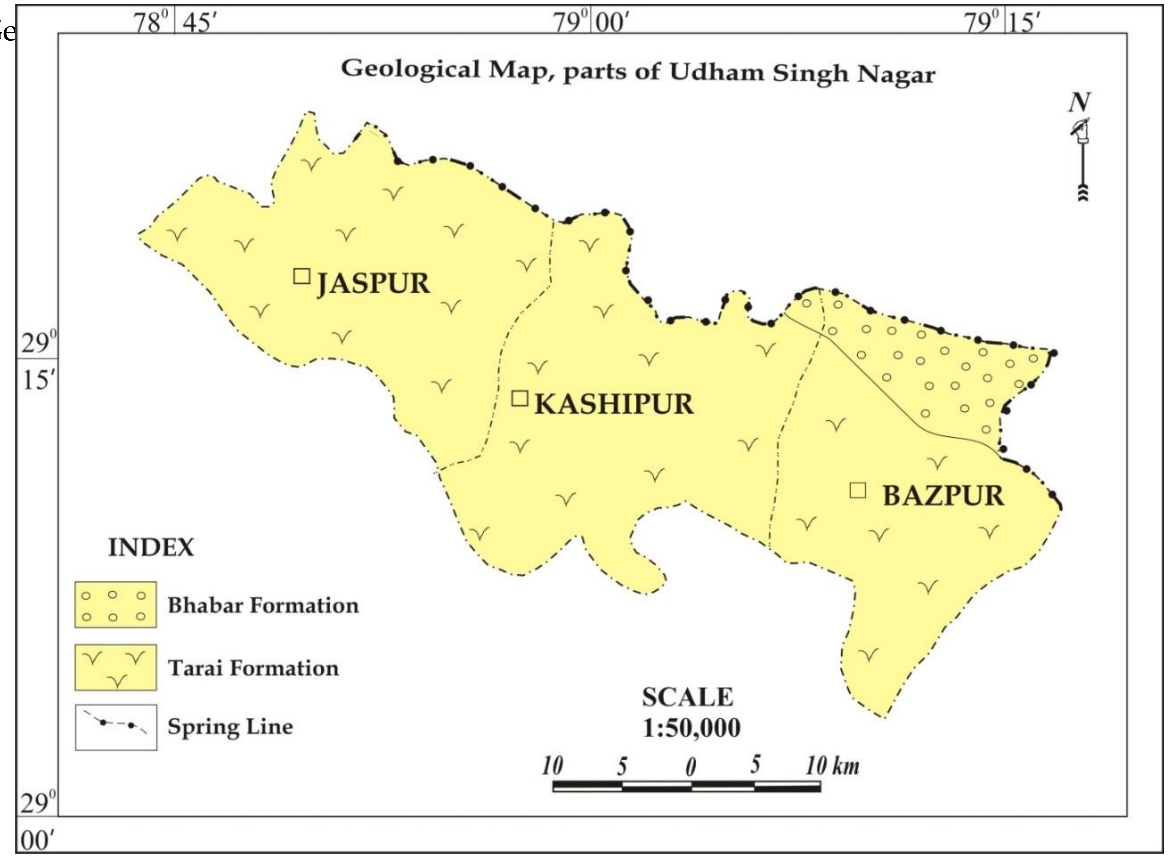


Fig 7.Geological Map, Parts of U S Nagar District, Uttarakhand Bhabar Formation

Table 9. Geological details, Parts of Udham Singh Nagar District, Uttarakhand

Age	Morpho-tectonic Unit	Divisions	Lithology
Recent to Quaternary	Piedmont	Bhabar	Boulder, sand and clay
	Alluvial plain	Tarai	Sand, clay and silt

Bhabar and Tarai deposits are essentially the alluvial deposits lying in the sloping plains adjoining the Himalayan foothills south of the formations comprising the Siwalik System of India. Bhabar formation is primarily constituted of unconsolidated sediments of sand-boulder succession along with clay-boulder layers. The grain size variations that are observed, range from material of sand grade (2 mm) through granules, pebbles, cobbles to boulders size i.e. > 256 mm. Sometimes the boulders have dimensions in feet. The clays are generally brown in color. Clay bed sequences have short lateral continuity, tend to pinch.TheBhabar belt extends in an elongated area lying immediately south of the Siwaliks of the Himalayan foothills and trending roughly with a general NW–SE trend to almost east–west in the east; in different states the exact trend and disposition depends largely upon the disposition of the Siwaliks. The extreme northern portion of the Bhabar zone is marked by the contact with Siwalik ranges whereas the southern limit is defined by the contact between Bhabar and Tarai, which forms the spring line. The gradient of the Bhabhar belt is roughly 4 to 16 meter/ km.

Tarai Formation

The Tarai formations is immediately lying south of the Bhabar formation, and its name being derived from marshy conditions characteristic of this type. Tarai formation primarily consists of clays, sandy clays, fine to medium sand and occasional gravels. In this formation there is a preponderance of clayey successions over sandy beds. The granular zones occur mostly as lenses and have inter–tonguing relationships with clastic and non-clastic units. The northern limits of the zone are roughly demarcated by the spring line, i.e. the contact between Bhabar and Tarai, whereas the southern limit of this zone is taken to be the region where auto flow conditions cease to exist in the tube wells. The Tarai sediments representing the finer portion of the channel bed load and the load in suspension and solution, which are brought by the streams and evenly sorted out by the river action. These materials are better sorted as compared to the Bhabar. South of the Tarai is a vast stretch of Older Alluvium (equivalent of Varanasi alluvium) of the extensive Indo–Gangetic and Brahmaputra plains, where water table conditions exist in the shallow groundwater. The gradient of the Tarai belt is roughly 2.5 meter/ km.

Data Gap Analysis

The non-availability of the Geological maps of the Study area on 1:50,000 Toposheet.

2.7 Hydrogeology

Data Availability

Information on hydrogeology of the study area is obtained from the district brochure of Udham Singh Nagar district.Generally, the groundwater flows from north to south in the study area. Based on the behavior and occurrence of groundwater, the district can be broadly categorized into two broad hydro-geomorphic units namely (1) Bhabar and (2) Tarai. Hydrogeological Map of the study area is shown in Fig. 8.

2.7.1 Bhabar Zone

The Bhabar is characterized by its high porosity and permeability by virtue of which they allow major part of the precipitation to infiltrate, within a very short span of time, leading to the formation of excellent groundwater reservoirs. Bhabars are poorly sorted unconsolidated sediments viz., boulders, cobbles, pebbles, and granules, coarse to fine sand, silt and clay. Due to arrest of flow velocity, change of topography, gradient, valley characteristics, the mighty streams emerging from the Himalayas shed their sediment load in the form of triangular alluvial fans and cones along the Siwalik foothills. The alluvial cones join together to form an extensive piedmont plain. It has NW-SE elongation and forms a highly potential hydrogeologic unit. The Bhabar merges gradually with the Tarai occurring in the south. The contact between these two hydro-geomorphic units is characterized by the change in slope gradient and groundwater effluents, which forms the spring line. The Bhabar zone acts as a recharge front for the Tarai belt.

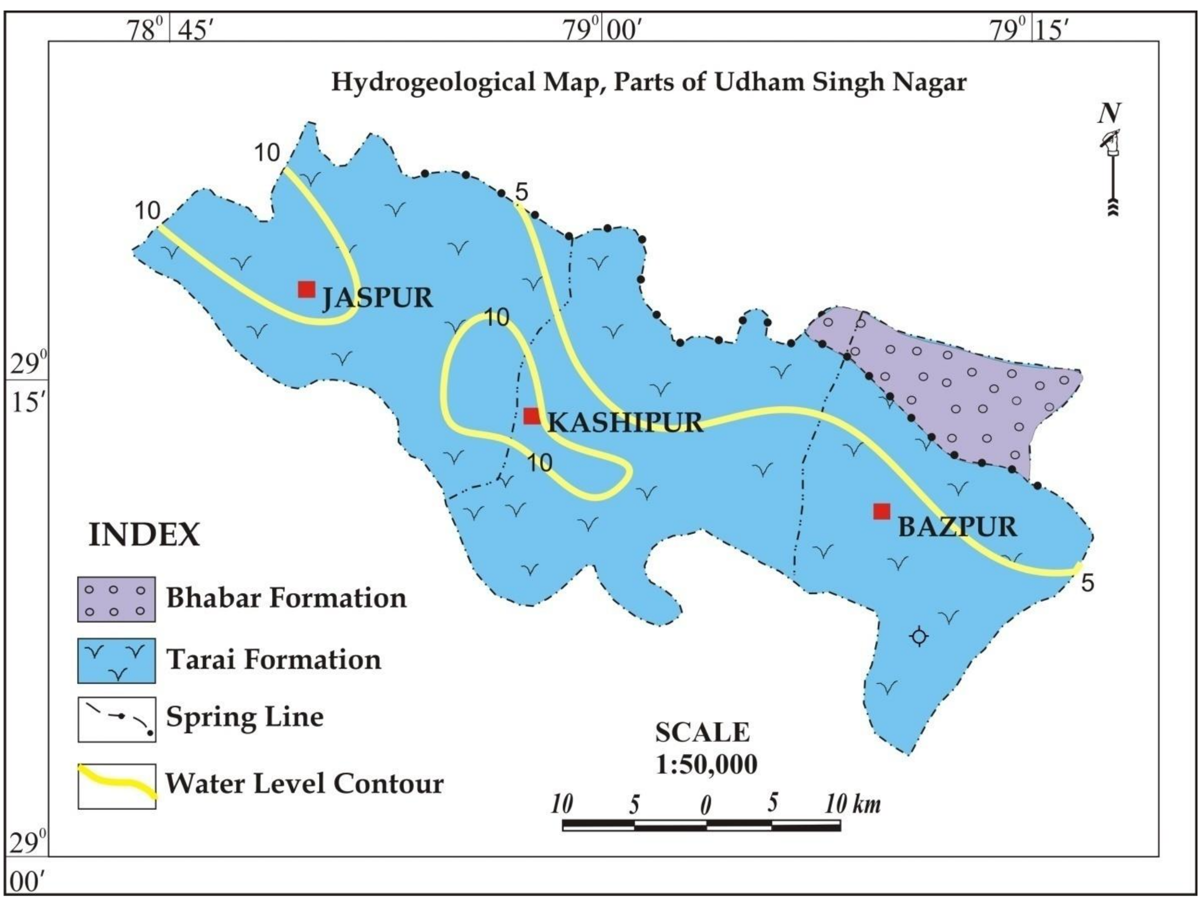


Fig 8. Hydrogeological Map, Parts of U S Nagar District, Uttarakhand

The aquifers in these zones are mostly unconfined but at some places perched aquifers also exist. Depth to water level progressively decreases towards south and water finally emerges at the surface as a line of spring. The depth to water level in Bhabar formation ranges from 2.07 to 5.25 m bgl duringpre-monsoon,2015 and 1.26 to 3.78 m bgl during post monsoon,2015. Based on the aquifer parameters of exploratory drilling in the area; estimated hydraulic gradient in this zone is approximately 2.97 m/km. Based on the available exploratory drillings aquifer parameters data in the office, the Transmissivity values range from 3696 to 23860 m^2/day, whereas the values for hydraulic conductivity ranges from 56 to 825 m/day.The hydraulic gradient ranges between 4 and 16 m/km.

The groundwater body appears to be sustained and recharged by (1) direct infiltration from precipitation on the land surface, and (2) infiltration from turbulent streams flowing across the belt. Considerable amount of water is also discharged by perennial springs at the southern limit of Bhabar.

2.7.2 TaraiZone

Tarai belt consists of finer segments of talus material brought down by the streams and sorted to some degree by fluvial action. It lies south of the Bhabar and predominantly comprises clays and silts with well-sorted granular material such as sand, gravel occasionally boulders and cobbles and pebble beds. The sands and gravels associated with the finer fractions are the major aquifers in this zone.The boundary between the Bhabar and the Tarai is defined by a spring line, which is characterized by auto-flow (free-flowing) zones. There are plenty of moist and waterlogged areas around the spring line particularly during monsoon season.

The groundwater occurs under unconfined and confined conditions. In the unconfined aquifer, the depth to water level varies from 2.78 to 14.72 m bgl during pre-monsoon, 2015. However, the post-monsoon,2015 depth to water level ranges from 0.42 to 12.7m bgl. Whereas, the groundwater in deeper confined aquifers occurs under artesian conditions. The artesian flow of individual wells may vary from just a trickle at the surface from the confined aquifer to that amounting to several hundred or in rare cases to even a thousand gallons per minute. Based on the aquifer parameters of exploratory drillings in the area, the transmissivity values range from 1180 to 2500 m^2/day, whereas the values for hydraulic conductivity ranges from 25 to 243 m/day. The hydraulic gradient ranges between 1.35 and 4.0 m/km.

The unconfined shallow groundwater of the Tarai may be charged by (1) the direct infiltration from rainfall on the land surface, (2) the infiltration from the streams when flooded, (3) return seepage from irrigation in cultivable fields, (4) lateral percolation from adjacent Bhabar zone and (5) by upward leakage from the upper most artesian horizon.

On the contrary, the confined Ground Waters are probable recharged by downward percolation and lateral flow from Bhabar belt. Bhabar, therefore, is also the intake area for Tarai as well.

2.7.3 Ground Water Conditions in Auto Flow Zone

Artesian conditions are restricted to the Tarai zone. In a well, penetrating through a confined aquifer, the water level will rise above the bottom of the confining bed. If the water level rises above the top of the upper confining layer, above the ground surface, free flowing /auto flow conditions result. In this zone confining conditions result due to intercalation of permeable materials like sand and gravel with impervious clay horizons. The difference in elevation of Bhabar and Tarai, together with the regional slope of the strata, appears to build the artesian head in the aquifers. Permeability of the Tarai aquifers is less than that of Bhabar, thereby playing a vital role in developing the pressure, as it impedes ground water flow. The discharge of the tubewells is dependent of aquifer properties, and local ground conditions. As per the surveyed numbers there are more than 150artesian wells existing in the study area. Central Ground Water Board has constructed artesian wells at Basai (Kashipur) and Bazpur in the study area.The drilled depth ranging from 84.4 to 433.0 m bgl, with free flowing head upto 8.69 m above ground level. The yield of these wells upto 3400 lpm, with the drawdown 5.39 to 10.69 m. The Transmissivity values range from 825 to 12274 m^2/day, and the hydraulic conductivity ranges from 16.17 to 106.6 m/day at the time of their construction.

It is observed that the pressure head of the artesian aquifers drastically reduced over the two decades and some of the shallower depth wells lost its artesian conditions. The causes of reduction in discharge of artesian wells have been discussed in the coming chapters.

Data Gap Analysis

The Aquifer wise hydraulic parameters and groundwater levels for confined aquifers are not available. These are required for water table contour map of respective aquifer. The hydraulic parameters available from the pumping test of CGWB wells provide information of aquifers resting mainly in the north-western and southern part of the area. The data of the northern and north-eastern part of the study area is not available. However, these wells were constructed by tapping multiple aquifers. The parameters of the individual aquifers are missing.

2.8 Sub-Surface Lithological Information

Data Availability

Sub-surface lithological information is obtained from the available reports in the office and from State Government departments of Uttarakhand. The exploration detail of seven wells within the study area is available. The five exploratory wells outside the study area have also been selected to depict the gradation and grain size variation in Bhabar and Tarai formation. The longitude and latitude of these 12 exploratory wells are given in Table 10 & 11.The details of exploratory wells are given in the Annexure I & Annexure II.

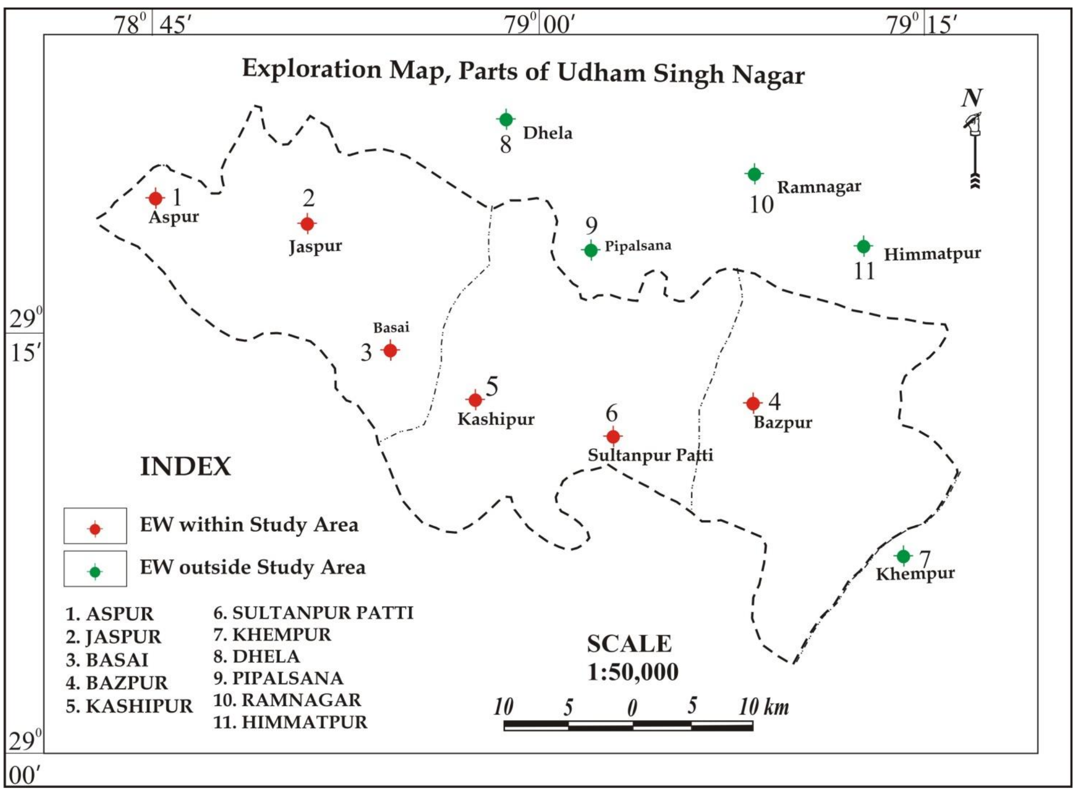


Fig 9. Location Map of Exploratory Wells, Parts of U S Nagar District, Uttarakhand

Table 10. Location details of exploratory wells within the study area, Parts of U S Nagar

S. No	Location	Latitude	Longitude	Drilled Depth (m)	Drilling Agency
1	Aspur	29° 18´ 45"	78° 45´ 47"	417.39	CGWB
2	Jaspur	29° 17´ 5"	78° 49´ 04 "	113.20	State Govt
3	Basai	29° 11´ 45"	78° 56´ 00"	268.37	CGWB
4	Sultnpur Patti	29° 09´ 45"	79° 02´ 60"	73.00	State Govt
5	Bazpur	29° 04´ 48"	79° 09´ 11"	101.60	CGWB
6	Kashipur	29° 20´ 10"	78° 57´ 00"	84.43	State Govt

Table 11. Location details of exploratory wells outside the study area, Parts of U S Nagar

S. No	Location	Latitude	Longitude	Drilled Depth (m)	Drilling Agency
1	Ramnagar	29° 23´ 53"	79° 07´ 52"	94.00	CGWB
2	Pipalsana	29° 16´ 56"	79° 02´ 21"	84.40	CGWB
3	Dhela	29° 24´ 57"	79° 00´ 12"	88.00	CGWB
4	Himmatpur	29° 13´ 09"	79° 29´ 30"	82.30	CGWB
5	Khempur	29° 05´ 53"	79° 14´ 52"	93.00	State Govt

Data Gap Analysis

Explorartion data of the Northern and north-eastern part of the study area is not available. It was apparent that all wells drilled by CGWB are concentrated in the north-western and southern part of the study area. These wells were constructed by tapping multiple aquifer zones. The lithologs of exploratory wells collected from the state agencies are limited to only 113 m depth. VES information was also not available for the study area. The objective of the project is to have an information up to 300m bgl. It was apparent from the available sub-surface lithological information that there was data gap both in terms of space and depth.

2.9 Monitoring Regime

Data Available

The water levels are being monitored through the Groundwater Monitoring Stations (GWMS) 4 times a year i.e May, August, November (2015) and January 2016. The Depth to Water Level (DTW) maps have been prepared based on 18 Ground Water Monitoring Stations (GWMS) (3 dug wells tapping the shallow aquifer and 16 Hand pumps tapping the deeper aquifers). The groundwater occurs under water table condition near surface and occurs under semi-confined to confined condition at deeper level. The block wisedetails of GWMSare given in **Table 12**and the location of the monitoring stations is plotted in **figure 10.**

Table12. Block-wise Ground Water Monitoring Stations (GWMS), Parts of U S Nagar District, Uttarakhand

S. No	Block Name	Ground Water Monitoring Stations (GWMS)
1	Jaspur	USN-09-HP (Jaspur), USN-32-HP (Angadpur), USN-09-HP (Patrampur) and USN-36-HP (Missarwala)
2	Kashipur	USN-01-DW (Kashipur), USN-HP-13 (Sultanpur Patti), USN-HP-26 (Dhanauri Patti), USN-11-HP (BarkharePande), USN-33-HP (Durgapur), USN-37-HP (Shankhera) and USN-10-HP (Bharatpur)
3	Bazpur	USN-03-DW (Bazpur), USN-29-HP (Jharkhandi), USN-23-HP (Jogipura), USN-14-DW (BanaKhera), USN-38-HP (Kanaura0, USN-39-HP (Pritpur) and USN-40-HP (Badaripur)

Data Gap

It was apparent that there was paucity of groundwater level data of project area. Within the study area, there are only 18 Ground Water Monitoring Stations GWMS (3 dug wells and 16 Hand pumps tapping the shallow aquifers). Aquifer wise groundwater level data is not available.

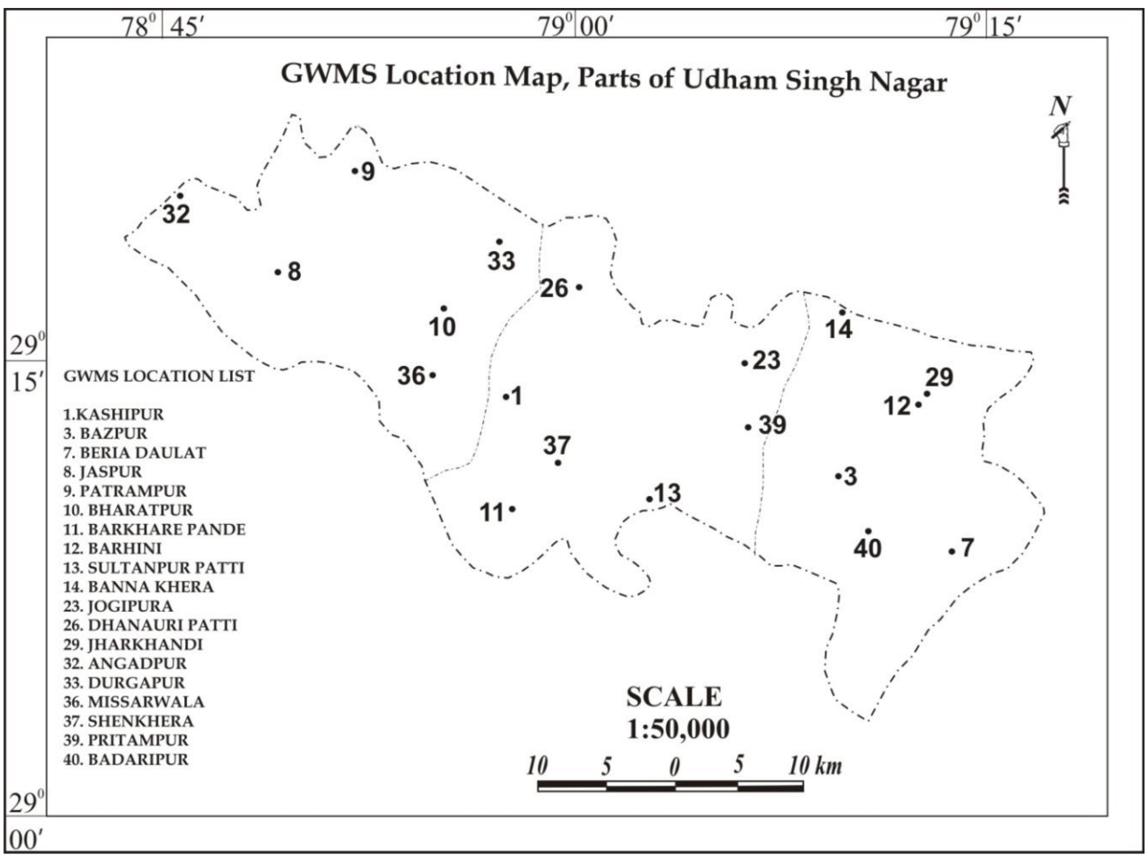


Fig 10. Ground Water Monitoring Stations Location Map, Parts of U S Nagar District, Uttarakhand

2.10 **Water Quality**

Data Availability

The water samples were collected and analyzed to get the idea of chemical quality variation in different aquifer from the 18 Ground Water Monitoring Stations (GWMS) (3 dug wells and 16 Hand pumps tapping the deeper aquifers). The basic chemical constituents available for the study are: pH, EC, TH, CO3, HCO3, NO3, Na, K, SO4, Fe & Mg and the Heavy metals are Cu, Fe, Zn, Mn and Ni.

Data Gap Analysis

More aquifer wise Ground Water Quality data.

CHAPTER – 3

DATA GENERATION

Data on various attributes of Aquifer Mapping has been generated based on the data availability and data gap analysis discussed in Chapter 2.

3.1 Rainfall

The 11 year monthly, annual rainfall data was collected from Irrigation Department, Tehsil and collectorate offices of Uttarakhand Government and India Metrological Department (IMD) centres of Kashipurand analysed. The rain gauge station is at Kashipur and Bazpur Tehsil office. The rainy season continues from June to the end of September, which receives South-west monsoon and accounts for about 90% of the total annual rainfall. The area receives an average normal monsoon rainfall of about 1283mm/year. The Annexure III shows annual monthly rainfall of last eleven years (2005 to 2015). The eleven-year annual rainfall has been graphically shown in fig 11. Minimum rainfall is observed for the year 2015 at Bazpur (Bazpur Block) of 303 mm (2015) and maximum rainfall observed at Kashipur (Kashipur block) of 3507 mm (2010). The average annual rainfall for the 11 years in the Kashipur block and Bazpur Block is 1921.63 mm and 733.91mm respectively (Table 13).

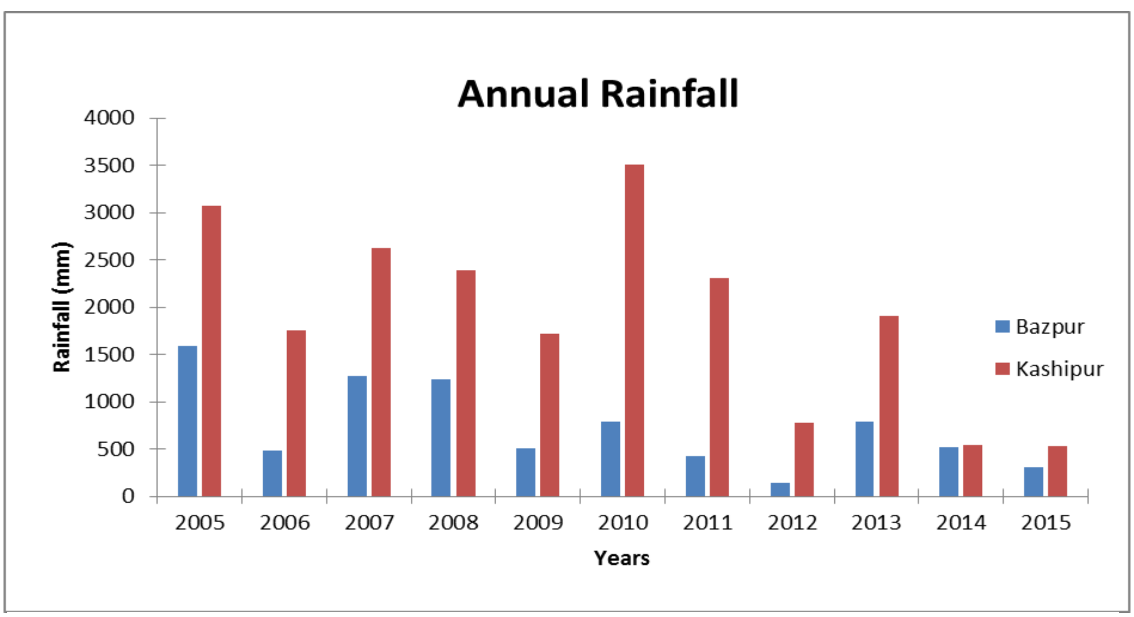


Fig 11. Long term annual Rainfall data, Parts of U S Nagar District, Uttarakhand

Long term Monthly and Annual Normal Rainfall in parts of Udham Singh Nagar District (Based on 2005-2015), Uttarakhand is shown in Annexure-III. Based on the Normal Rainfall d[illegible] tal map s[illegible]

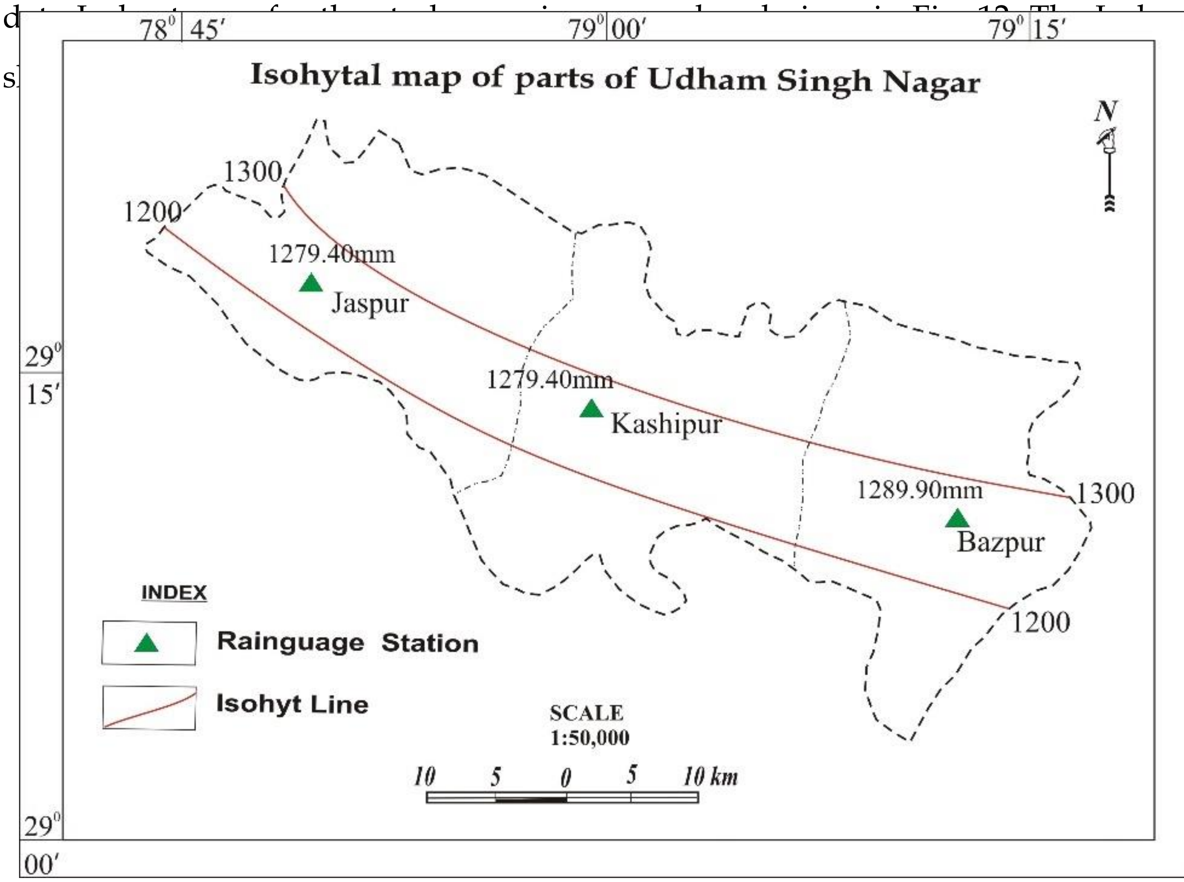


Fig 12.Isohytal Map, Parts of U S Nagar District, Uttarakhand

Table 13. Station-wise Annual Rainfall Data, parts of Udham Singh Nagar District, Uttarakhand

S. No	Station	No. of Years considered	Average Annual Rainfall (mm)	Maximum Rainfall		Minimum Rainfall	
				(mm)	Year	(mm)	Year
1	Kashipur	11 (2005-2015)	1921.63	3507	2010	533	2015
2	Bazpur	11 (2005-2015)	733.9	1589	2005	303	2015

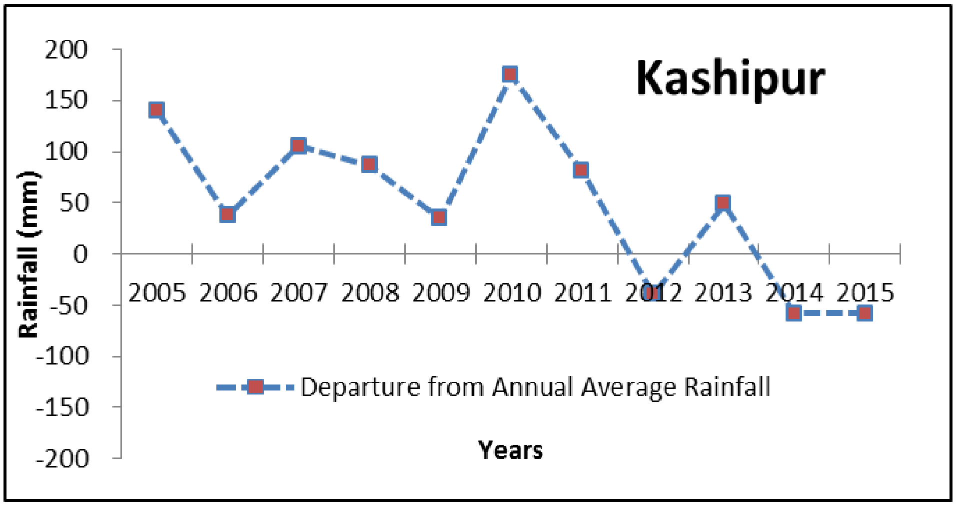
Statistical Analysis of Rainfall

The annual rainfall departures from average annual rainfall for both the raingauge stations are given in **Table 14.** The standard deviation is 995.51 mm and 454.70 mm for Kashipur and Bazpur stations respectively. The coefficient of variation is 51.8 % and 62 % Kashipur and Bazpur stations respectively.

Table 14. Annual Rainfall Departures from Average Annual Rainfall (AAR), Parts of Udham Singh Nagar District, Uttarakhand.

S. No	Station	Year	Rainfall	Departure from AAR (mm)	% Departure from AAR
1	Kashipur	2005	3073.4	1794.0	140.22
		2006	1759.5	480.1	37.53
		2007	2624	1344.6	105.10
		2008	2384	1104.6	86.34
		2009	1724	444.6	34.75
		2010	3507	2227.6	174.11
		2011	2311	1031.6	80.63
		2012	780	-499.4	-39.03
		2013	1904	624.6	48.82
		2014	538	-741.4	-57.95
		2015	533	-746.4	-58.34
2	Bazpur	2005	1589	299.1	23.19
		2006	490	-799.9	-62.01
		2007	1275	-14.9	-1.16
		2008	1238	-51.9	-4.02
		2009	509	-780.9	-60.54
		2010	785	-504.9	-39.14
		2011	431	-858.9	-66.59
		2012	142	-1147.9	-88.99
		2013	791	-498.9	-38.68
		2014	520	-769.9	-59.69
		2015	303	-986.9	-76.51

To know the behavior of rainfall, departures from the mean annual average rainfall (mm) versus departures of annual average rainfall (mm) plots were plotted and depicted in **Fig. 13,** for the period from 2005 to 2015 for Kashipur and Bazpur stations respectively, where the mean values are tabulated as "0" base lies.From these plots, it is observed that departures from annual average rainfall are mainly positive in Kashipur whereas in Bazpur it is highly negative.



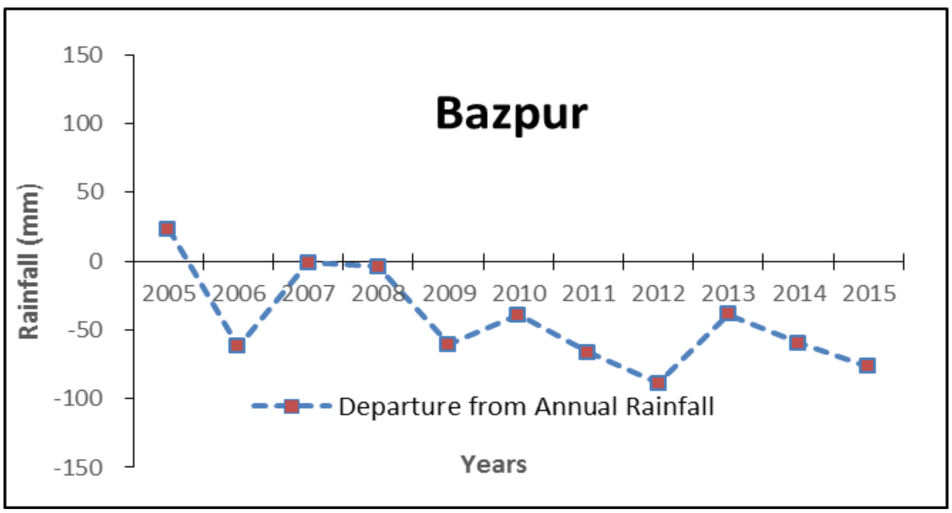


Fig. 13. Plots of Departures of Annual Average Rainfall

The analysis also revealed that out of 11 years, the study area experiences the 2 Mild Droughts, 3 Normal droughts, 4 severe Droughts and 1 Most Severe Drought. The Kashipur experiences the 3 Drought years (1 Normal and 2 severe droughts) whereas, the Bazpur experiences the 10 drought years (2 Mild droughts, 2 Normal Drought Years, 4 severe Droughts and 2 Most Severe Drought (2012 and 2015)).

Percentage of Departure	**Type of Drought**
0.0 to –25.0	Mild Drought
-25.1 to –50.0	Normal Drought

-50.1 to –75.0	Severe Drought
-75.1 to –100.0	Most Severe Drought (Rare Drought)

3.2 Ground Water Level

To study the behaviour of ground water in time and space, 18 monitoring wells were monitored 4 times a year. Subsequently, the depths to ground water level data of the observation wells aregiven in Annexure - IV. Based on ground water level data of all the observation wells, five types of maps are generated

a) Depth to Ground Water Level Map Pre-monsoon (May 2015)

b) Depth to Ground Water Level Map Post-monsoon (November 2015)

c) Decadal Water Level Map Pre-monsoon (May 2004-2015)

d) Decadal Water Level Map Pre-monsoon (November 2004-2015)

e) Seasonal Fluctuation Map (May vs November 2015)

Depth to ground water level map pre-monsoon(May) and Post- monsoon (November) gives information on change in ground water level and hence, change in ground water storage between two different periods of time.

3.2.1. Pre - Monsoon (May), 2015

During May 2015, the minimum and the maximum depths to ground water level are 2.07 m bgl (Jharkhandi) to14.72 m bgl (Jaspur). The major part of the area is having depth to ground water levelranging from 5 to 10 m bgl. Depth to Ground Water Level of

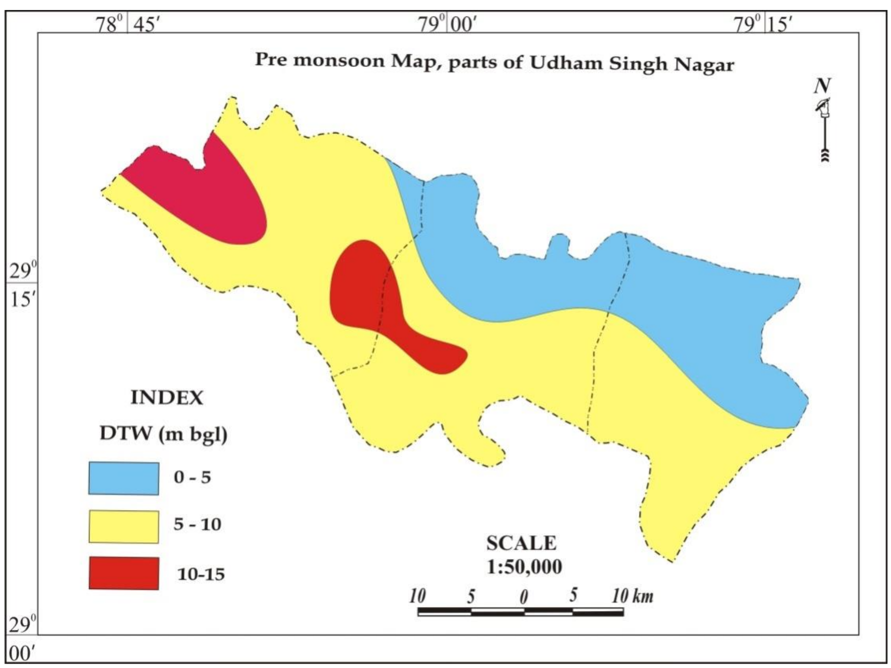


Fig. 14. Depth to Water Level Pre-Monsoon Map, Parts of U S Nagar District, Uttarakhand

more than 10 m bgl is noticed as isolated patches at Bharatpur- Shankhera in Kashipur Block and Angadpur- Jaspur section in Jaspur Block. The thematic water level map for the Pre-Monsoon (May, 2015) (Fig. 14) shows that the depth to water level gradually increases from north-west to south-east.

*3.2.2. P*ost - Monsoon (November), 2015

The depth to water level scenario during November, 2015 has changed due to the rainfall which has resulted in shallower Ground Water Level in the central and southern part of the study area. The depth to water level in the area varies from 0.42 m bgl at BarkharePande (Kashipur Block) to 13.1 m bgl at Jaspur (Jaspur Block). The water levels deeper than 10 mbgl is found around Angadpur-Jaspur section only.

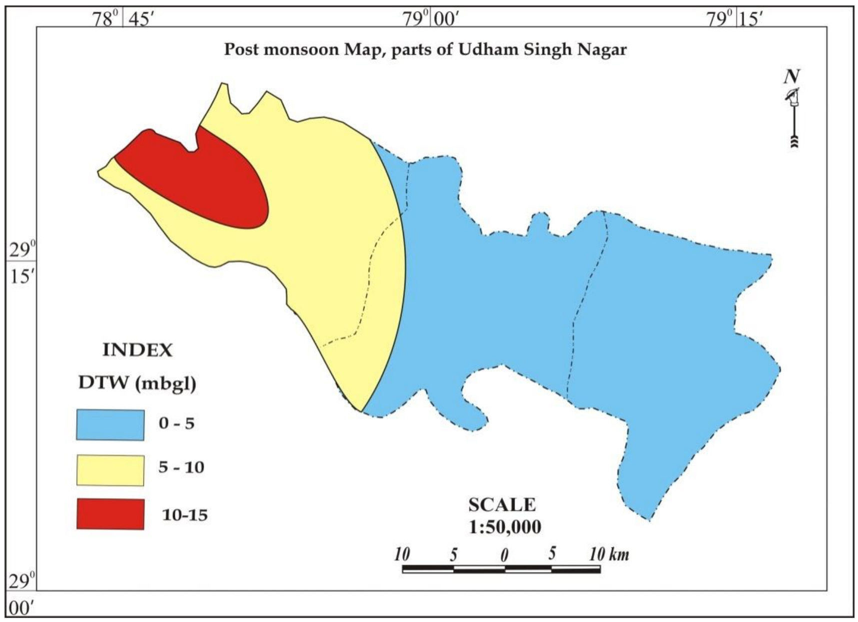


Fig. 15. Depth to water level Post-Monsoon Map, Parts of U S Nagar District, Uttarakhand

3.2.3. Decadal Water Level Fluctuation Pre-monsoon (May 2005-2014 Vs 2015)

Decadal (long-term) Water Level data of10 Ground Water Monitoring Stations for the period May 2005-2014 Vs 2015is analyzed and is given in **Annexure V-A**. Analysis of the data reveals that the lowest decadal rise of0.58mglis observed at Kashipur whereas the highest decadal rise of 2.90 m at Jogipura (Bazpur Block). As far as decadal decline in water level is concerned, majority of the study area shows the decadal decline in the range of 0-2 m. The highest being 9.01 m at Angadpur (Jaspur Block) while the lowest was 0.02m at Bazpur (Bazpur Block).

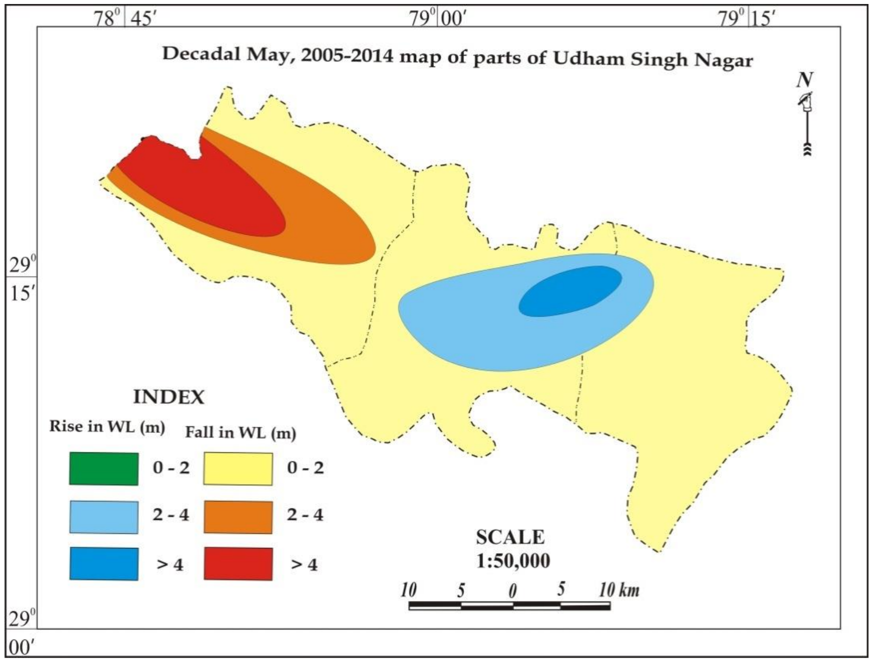


Fig. 16. Decadal Depth to water level fluctuation Map (May 2005-2014 Vs 2015), Parts of U S Nagar District, Uttarakhand

3.2.4. Decadal Water LevelFluctuation Post-monsoon (November 2005-2014 Vs 2015)

Decadal (long-term) water level data of10 Ground Water Monitoring Stations for the period November 2005-2014 Vs 2015is analysed and is given in **Annexure V -B**. Analysis of the data reveals that the lowest decadal rise of2.01mgl is observed at

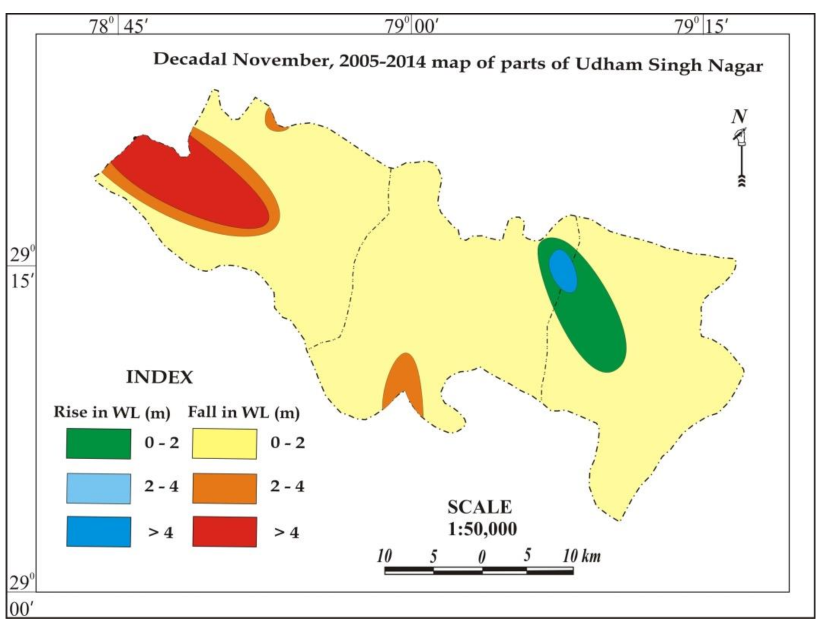


Fig. 17. Decadal Depth to water level fluctuation Map (November 2005-2014 Vs 2015), Parts of U S Nagar District,

Jogipura (Bazpur Block) whereas the highest decadal rise of3.87 m at BarkharePande (Kashipur Block). As far as decadal decline in water level is concerned, majority of the study area shows the decadal decline in the range of 0-2 m. The highest being8.26 m at Angadpur (JaspurBlock) while the lowest is0.09m at Bazpur (Bazpur Block).

3.2.5. Seasonal fluctuation – May 2015 vs. November 2015

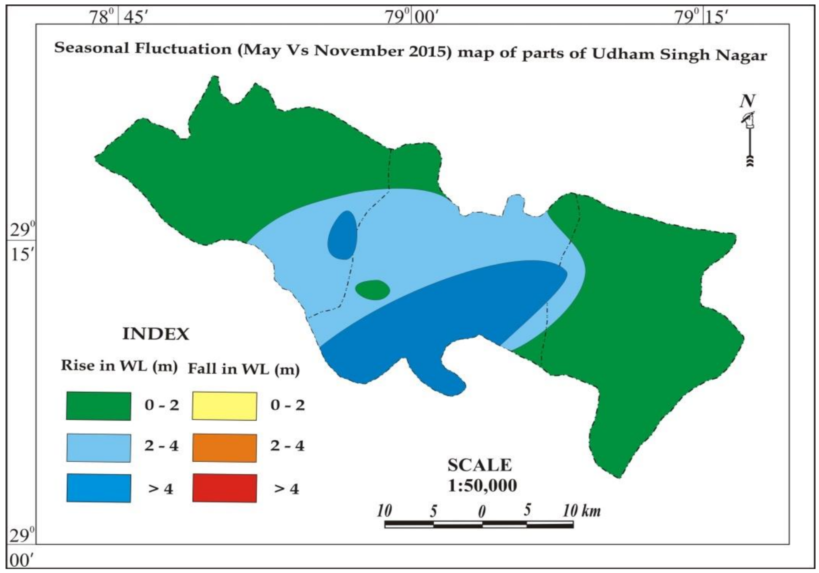


Fig. 18 Water level Fluctuation Map (May 2015Vs November 2015), Parts of U S Nagar District, Uttarakhand

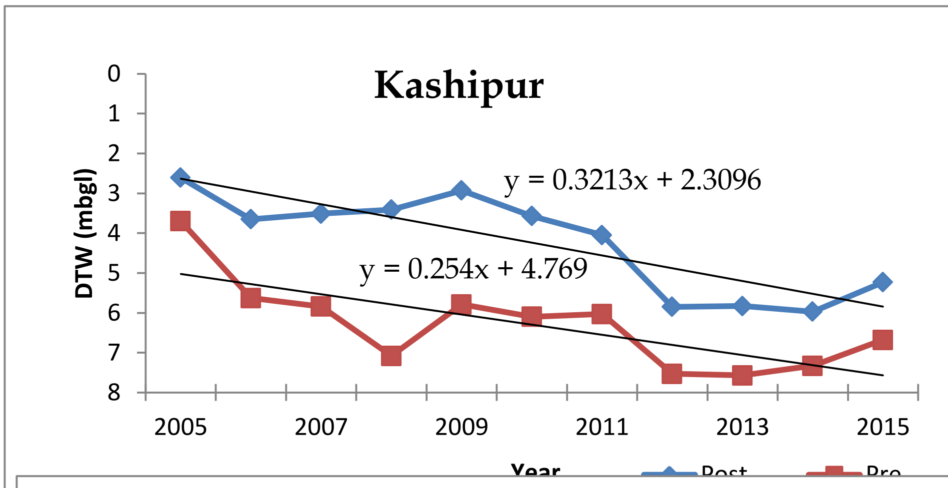
The water level fluctuation data of May 2015is compared with that of November 2015 for 18 Ground Water Monitoring Stations in Uttarakhand and the result is given in **Annexure VI.** Analysis of the fluctuation data for the period May-November (pre-monsoon versus post-monsoon) indicates dominantly rise in water level. The minimum rise being at Kashipur (0.45 m) while the maximum at Barkhare Pande (9.2 m) both in the Kashipur block in the study area. No GWMS shows the declining fluctuation, this means after monsoon the groundwater in the shallow aquifers recharges abruptly.

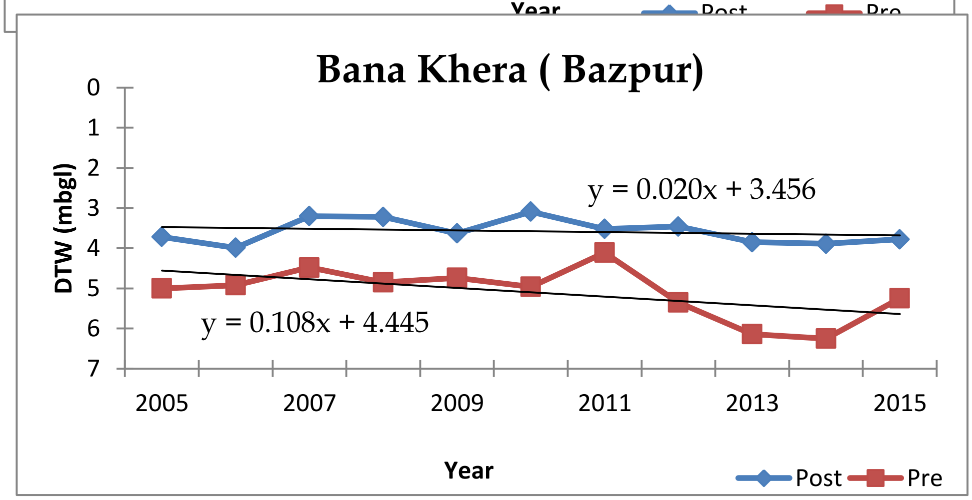
3.2.6. Long term Ground Water Level trend

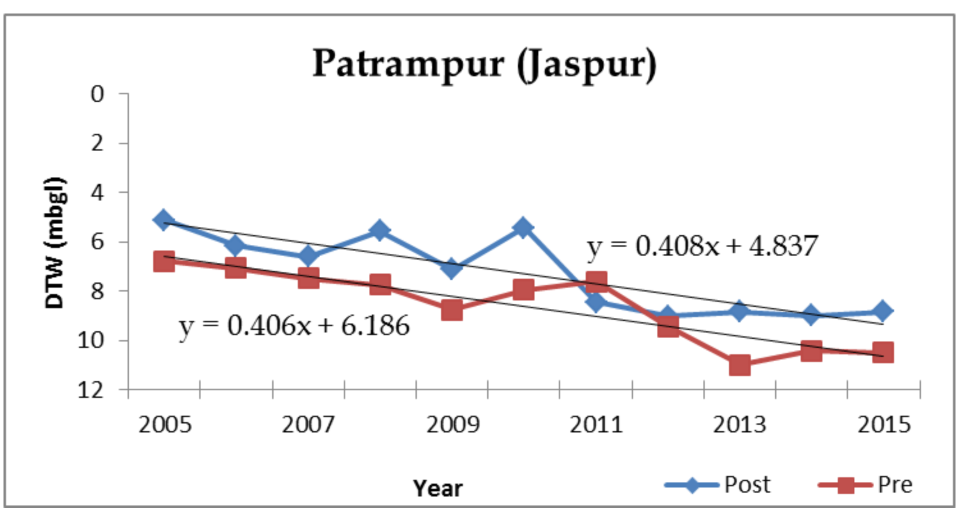
The long-term water level trend was computed for three Ground Water Monitoring Stations of CGWB exiting within the study area. These are Kashipur DW (Kashipur Block), Patrampur HP (Jaspur block) and BanaKhera HP (Bazpur Block).The Hydrographs of the Long-term water level trend stations are shown in Figure 13.The long-term ground water level data (Period: May 2005–May 2015 & November 2005-2015) of the study area has been examined (TableAnnexure– *V A & V B*) and thehydrograph plots are plotted for both pre and post monsoon periods against the depth to water level (m) (Fig. 19a, 19 b and 19 c). All the hydrographs are showing the falling water level trend both during the pre-and the post-monsoon periods. The Patrampur (Jaspur block) shows the significant decline to the tune of 40cm per year.

Table 15. Long term water level trend of Ground Water Monitoring Stations, parts of Udham Singh Nagar District, Uttarakhand

S. No	Location	Block	Data Availability	Pre-monsoon long Trend (m/yr.)	Post-monsoon long Trend (m/yr.)
1	Patrampur HP	Jaspur	2006-2015	(-)0.4062	(-) 0.4082
2	Kashipur DW	Kashipur	2006-2015	(-) 0.2548	(-) 0.3213
3	BanaKhera HP	Bazpur	2006-2015	(-) 0.1084	(-) 0.0202







3.3 Water Quality

The chemical composition of ground water is derived from different sources and the relationship of ground water composition to source rock type is well known. Human activities may modify water composition extensively through direct effects of pollution and indirect results of ground water development. To study the chemical quality of ground water, 18 groundwater samples were collected during May 2014 from the monitoring stations. The chemical quality data, Pre-monsoon 2014 is given in Annexure-VII and the long term chemical quality data (2004-2014) is given in Annexure-VII.

3.3.1 Suitability of Ground Water for Domestic purpose

The chemical parameter wise suitability of ground water for drinking purpose as per IS 10500:2012 is given below. The suitability of groundwater of the area for drinking purposes has been assessed as per the guide line laid down by Indian Standard Drinking Water Specification (BIS, 2012), which assure, in general, the protection of human health. Accordingly, the concentration of various major and trace elements in the groundwater samples of the study area are compared with the drinking water standard of Indian Standard Drinking Water Specification (BIS, 2012) as summarized in Table- 16.

Table 16. Range of Chemical Constituents, parts of U S Nagar, Uttarakhand.

S. No	Chemical Constituent	Range (mg/l)	Drinking Water Standard (BIS, 2012)	
			Acceptable Limit	Permissible Limit
1	pH	7.70 – 8.30	6.5 - 8.5	No relaxation
2	Electrical Conductivity (µS/cm at 25^0 C)	399 – 750	750	3000
3	Calcium (mg/l)	20 – 64	75	200
4	Magnesium (mg/l)	9.7 – 49	30	100
5	Fluoride (mg/l)	0.16 – 1.4	1.0	1.5
6	Nitrate (mg/l)	0.02 – 9.8	45	No relaxation
7	Chloride (mg/l)	7.1 – 85	250	1000
8	Total Hardness as $CaCO_3$ (mg/l)	90 – 320	300	600
9	Copper (mg/l)	0.002-0.144	0.05	1.5
11	Zinc (mg/l)	0.024 – 0.094	5	15
12	Iron (mg/l)	0.183 – 0.547	0.30	1.00
13	Nickel (mg/l)	0.021	0.05	No relaxation
14	Manganese (mg/l)	0.093 – 0.11	0.1	0.3

3.3.1.1. Hydrogen Ion Concentration (pH)

pH is indicative of acidity or alkalinity waters, and it affects taste, corrosivity and the water supply systems. The pH value ranges from 7.70 to 8.30, which show alkaline nature of groundwater. The prescribed limit for pH is 6.5 to 8.5. The groundwater in the study is well within the limits and hence, suitable for domestic use.

3.3.1.2. Electrical Conductivity (EC)

The EC is a measure of mineralization and indicative of salinity of Ground Water. The acceptable and permissible limit for EC is 750 & 3000 μS/cm – 25 °C respectively. The EC of ground water samples collected from the study area ranges from 399 - 750μS/cm – 25 °C and is well within the acceptable limit of750μS/cm and hence, suitable for domestic use. The distribution of EC is shown in Fig. 20. The block-wise long term EC hydrograph is shown in Fig 21.

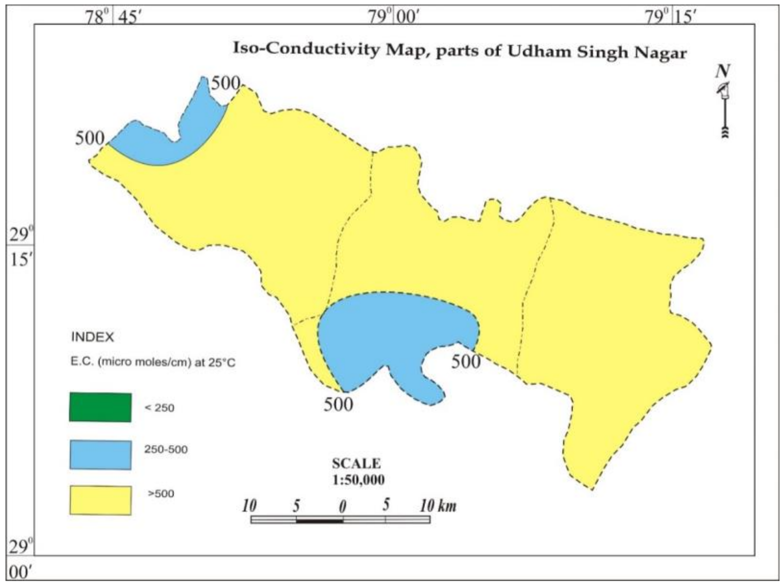
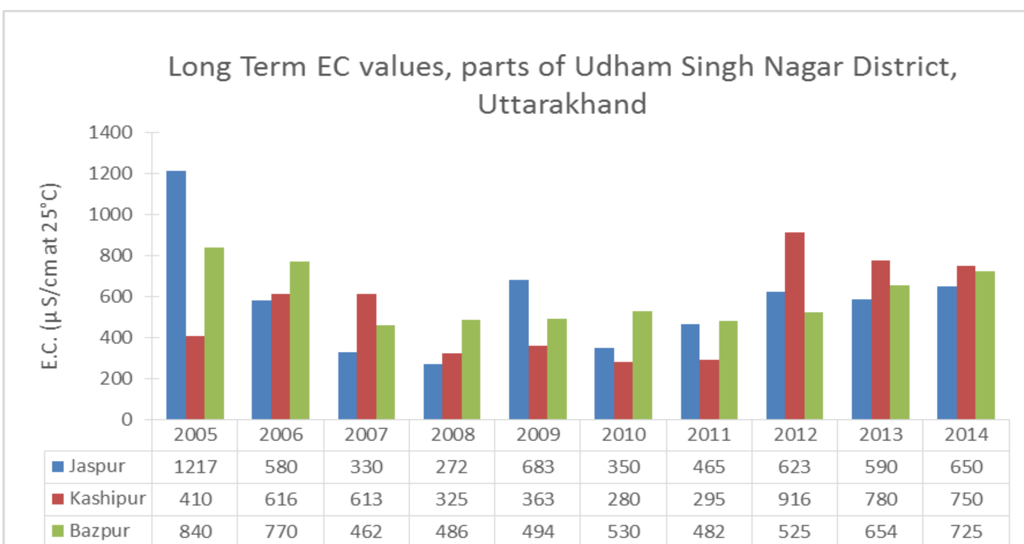


Fig. 20. Iso-Conductivity map, Parts of U S Nagar District, Uttarakhand



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Jaspur	1217	580	330	272	683	350	465	623	590	650
Kashipur	410	616	613	325	363	280	295	916	780	750
Bazpur	840	770	462	486	494	530	482	525	654	725

Fig. 21. Block-wise Long term EC hydrograph**, Parts of US Nagar District, Uttarakhand**

3.3.1.3.

Total hardness (TH)

Hardness is an important criterion for determining usability of water for domestic, drinking and industrial supplies. Hardness in water is mainly caused by Calcium and Magnesium cations and it is mainly of two types, viz., carbonates and non-carbonates. Based on the concentration of TH, the waters are classified as soft (0 - 50 mg/l), moderately hard (50 – 100 mg/l), hard (100 - 300 mg/l) and very hard if more than 300 mg/l. The acceptable and the permissible limits for TH are 200 and 600 mg/l respectively. TH of ground water of the study area ranged from 90 - 320mg/l which indicates that the ground water samples fall in moderately hard to very hard type and hence, mostly suitable for domestic use.

3.3.1.4. Calcium

The acceptable and the permissible limits for calcium are 75 and 200 mg/l respectively. The concentration of calcium in ground water ranged from 20 - 64 mg/l and the ground water is within the permissible limit and suitable for domestic use.

3.3.1.5. Magnesium

The Mg concentration in the study area ranges from 9.7 to 49mg/l and is well within the prescribed limits and mostly suitable for domestic use. The acceptable and the permissible limits for magnesium are 30 - 100 mg/l respectively. Its salts are cathartics and diuretic high concentrations may have laxative effect particularly on new users. Magnesium deficiency is associated with structural and functional changes. It is essential as an activator of many enzyme systems.

3.3.1.6. Sodium

There are no acceptable and permissible limits for sodium concentration. The excess consumption of Sodium may be harmful to the users suffering from cardiac, renal and circulatory diseases. The Na concentration in the study area ranges from 8.9 to 113mg/l. and is mostly suitable for domestic use.

3.3.1.7. Potassium

Acceptable and permissible limits for potassium concentration are not fixed. Potassium is an essential nutritional element but consumption of excessive amounts is cathartic. The K concentration in the study area ranges from 0.89 to 1.96mg/l. and is mostly suitable for domestic use.

3.3.1.8. Carbonate and Bicarbonate

There are no acceptable and permissible limits for carbonate and bicarbonate concentrations. In the study area, the concentration of bi-carbonate ranged from 207-403 mg/l and carbonate is not detected.

3.3.1.9. Chloride

The acceptable and the permissible limits for chloride are 250 and 1000 mg/l respectively. In the study area, the concentration of chloride in ground water ranged from 7.1 – 85 mg/l and is well within the permissible limit and suitable for domestic use. The distribution of Cl is shown in Fig. 22.The block-wise long term Chloride hydrographs is shown in Fig 23.

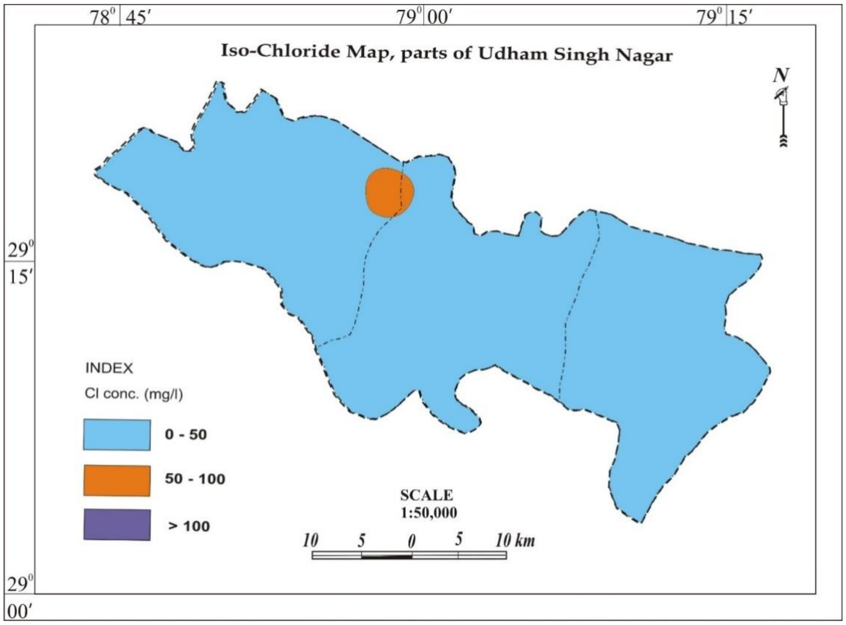
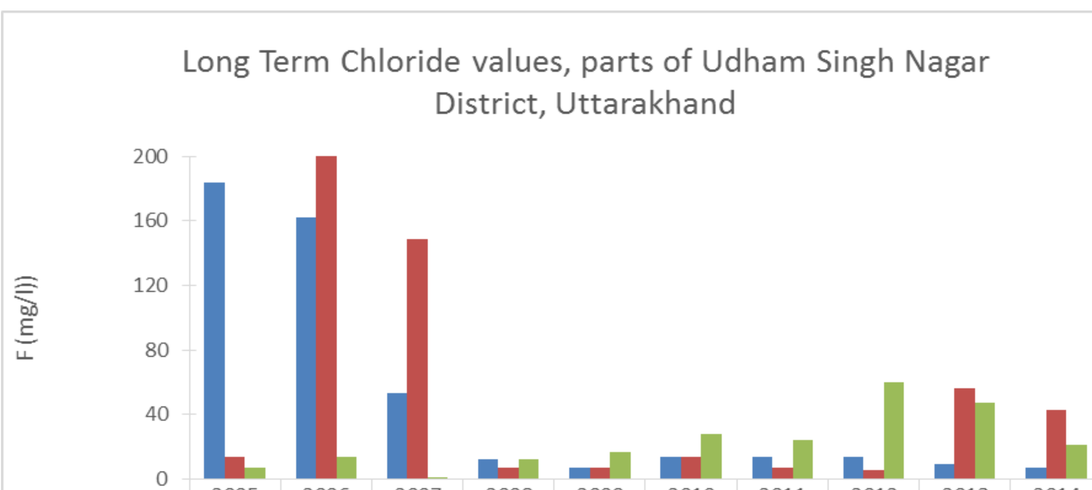


Fig. 22. Iso-Chloride map, Parts of U S Nagar District, Uttarakhand



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Jaspur	184	162	53	12	7.1	14	13.6	14	8.9	7.1
Kashipur	14	206	149	6.7	7.1	14	7.1	5.3	56	43
Bazpur	7.1	13.5	1.1	12	17	28	24	60	47	21

Fig. 23. Block-wise Long Term Chloride hydrograph, Parts of U S Nagar District, Uttarakhand

3.3.1.10. Fluoride

The acceptable and the permissible limits for chloride are 1 and 1.5 mg/l respectively. In the study area, the concentration of Fluoride in ground water ranged from 0.16 – 1.4 mg/l and is well within the permissible limit and suitable for domestic use. The distribution of F is shown in Fig. 24.The block-wise long term Fluoride hydrographs is shown in Fig 25.

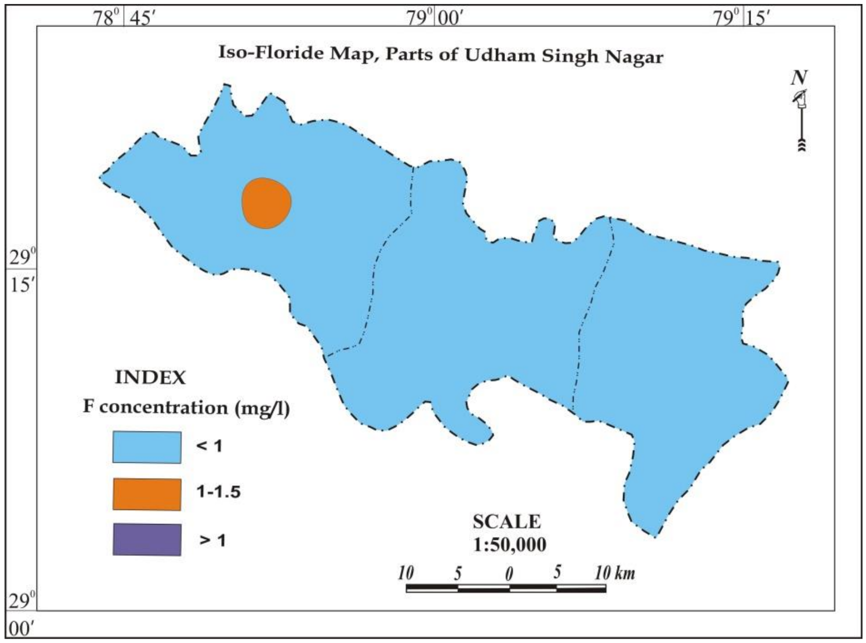


Fig. 24.Iso-Fluoride Map, Parts of U S Nagar District, Uttarakhand

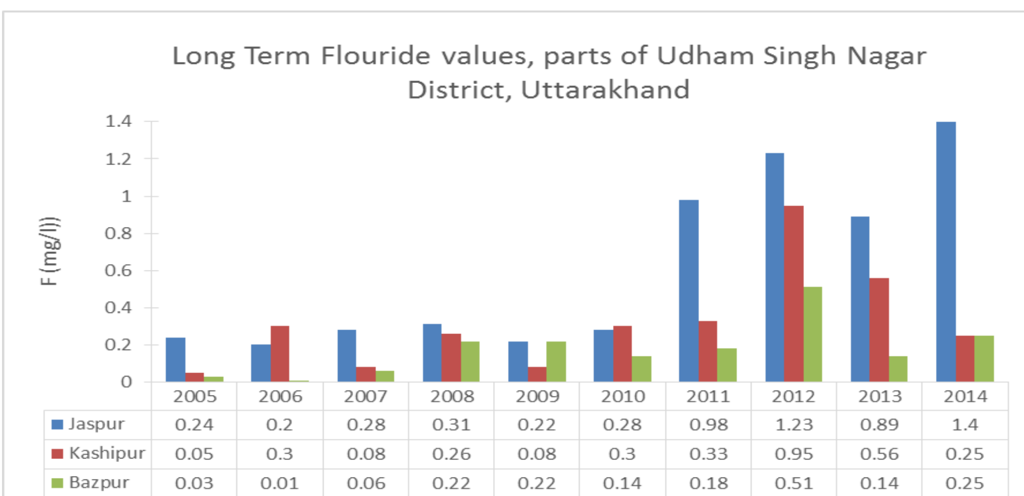


Fig. 25 Block-wise Long Term Fluoride hydrograph**, Parts of U S Nagar District, Uttarakhand**

3.3.1.11. Nitrate

The acceptable and the permissible limits for chloride are 45 and 100 mg/l respectively. In the study area, the concentration of Nitrate in ground water ranged from 0.02 – 9.8 mg/l and is well within the permissible limit and suitable for domestic use.

3.3.2. Concentration of trace metals/ Heavy Metals

Trace metals are widely distributed in the environment with sources mainly from weathering of minerals and soils (Merian, 1991; O'Neil, 1993). Trace elements in ground water are defined as chemical elements dissolved in water in minute quantities, always or almost always, in concentration less than one mg/l (USGS,1993). Trace metals are needed by the body to satisfy its nutritional requirements. Some metals present in trace concentration are important for physiological functions of living tissue and regulate many biochemical processes. The same metals, however, at increased concentration may have severe toxicological effects on human being (Chapman, 1992). The excess or deficiency both may pose health hazard. In the study area groundwater samples were collected for analysis of Cu, Mn, Zn, Fe, Ni. A brief description on concentration levels and chemical behaviour of these trace metals is given below:

3.3.2.1. Zinc (Zn)

The acceptable and the permissible limits for Zinc are 5 and 15 mg/l respectively. Zinc concentration in the area is within the permissible limit (0.024 – 0.094 mg/l).

3.3.2.2. Manganese (Mn)

Manganese is one of the most abundant metals in the earth's crust and usuallyoccurs together with Fe. Dissolved manganese concentrations in ground and surface waters, poor in oxygen, can reach higher concentration levels. The acceptable and the permissible limits for Mn are 0.1 and 0.3 mg/l respectively. The manganese concentration in the area is within the permissible limit (0.093 – 0.11mg/l).

3.3.2.3. Copper

The acceptable and the permissible limits for copper are 0.05 and 1.5 mg/l respectively. The concentration of copper in ground water ranged from 0.002 - 0.144 mg/l and lies within acceptable limit

3.3.2.4. Nickel

There are no standards for Nickel concentration. The concentration of nickel in ground water is 0.021mg/l.

3.3.2.5. Iron (Fe)

Iron is one of the most abundant metals in the earth's crust. Iron is an essential element for human nutrition. As per BIS (2012), acceptable limit for iron concentration in potable water is 0.3 mg/l there is no relaxation for permissible limit. Iron concentration in the groundwater of the study area ranges within 0.183 to 0.547 mg/l and lies within acceptable limit.

3.3.3 Suitability of Ground Water for Irrigation purposes

The chemical quality of water is an important factor to be considered in evaluating its suitability for irrigation purposes. Irrigated plants absorb and transpire the water but leave nearly all the salts behind in the soil, where these salts accumulate and eventually prevent plant growth. The suitability of groundwater for irrigation is dependent on the effects of the mineral constituents of water on both the plant and soil. Electrical conductivity and sodium play a vital role in suitability of water for irrigation. Higher Electrical conductivity in water creates soil salinity. Harmful effects of irrigation water increases with the total salt concentration, irrespective of the ionic composition. Higher salt content in irrigation water causes an increase in soil solution osmotic pressure (Txorne and Peterson, 1954). The salts apart from affecting the growth of plants also affect the soil structure, permeability and aeration which indirectly affect plant growth(Todd, 1980).

The irrigation water containing a high proportion of sodium will increases the exchange of sodium content of the soil, affecting the soil permeability, and texture making the soil hard to plough and unsuitable for seeding emergence (Triwedy and Goel, 1984; Sujatha and Reddy, 2003). If the percentage of Na+ with respect to (Ca+2 +Mg+2 +Na+) is considerably above 50% in irrigation waters, soils containing exchangeable calcium and magnesium take up sodium in exchange for calcium and magnesium causing deflocculation and impairment of the quality and permeability of soils (Karanth,1987). Soil amendments, such as, gypsum or lime may correct the situation.

Electrical conductivity (EC), Percent Sodium (%Na), Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are considered for the determination of suitability of water for irrigation purpose. The computed values of percent Sodium, SAR and RSC are given in Table 17.

Table 17. Computed values of EC, percent sodium, SAR and RSC

S. No	Sample Id	Location	EC(µS/cm-25°C)	% Sodium	SAR	RSC
1	W-1	Jaspur HP	650	73.31	5.18	4.81
2	W-2	Patrampur HP	520	33.55	1.33	1.62
3	W-3	Angadpur HP	400	13.16	0.39	0.40
4	W-4	Missarwala HP	500	23.34	0.83	0.81
5	W-5	BarkharePande HP	450	29.26	1.04	0.82
6	W-6	Sultanpur Patti HP	369	12.29	0.33	0.19
7	W-7	Kashipur DW	750	37.95	1.81	1.02
8	W-8	Bharatpur HP	570	58.18	3.03	3.17
9	W-9	Dhanauri Patti HP	500	23.20	0.83	0.80
10	W-10	Durgapur HP	685	25.01	1.05	-1.04
11	W-11	Shankhera HP	399	11.63	0.32	-0.02
12	W-12	Bazpur DW	725	24.23	1.04	0.44
13	W-13	Jharkhandi HP	680	6.11	0.22	-0.04
14	W-14	Jogipura HP	620	12.03	0.42	0.63
15	W-15	BannaKhera DW	650	11.28	0.41	0.62
16	W-16	Kanawra HP	597	11.77	0.40	0.42
17	W-17	Pritpur HP	627	12.63	0.45	0.41
18	W-18	Badaripur HP	740	17.26	0.70	-0.05

3.3.3.1 Electrical Conductivity

Based on the values of EC, ground waters are categorized into excellent, good, permissible, doubtful and unsuitable for irrigation. In the study area, all the 18 samples fall under good category (Table 15) and are suitable for irrigation purposes.

EC Value (µS/cm at 25 °C)	Type of water
250	Excellent
250-750	Good
750-2000	Permissible
2000-3000	Doubtful
>3000	Unsuitable

3.3.3.2 Sodium hazard

Sodium concentration is very important in classifying irrigation water because; sodium by process of Base Exchange replaces calcium in the soil thereby reduces the permeability of soil which has greater effect on plant growth. Sodium content in chemical analysis is reported as percent sodium which is determined by –

Sodium Percentage (%Na) = ((Na+K) / (Ca+Mg+Na+K)) *100

Where, all ionic concentrations are expressed in equivalent per million (epm).

% Sodium	Type of water
<20	Excellent
20-40	Good
40-60	Permissible
60-80	Doubtful
>80	Unsuitable

In the study area, all the18 sample falls under excellent category (Table 15) and are suitable for irrigation purposes.

3.3.3.3 Sodium Adsorption Ratio (SAR)

The relative activity of sodium ion in the exchange reaction with soil is expressed in terms ofa ratio known as Sodium Adsorption Ratio (SAR) which is determined by

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

Where, all ionic concentrations are expressed in epm.

SAR Value	Type of water
<10	Excellent
10-18	Good
18-26	Fair
>26	Poor

Based on the SAR values the Ground Water is classified as excellent, good, fair and poor. In the study area, all the18 sample falls under excellent category (Table 15) and are suitable for irrigation purposes.

3.3.3.4 Wilcox diagram

In order to determine suitability of class of water for irrigation purpose, Wilcox (1948 &1955) proposed a diagram in which percent sodium is to be plotted against electrical conductivity. Wilcox diagram is prepared and presented in Fig.26. The diagram reveals that all the 18

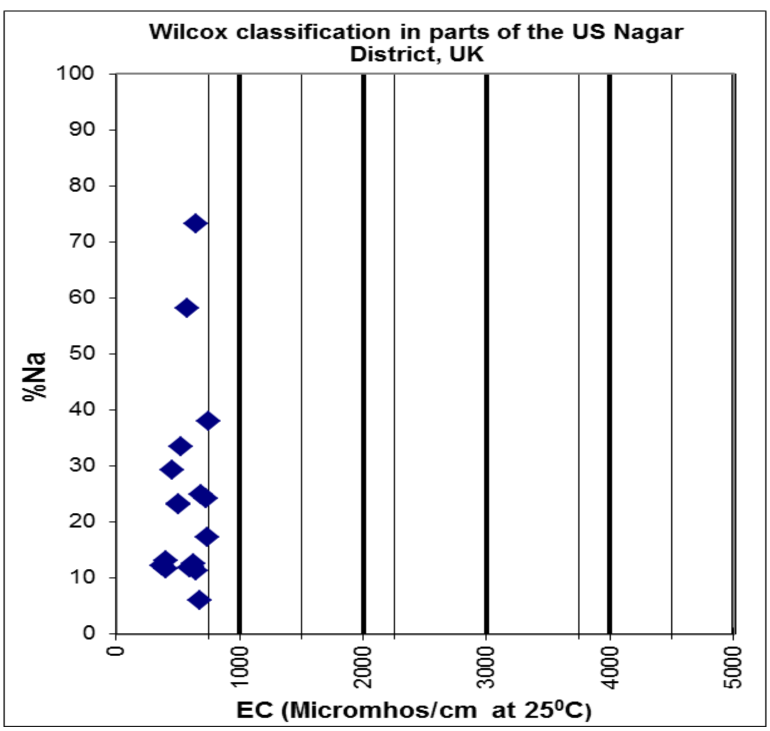


Fig. 26. Wilcox classification in Parts of U S Nagar District, Uttarakhand

samples fall in excellent to good (Class–I) category (Table 17).

3.3.3.5 US Salinity diagram

The US Salinity Laboratory staff (1954) has constructed a diagram for classification of irrigation water with reference to SAR as an index for sodium hazard 'S' and EC as an index of salinity hazard 'C'. The sodium hazard is classified into low (S1), medium (S2), high (S3) and very high (S4) whereas, salinity hazard is classified into low (C1), medium, (C2), high (C3) and very high (C4). In this diagram, the values of SAR are plotted on arithmetic scale against EC on log scale and different classes of water have been marked and presented in Fig. 27. From the figure it is concluded that, all the 18samples fall in C2-S1 category (Medium salinity - Low sodium hazard category), which can be used for irrigation in almost all types of soil with little danger of exchangeable sodium.

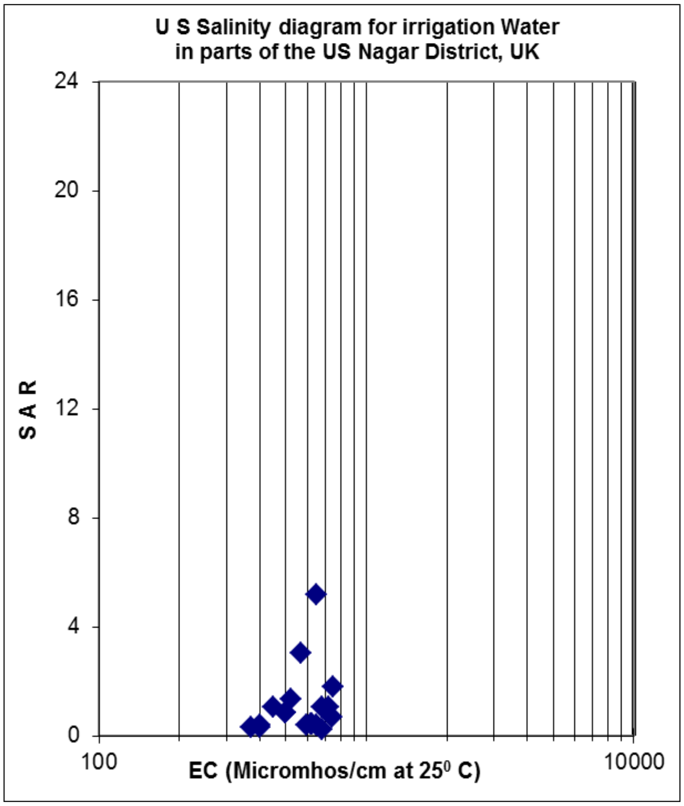


Fig. 27.U S Salinity diagram for irrigation Waters, parts of U S Nagar District, Uttarakhand

3.3.3.6 Bicarbonate hazard

The Bi-carbonate concentration of water has been suggested as additional criterion to study the suitability of ground water for irrigation purpose. If the water contains high concentration of bicarbonate ion, there is a tendency of calcium and magnesium ions to precipitate as carbonates. The convenient way of expressing values of the water in terms of Residual Sodium Carbonate (RSC) is as follows:

Residual sodium Carbonate (RSC) = (HCO_3 + CO_3) – (Ca + Mg)

Where all the ionic concentrations are expressed in epm

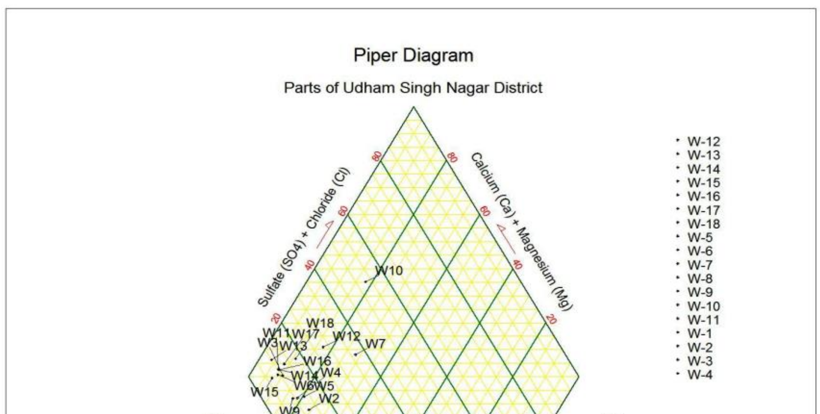
RSC Value	**Type of water**
<1.25	Safe
1.25 – 2.5	Marginal
>2.5	Unsuitable

On the basis of RSC, ground waters are divided into three categories viz., safe, marginal and unsuitable. In the study area, out of 18 samples (Table 15), 15 samples fall in safe category, 1 sample in marginal and 2 samples in unsuitable category (Jaspur and Bharatpur).

3.3.4. Types of Ground Water in the study Area

Ground waters in the study area are generally alkaline in nature and the pH varies from 7.70 to 8.25. The concentration of EC varies from 369 to 750µS/cm-25 °C and mostly suitable forirrigations purposes. According to percent sodium, all 18 samples fall in excellent category. According to Sodium Adsorption Ratio all the samples fall in excellent category. As per RSC, 15 samples fall in safe category, 1 in marginal category and 2 samples in unsuitable category. Also, the concentration of heavy metals like zinc, copper, iron, manganese and nickel are well within the permissible limits.

The major ion composition of groundwater was used to classify groundwater into various types based on the dominant cations and anions (Deutsch, 1997). The piper diagram(Fig 28) and the modified piper diagram(Fig 29) was prepared for groundwater samples collected from 18 monitoring stations in the study area. Both the diagrams indicate that the groundwater of the area is mainly of (Ca-Mg-HCO3) type which



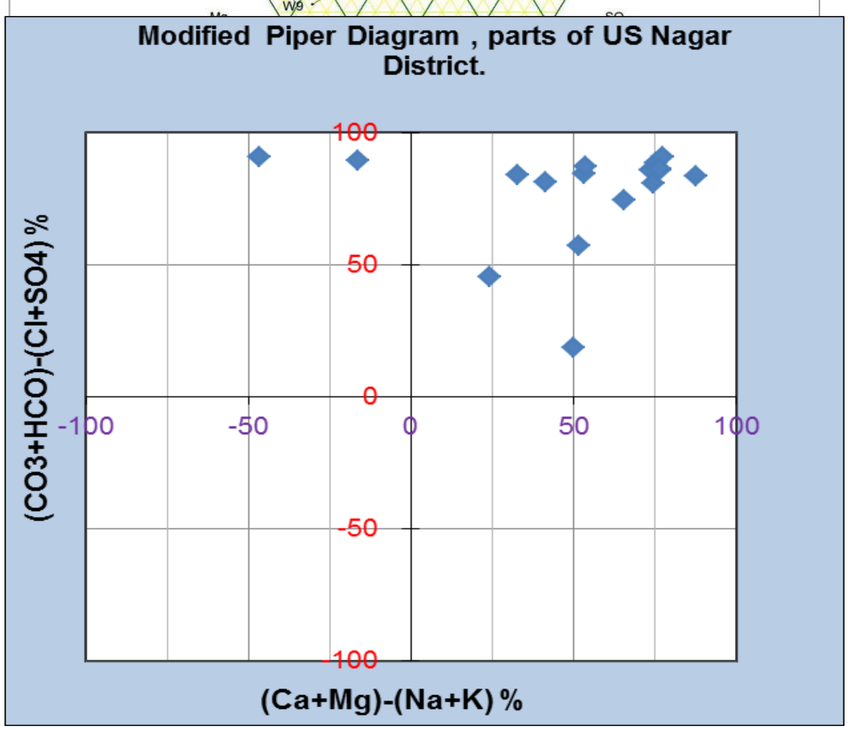


Fig. 29. Modified Piper Diagram, Parts of U S Nagar District, Uttarakhand

means the groundwater is recharged type. However, two samples i.e Jaspur (Jaspur Block) and Bharatpur (Kashipur Block) are showing (Alkali-Cl-SO_4) type of water.

From the above study it is concluded that the ground water in the study area is generally suitable for drinking and Irrigation purpose and are well within the permissible limits.

CHAPTER – 4

AQUIFER DISPOSITION

The subsurface configurations of aquifers have been delineated based on available lithological logs of CGWB and State Govt. agencies. Three lithological cross-sections along different orientation have been prepared to depict the aquifer geometry (Fig 30). As the study area falls pre-dominantly in the TaraiFormation, fou rlithologs, which falling outside of the present study area, have also been considered to demarcate the transition zone from Bhabhar to TaraiFormation in terms of sediments variations. Based on the observations, the lithologyreveals the presence of a thick granular zone within the thick confining clay layers. The hydrogeological details of the exploratory wells, which have been used for the preparation of the hydrogeological cross-sections for knowing the aquifer geometry in the study area is given in **Annexure-VIII**. To understand the aquifer geometry of the study area the following cross-sections have been prepared:

1) A – A′ Section or Aspur - Sultanpur Patti - Khempur Section.
2) B – B′ Section or Dhela -Pipalsana – Sulanpur Patti Section.
3) C – C′ Section or Ramnagar – Himmatpur – Bazpur Section.

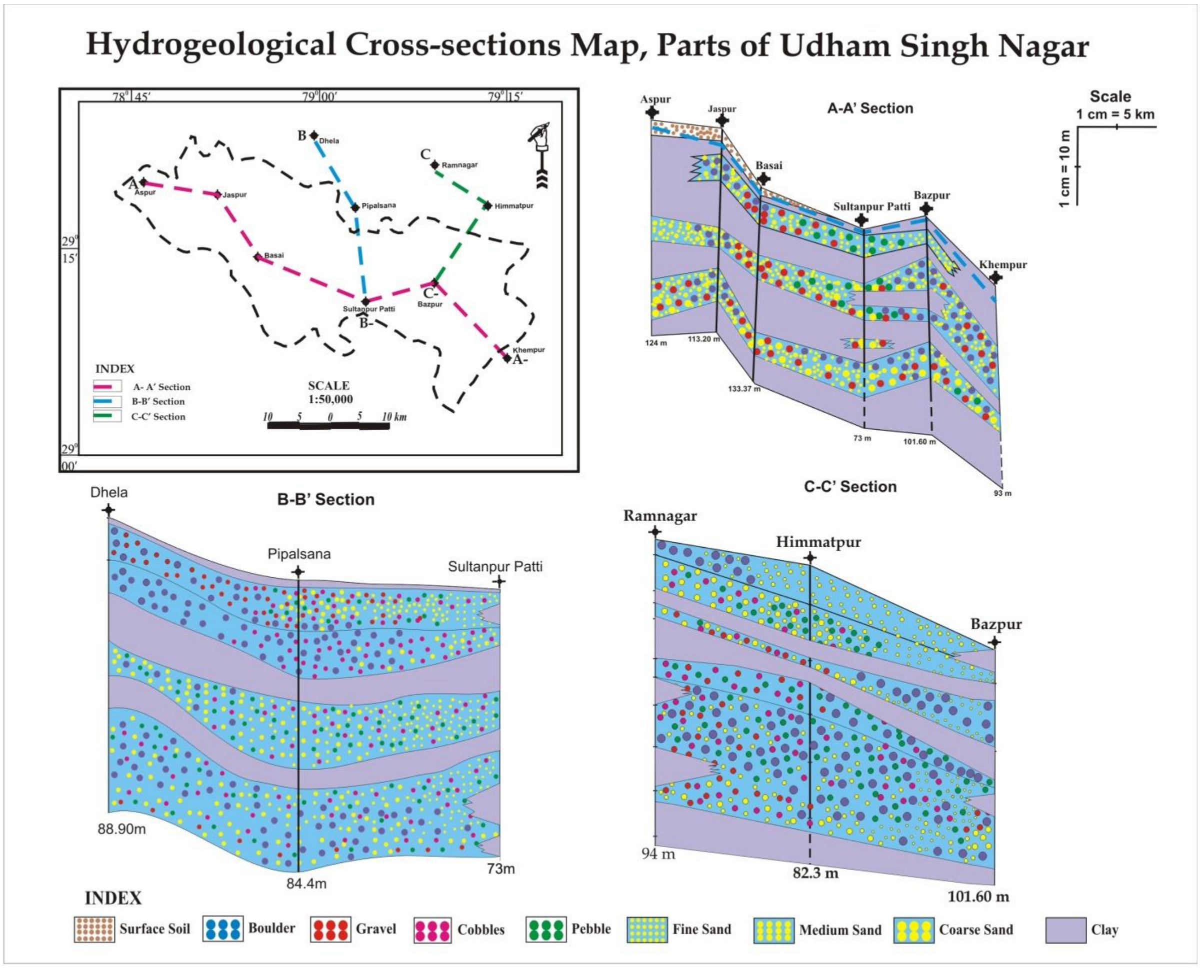


Fig 30. Hydrogeological Cross-section Map, Parts of U S Nagar District, Uttarakhand.

4.1. A – A′ Section or Aspur - Sultanpur Patti - Khempur Section

Based upon the exploration data and available lithologs, a cross section along A – A′ showing the subsurface correlation of strata and inter relationship of granular zones has been prepared. The A – A′ cross - section falls pre-dominantly in the Tarai formation and comprises of sixexploratory wells i.eAspur, Jaspur, Basai, Sultanpur Patti, Bazpur and Khempur. The section is aligned roughly along the northwest to southeast(NW-SE) direction. The study of the sections shows that there existmultiple aquifer systems. The granular zones are composite in nature (Boulders mixed with pebbles, gravels, cobbles sand and clay), and are separated by the thick confining clay layers. The thickness of granular zone varies from 10 to 30 m. The thickness of the clay layersvaries from 17 to 39 m.The sand grains also show gradation from coarse to fine grain. The piezometerichead in existingwells is very shallow and rangesfrom 1 to

4 mbgl. The deeper piezometric head observed atKhempur (Gadarpur block), which is of 7mbgl. During the monsoon season,the well located at Sultanpur Patti gains the artesian conditions and free flows.

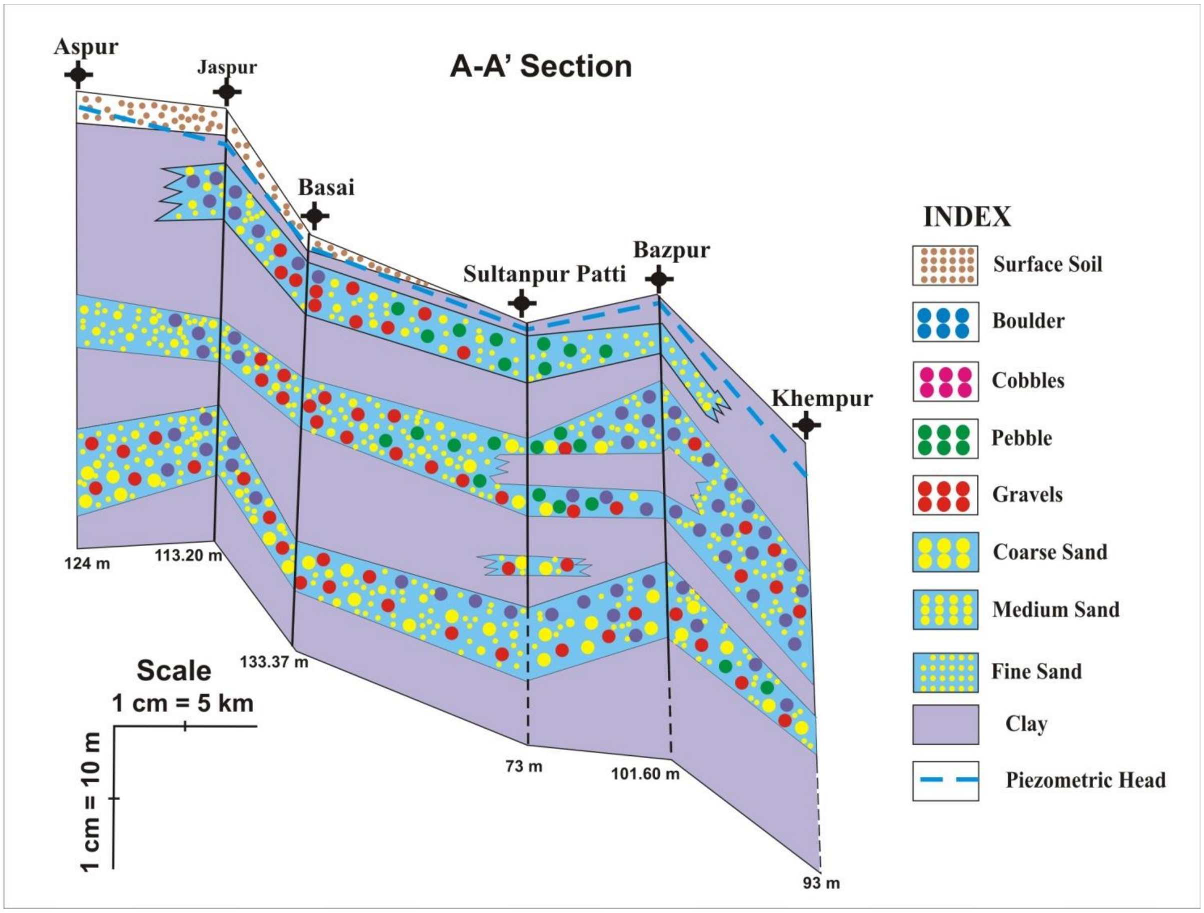


Fig 31. Hydrogeological Cross-section Map along A – A′ Section.

4.2. B – B′ Section or Dhela - Pipalsana – Sulanpur Patti Section

The hydrogeological cross – section along the B – B′ section consists of three exploratory wells i.eDhela(falls in BhabarFormation), Pipalsana(transition zone) and Sultanpur Patti (falls in Tarai Formation). The Pipalsana EW shows special significance due to its location and it defines precisely the boundary between Bhabhar and TaraiFormation. It also provides the information on the artesian pressure head and the nature of strata close to the spring line. The section is aligned roughly along the northwest to south direction. The section clearly depicts the sediments deposition history with the change in gradient, with the dominance of boulders at Dhela to admixture of sediments at Pipalsana well lies in the depression;to medium to fine grained sands along with few pebbles at SultanpurPatti. The granular zones are separated by clay layers, having thickness of 12 to 18 m.

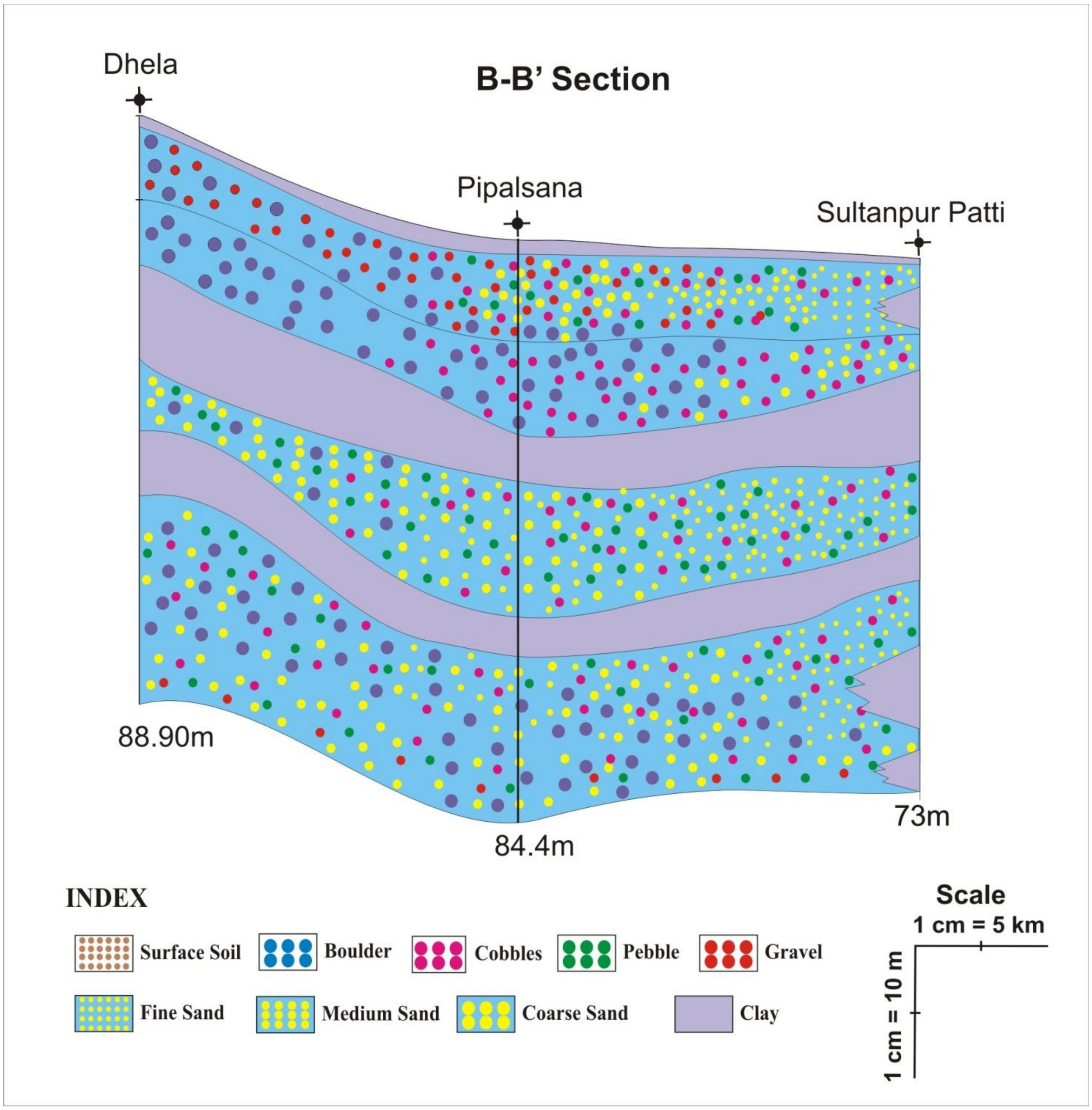


Fig 32. Hydrogeological Cross-section Map along B – B' Section.

4.3. C – C' Section or Ramnagar – Himmatpur – Bazpur Section

The hydrogeological cross – section along the C– C' section covers 3 Exploratory wells i.eRamnagar (falls in BhabarFormation), Himmatpur and Bazpur (falls in Tarai Formation). The section is aligned roughly along the Northwest to south direction. The section clearly depicts the sediments deposition history with the change in gradient, with the dominance of boulders at Dhela to admixture of sediments at Pipalsana well lies in the depression; to medium to fine grained sands along with few pebbles at SultanpurPatti. The granular zones are separated by thick clay layers of 12 to 18 m thickness. The significant observation has been made here that,Tarai sediments close to the spring line in the region resembles that of the Bhabhar. Coarser and heterogenous nature of the Taraisediments reveals that Tarai aquifers are nothing but in

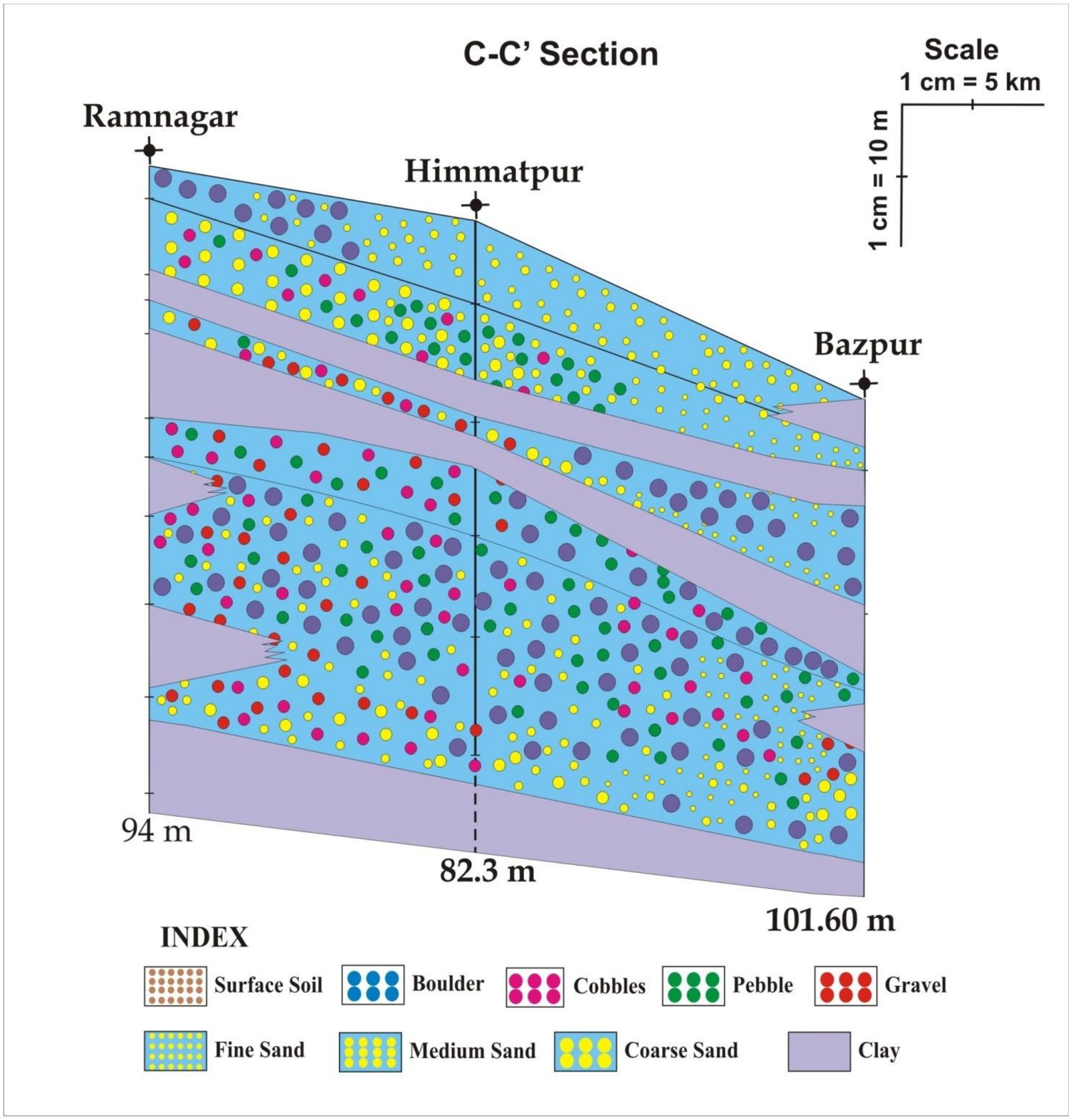


Fig 33. Hydrogeological Cross-section Map along C – C′ Section.

continuation of the Bhabhar aquifers.

CHAPTER – 5

GROUND WATER RESOURCE AND GROUNDWATER DEMAND

5.1. Groundwater Resources Estimation

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

The Gangetic Alluvium of study area has a vast storage of water in static as well as confined reservoir and provides a favourable situation to optimally develop the alluvial aquifer as a whole. Therefore, the groundwater resources must be described, evaluated and managed within precisely defined framework: **aquifer system** which forms the natural units of groundwater management

The occurrence of alternate clay and sandy layer give rise to the multi-aquifer system in the study area. The aquifers occurring below the phreatic zone have been considered as the deeper aquifer. In the present context the deeper aquifers are separated from the phreatic aquifer by a thick and impermeable clay layer. The deeper aquifer includes semi-confined and confined aquifers, depending upon the extent and nature of the confining beds.

The Ganga basin has deeper aquifers of large extension falling in the study area. Auto-flow conditions also exist in the Kashipur and Bazpur blocks of the study area. There is a stress on the unconfined aquifer in the parts of Jaspur block where significant declining water level trend are observed. **Thus it is the need of the hour that resources of deeper aquifer are precisely quantified and ground water resources are developed, used and managed in sustainable manner.**

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

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

5.2.1. Dynamic Ground Water Resource

It is essential to have a review on the groundwater resources periodically. The present '**Dynamic Ground Water Resource Estimation'** (as on 31st March, 2011) has been carried out in all the blocks of the study area, based on GEC (1997) norms, using the '**Water Table Fluctuation Method'** (WTF). The water level fluctuation method is based on the concept of storage change due to difference between various input and output components. Input refers to recharge from rainfall and other sources and subsurface flow into the unit of assessment. Output refers to ground water draft, groundwater evapotranspiration, base flow to streams and subsurface outflow from the unit.

Total annual ground water recharge from rainfall during monsoon and non-monsoon and other sources, is estimated as 29395.61 ha m, annual draft for all uses (domestic, industrial and irrigation) is 23786.54 ha m. The net ground water availability for future irrigation is 17303 ha m. The block-wise stage of Ground Water Development in the study area is shown in Table 18. A perusal from the table 17, the highest groundwater draft is in Bazpur block and least is in the Jaspur Block. The block wise pictorial presentation of net groundwater availability and total draft of the study area is shown in Fig. 34.

Table 18 Block-wise Groundwater Resources Potential, Parts of Udham Singh Nagar District, Uttarakhand as on 31/03/2011 (ham)

S. No	Block	Net annual GW Availability	Gross GW Draft	Net GW Availability for Future	Stage of Development	Categorization
1	**Jaspur**	7039.76	5669.71	1029.84	80.54 %	Critical
2	**Kashipur**	8755.30	7625.11	913.04	87.09 %	Critical
3	**Bazpur**	13164.14	10491.72	2252.94	79.70 %	Safe
	Total	28959.2	23786.54	4195.82		

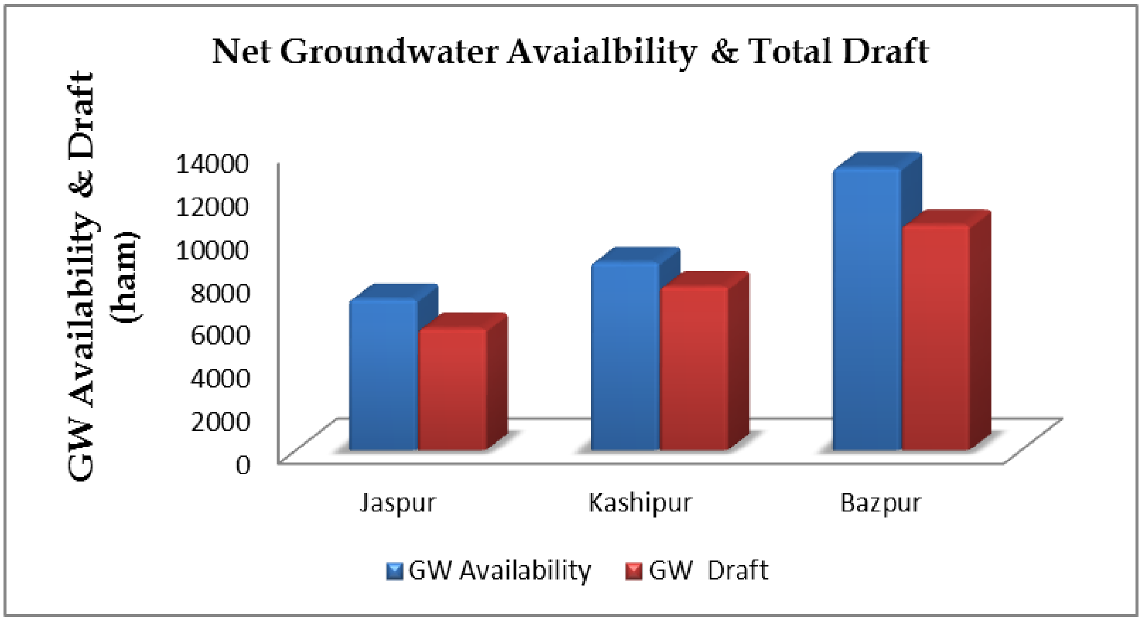


Fig. 34. Block-wise Net groundwater availability and total draft, Parts of U S Nagar District, Uttarakhand

5.2.1.1. 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 2009 with the present resources 2011. Based on these groundwater development statistics, it reveals that the Kashipur block (12.51%) has the highest trend of groundwater development due to growth industrial and agricultural activities. Due to effective natural recharge in and around Bazpur block, the stage groundwater development is reduced by 9.16% and also in Jaspur block by 4.94%. The details of the stage of groundwater development is mentioned in the Table 19.

Table 19. Comparison of the Ground Water Development, Parts of Udham Singh Nagar District, Uttarakhand

S. No	Block	Stage of Groundwater Development 2009 (%)	Stage of Groundwater Development 2011 (%)	Percent of Rise / Fall (%)
1	Jaspur	85.48	80.54	4.94
2	Kashipur	74.58	87.09	-12.51
3	Bazpur	88.86	79.70	9.16

5.2.2. Static Ground Water Resource

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

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

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

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

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

Table 20. Parameter & Static Resources for Unconfined Aquifer, Parts of U S Nagar District, Uttarakhand

Name of Aquifer mapping Area		Area (Sq. Km) considered for mapping	Predominent DTW (mbgl)	Av. Bottom depth (mbgl)	Thickness of Grainular Zones in Un-confinned Aquifer (m)	Adopted Specific Yield %	Static GW resources in unconfined aquifer (MCM)
District	Block	Fresh					Fresh
U S Nagar	Jaspur	251	6.32	31	24.68	.084	520.35
	Kashipur	310	5.14	26	20.86	.084	543.19

	Bazpur	327	3.81	23	19.19	.084	527.11
TOTAL (MCM)							**1590.65**
TOTAL (BCM)							**1.591**

5.2.3. Confined Resource

Methodology and Assumption

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

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

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

i. **Ground water flow rate concept**

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

Q = T I L

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

T = Transmissivity in m^2/day,

I = Hydraulic gradient m/km

L = Average width of Cross-section in km

Table 21. Ground Water Resources based on Flow Rate Concept, Parts of U S Nagar District, Uttarakhand

Section	T (m^2/day)	Contour Interval of the Piezometric Surface (m) (∂h)	Length of the Flow Line (m) (∂l)	Length of the Section across which groundwater flows (km)	Hydraulic Gradient	Groundwater flow through the Section by maintaining confined conditions (m^3/day)	Groundwater flow per year (MCM)
I	2785	20	11.75	48	20/11.75 X 1000	227540	82.85
Total groundwater flow (flux) across the area							**82.85**

5.2.4. Ground water storage concept

The co-efficient of storage or storativity of an aquifer is defined as the volume of water it releases or takes into storage per unit surface area of the aquifer per unit change in head. Hence, the quantity of water added to or released from the aquifer (ΔV) can be calculated as follows:

$$\mathbf{\Delta V = S \, \Delta \, h}$$

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

$$\mathbf{Q = S \, \Delta \, h \; X \; A}$$

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

S= Storativity

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

Δh = Change in piezometric head

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

$$\mathbf{Q_p = S \; A \; \Delta \; h}$$

$$\mathbf{= S \; A \; (h_o - h_1)}$$

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

S= Storativity

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

Δh = Change in piezometric head

H_t = Piezometric head at time 't'

h_o = Bottom of the confining layers

Summarised aquifer wise groundwater resources, parts of udham singh nagar district, uttarakhand.

1. Unconfined Aquifer

a. Dynamic Zone

Net Groundwater Availability= 42 MCM

b. In Storage

Fresh Groundwater Resources= 1590.65 MCM

2. Confined Aquifer

a. Flow Rate Based Assessment= 82.85 MCM

b. Storativity Based Assessment= 170.94 MCM

Table 22. Ground water Resources based on Storativity Concept, Parts of Udham Singh Nagar District, Uttarakhand

Name of the District	Area km^2	Storativity of the confined aquifer	Average thickness of the granular zone confined aquifer (m)	Average depth of the bottom of the confined layer	Time averaged Piezometric Head (mbgl)	Scenarios head loss (m)		Ground water resource released form storage of the confined aquifer MCM
						No.	Head loss (m)	
Parts of Udham Singh Nagar	888	3.85×10^{-3}	70	53	3	1 2 3	1.0 10.0 50.0	3.42 34.19 170.94
Maximum volume of ground water that may be released from the storage of confined aquifer								170.94

5.3. Water Requirement/ Demand

5.3.1 Domestic Water Demand

With the industrial development in district, population of district also increases with higher growth rate. The domestic water demand is given in Table 23.

Table 23. Domestic Water Demand, Parts of Udham Singh Nagar District, Uttarakhand

Block	Population in 2015	Projected population in 2020	Gross Water Demand (BCM)
Jaspur	107858	110000	0.000015
Kashipur	144297	220000	0.000022

Bajpur	141250	220000	0.00000574
Total	393405	550000	0.00004274

5.3.2 Crop-wise Water Demand

The district has highest production and productivity of cereal crops in state due to good irrigation facilities. The domestic water demand is given in Table 24.

Table 24. Crop wise Water Requirement, Parts of U S Nagar District, Uttarakhand

Block	Crops	Area Sown (ha.)	Irrigated Area (ha.)	Crop Water Demand (mm)	Water Potential required (BCM)	Existing Water Potential (BCM)	Water Potential to be created (BCM)
Jaspur	Wheat	11313	11313	6222150	0.062	5.558	-
	Rice	11479	11479	19514300	0.195		
	Sugarcane	3392	3392	6784000	0.068		
Kashipur	Wheat	9004	9004	4952200	0.049	7.475	-
	Rice	9377	9377	15940900	0.159		
	Sugarcane	2119	2119	4238000	0.042		
Bajpur	Wheat	13146	13146	7230300	0.072	10.286	-
	Rice	14379	14379	24444300	0.244		
	Sugarcane	4777	4777	9554000	0.095		
Total		78986	78986	98880150	0.986	23.319	

5.3.3 Livestock Water Demand

Agriculture and animal husbandry are the main occupation of rural population and due to large number of animals; the water demand of livestock sector is high. The livestock water demand is given in Table 25.

Table 25. Livestock Water Demand, Parts of U S Nagar District, Uttarakhand

Block	Total number of live stock	Present water demand (BCM)	Water demand in 2020 (BCM)	Existing Water Potential (BCM)	Water Potential to be created (BCM)
Jaspur	66879	0.00120	0.00126	0.00120	0.00006
Kashipur	160795	0.03345	0.05010	0.0334	0.0167
Bajpur	396186	0.00713	0.00748	0.00713	0.00035
Total	623860.04	0.14235	0.05884	0.04173	0.01711

5.3.4 Industrial Water Demand

After the formation of state, industrial development occurs very speedily in district, so water demand also increases as industrial development going on. The industrial water demand is given in Table 26.

Table 26. Industrial Water Demand, Parts of Udham Singh Nagar District, Uttarakhand					
Block	**Name of the Industry**	**Water Demand (BCM)**	**Water demand in 2020 (BCM)**	**Existing Water Potential (BCM)**	**Water Potential to be created (BCM)**
Jaspur	**-**	**0.0000060**	**0.0000069**	**0.000006**	**0.0000003**
Kashipur	**-**	**0.000045**	**0.000052**	**0.000045**	**0.000007**
Bajpur	**-**	**0.0000052**	**0.0000060**	**0.0000052**	**0.0000008**
Total	**-**	**0.0001773**	**0.0001292**	**0.0000643**	**0.0000081**

5.3.5 Water Demand for Power Generation

There is seasonal nature of rivers and low gradient of slop, the development of hydro power generation project is very low. There is no hydro power generation project in the study area, thus demand for power generation is nil.

The water budget is given in Table 27

Name of Block	**Existing Water availability (BCM)**		**Total (BCM)**	**Water Demand (BCM)**		**Water Gap (BCM)**	
	Surface water	**Ground water**		**Present**	**Projected (2020)**	**Present**	**Projected (2020)**
Jaspur	0.000014	7.039	7.039014	0.32622	0.00004274	-	-
Kashipur	0.0000139	8.755	8.7550139	0.28347	0.986	-	-
Bajpur	0.0000138	13.164	13.1640138	0.41814	0.05884	-	-
Total	**28.95804**	**57.91604**	**28.95804**	**1.02789**	**1.04488**		

CHAPTER - 6

GROUNDWATER RELATED ISSUES AND THEIR SOLUTION

Autoflow/artesian conditions are restricted to the Tarai zone in the Kashipur and Bazpur Block of the study area, south of the spring line. In a well, penetrating through a confined aquifer, the water level will rise above the bottom of the confining bed. If the water level rises above the top of the upper confining layer, above the ground surface, free flowing /auto flow conditions result. The water level in a well penetrating a confined aquifer defines the elevation of the piezometric surface, which is an imaginary surface coinciding with the hydrostatic pressure level of the water in an aquifer. Rises and falls of water in wells penetrating confined aquifers result primarily from changes in pressure rather than changes in strorage volumes. In this zone confining conditions result due to intercalation of permeable materials like sand and gravel with impervious clay horizons. The Bhabar serves as the recharge zone for the Tarai aquifers which appear to be continuous with the aquifers at higher level (as shown in aquifer disposition Figures 36, 37 & 38).

6.1. Factors Controlling Artesian Conditions

1) The difference in elevation of Bhabar and Tarai, together with the regional slope of the beds, appears to build the artesian head in the Taraiaquifers.

2) Permeability of the Tarai aquifers is less than that of Bhabar, thereby playing a vital role in developing the pressure, as it impedes ground water flow.

3) Most importantly it is the subsurface aquifer geometry and local ground conditions., along with all the factors discussed above, wherever conforming to the ideal configuration of permeable aquifer confined by thick impervious elastic clay layer, leads to artesian/free flowing conditions.

The discharge of the tubewells is dependent of aquifer properties. There are more than 90 artesian wells existing in the study area. Central Ground Water Board has constructed artesian wells at Basai, Kashipur and BahugunaIslampur, Bazpur in the study area. The drilled depth ranging from 84.4 to 433.0 m bgl, with free flowing head upto 8.69 m above ground level (at the time of construction) and now it is 1.55 m below the ground level. The yield of these wells upto 3400 lpm, with the drawdown 5.39 to 10.69 m (at the time of construction). The

Transmissivity values range from 825 to 12274 m^2/day, and the hydraulic conductivity ranges from 16.17 to 106.6 m/day. The artesian granular zones have been established to exist between a) 40.0 and 66.0 mbgl b) 90.0 and 107.0 mbgl in Kasipur Block and between a) 55.0 to 79.0 mbgl b) 99.0 to 101.0 mbgl in Bazpur Block.

Based upon the data of inventoried artesian/free flowing wells as well as artesian wells constructed by the CGWB in the study area it is established that wherever a thick granular zone bound by impervious, elastic clay layer is encountered good head development is favoured, and if numerous thin granular zones intercalated by several clay layers is encountered they tend to decrease the head or head decreases with increase in intercalations of sand and clay layers irrespective of the depth. Further discharge is dependent upon the aquifer characteristics, it transitivity and permeability and local underground reservoir conditions & is independent of depth & head.

6.2. Extent of Autoflow Zone

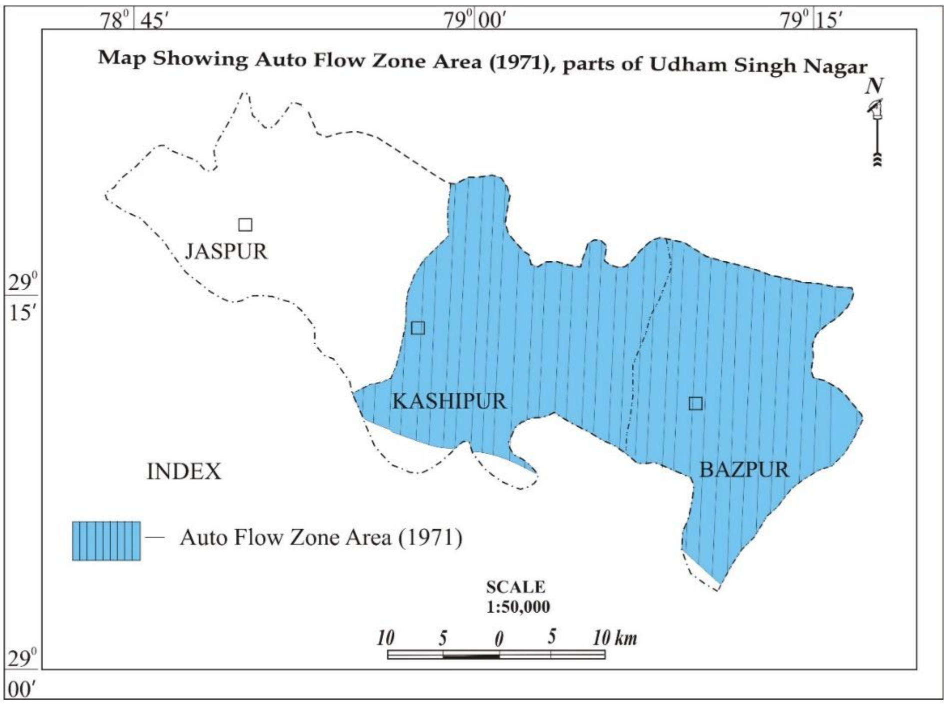
On the basis of reported information gathered during the course of present study from various old reports and Old Toposheets, it is marked that in the past autoflow zone extended inthe west upto the boundary marked by the Dhela river, in the eastupto the boundary marked by NanakSagar and the Deoha river emerging from south of Nanak Sagar in the Udham Singh Nagar District, in the south it extended even 2 – 10 km outside the study area uptoBosina village falling in Rampur district of Uttar Pradesh. In the north it is restricted by the spring line. In the study area, the entire Bazpur and almost 80% of the Kashipur Block exhibits the artesian conditions (Fig 35).

Presently on the basis of hydrogeological investigation and free flowing well inventory in the Tarai zone, it has been established that in the west the autoflow zone still extends upto the Dehla river as in the past, but in the east it has receded westward by approximately 5-7 kms from river Deoha to river Kailash, which marks the present extent of the zone in the district. In the south the autoflow zone which in the past used to extend outside the boundary of the district has receded northwards upto the north of Kashipur-Sitarganj-Nanak Mata road (Fig 36 & 37).

Present studies clearly indicate that the southern extension of the autoflow zone has considerably shrunk northward by atleast 2-7 kms and the eastern extension westwards by atleast 5-8 kms. Discharge and pressure heads also show a diminishing pattern over the years (Fig 38).

6.3. Observations

It is observed that the pressure head of the artesian wells drastically reduced over the two decades and some of the shallower depth wells lost its artesian conditions. If the same conditions prevail, some of the wells may loose artesian nature forever. The potential artesian area exists in Kashipur and Bazpurblocks.



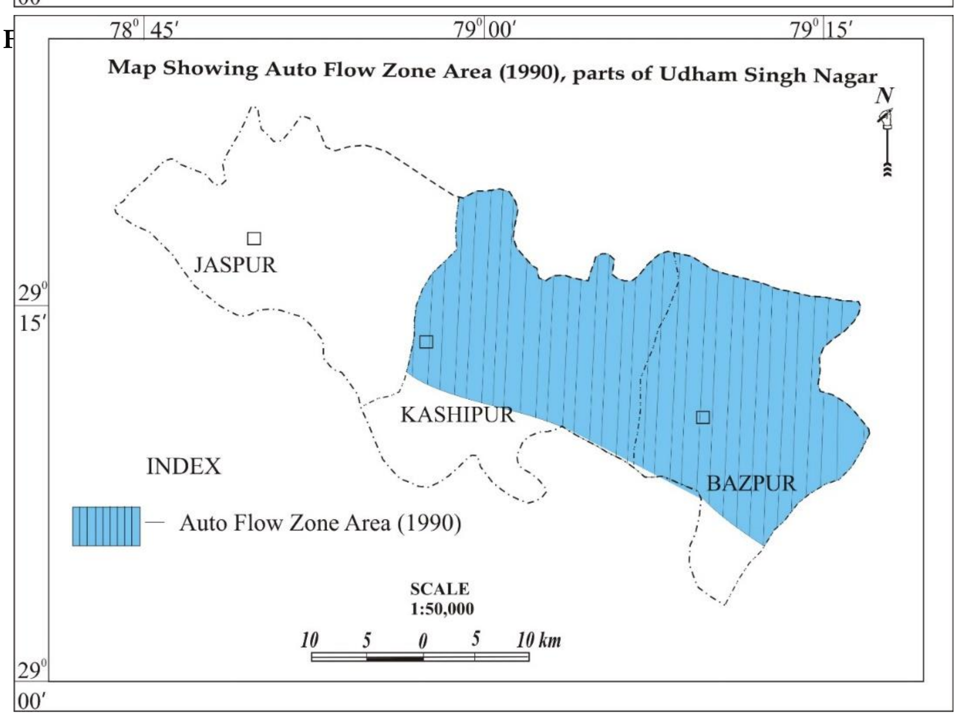


Fig 36. Map showing Auto Flow Zone Area (1990), Parts of U S Nagar District, Uttarakhand.

6.4. Causes for shrinkage of the Auto Flow Zones

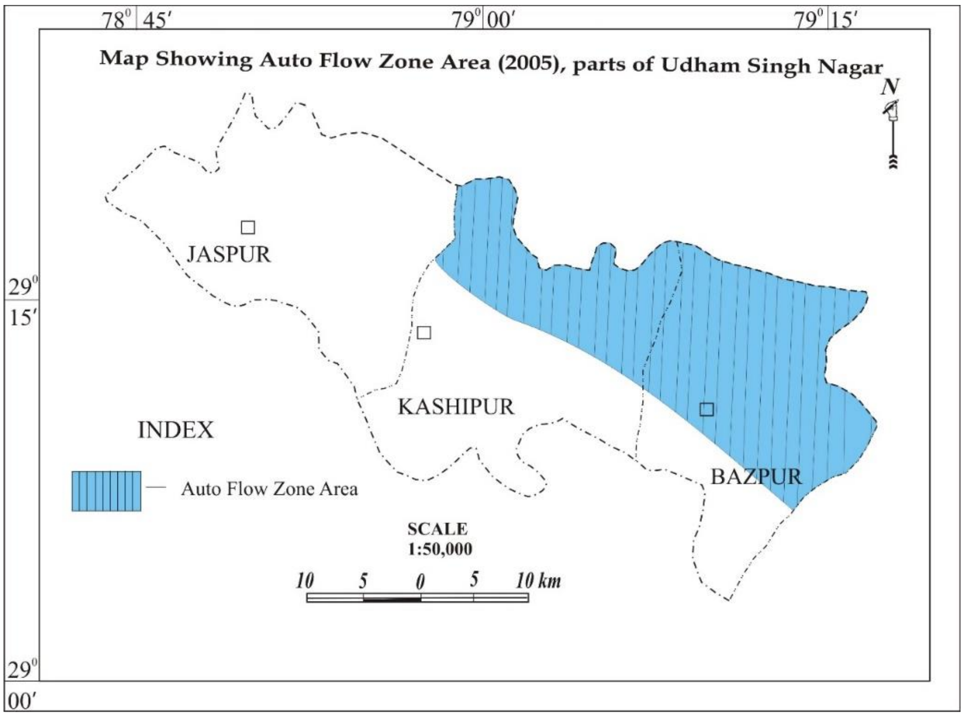


Fig 37. Map showing Auto Flow Zone Area (2005), Parts of Udham Singh Nagar District, Uttarakhand.

Possible Causes for shrinkage of the Auto Flow Zones and reduction in discharges of the Artesian wells

(I) Massive deforestation in the Bhabhar zone, as 20-30 years back the area was covered by dense forest, consequently deforestation has caused more run off resulting in declining recharge.

(II) Increase in agricultural land due to deforestation where intensive agricultural practices are employed.

(III) Increase in population over the last 20-30 years resulting in more groundwater consumption.

(IV) More development in Bhabar, which is the recharge area, consequent upon urbanisation.

(V) Rapid increase in the number of shallow tubewells in the region consequent upon increase in agricultural land.

(VI) Most of the flowing well in the zone area devoid of any mechanism to control and regulate their flow. In other words, their non-capping has led to decrease in pressure heads and wastage of the valuable groundwater resource.

(VII) General downward trend in the rainfall in the region, and

(VIII) Faulty construction and designing of the tubewells.

6.5. Recommendations

Based on the present and past studies certain recommendations are made to augment the artesian wells for further future needs and development.

1. It has been observed during the study that a lot of private & state auto flowing tubewells in the Tarai zone have been constructed tapping the shallow artesian aquifer existing in the depth ranging from 50.0 to 100.0 mbgl. It is recommended that to lessen the strain on artesian aquifers occurring in this depth range, the deeper artesian aquifers should be tapped.
2. To augment the dwindling heads and discharges and shrinking extent of the autoflow zone in the south and the west in the Tarai belt, it is recommended to experiment artificial recharge in the Bhabar, which serves as the recharge zone, by building successively bigger bunds at suitable distance on the stream channels flowing through the Bhabar. This will check the rum off and allow the water to stay for a greater period of time leading to percolation downwards.
3. Further to augment the recharge, massive afforestation in the Bhabar belt should be undertaken since this would arrest runoff and also help restore the past climatological order. The deforestation has adversely affected the rainfall in the district over the past resulting into greater runoff and lesser recharge.
4. Auto flow wells should be provided a mechanism to control and regulate the flow so that the unnecessary wastage can be controlled/avoided, thus pressure heads can be preserved for more sometime. It is recommended that the free flowing wells be equipped with sluice valve so that the yield is fully controlled.
5. Change of cropping pattern also to be adopted, which helps to augment the groundwater.
6. Battery of tube wells can be constructed at the flood plains of the river, instead of drilling cluster of tube wells in the different areas.

CHAPTER 7
MANAGEMENT STRATEGIES

Groundwater resources is a multidimensional concept. It is defined by its location, its occurrence over time, its size and cost to mobilize which are required for planning its development. Groundwater in the study area occurs both under unconfined and confined condition. A comprehensive development plan requires the assessment of development worthy groundwater resources, draft per Tubewell and cost to develop this resource. Keeping this in view, development plan has been prepared aquifer wise. The methodology adopted is given below.

Dynamic Ground Water Resources – Unconfined aquifer

Ground water resources, in an unconfined aquifer, are classified in two categories namely the dynamic and the in-storage resources. The ground water resource which gets replenished annually forms the dynamic resource whereas the resource occurring below the average fluctuation zone forms the in-storage/static recourse.

The dynamic ground water resource is assessed for each block of the district as on 31.03.2011. Block has been taken as the assessment unit. The resources were estimated for the zone of water level fluctuation using the specific yield of the aquifer for the respective assessment unit and integrated upon its area. The block wise dynamic resources, in unconfined aquifer, are summarized in **Table 18.** The Net Ground Water Availability for future irrigation, for the study area, is assessed to be **289.59 MCM**.As the stage of Ground Water development has already reached 82%, hence no additional Ground Water abstraction structures are proposed. However, in case of emergency situation groundwater available in -storage portion of unconfined aquifer can be developed.

In-storage Groundwater Resources – Unconfined Aquifer

The in–storage resource of fresh ground water for the unconfined aquifer has been estimated 1.59 BCM. For development of this resource a total of 579tubewells can be constructed. This will require an investment of about Rs. 4632 Lakhs. The details of the number of tubewells and the cost of construction are given in **Table 28.**

For the computation of the number of tube wells the draft for each tube well has been considered for its assumed life of 25 years. And the resources in-storage portions have been considered as non-replenishable on an annual basis.

Table 28 Development Plan for In-storage Resources of Unconfined Aquifer

<table>
<tr><th colspan="3" rowspan="2">PARTS OF US NAGAR DISTRICT UNCONFINED AQUIFER DEVELOPMENT PLAN AND FINANCIAL ASPECT</th><th colspan="3">Dynamic Resources Unit Draft (mcm/yr)*Life of well</th><th colspan="3">Static Resources Unit Draft (mcm/yr)* Life of Well</th></tr>
<tr><th colspan="3">1.65</th><th colspan="3">2.75</th></tr>
<tr><th rowspan="2">Area (sq. km.)</th><th rowspan="2">GW Availability Dynamic Resources (mcm)</th><th rowspan="2">GW Resources Below Fluctuation zone, Static Resources (mcm)</th><th colspan="6">No. of Additional Wells Required to Develop Additional Potential</th></tr>
<tr><th>No. of Wells</th><th>Unit cost (Rs. Lac)</th><th>Total Cost (Rs lac)</th><th>No. of Wells</th><th>Unit cost (Rs lac)</th><th>Total Cost (Rs lac)</th></tr>
<tr><td>888</td><td>42</td><td>1591</td><td colspan="3" rowspan="3">Not Recommended for further development as Stage of Groundwater development is already 82 %</td><td>579</td><td>8</td><td>4632</td></tr>
<tr><td>TOTAL (MCM)</td><td>42</td><td>1591</td><td>579</td><td>8</td><td>4632</td></tr>
<tr><td>TOTAL (BCM)</td><td>0.042</td><td>1.591</td><td></td><td></td><td></td></tr>
</table>

The intensive ground water development of the in-storage groundwater resources leads to vide spread consolidation of sediments in the alluvial aquifer. This is accompanied by a change in the state of both the water bearing and confined layer It is caused by the release of hydrostatic pressure. At first compaction is due to deformation by compression of the layers; this is succeed by plastic deformation that is accompanied by displacement of rock particles. The interaction of particles is increased by the forces of molecular attraction resulting in an increase of the amount of bound water. These processes are irreversible and ground water level recovers only partially when the water withdrawal is terminated or decreased. The effects of intensive ground water development can be simulated by the numerical solution of equation of two dimensional unsteady flow and equation of loamy soil deformation.

Groundwater Resources of Confined Aquifer – Storativity Based Assessment

The ground water resources of confined aquifer have been built up over considerably long period of time and are annually not replenishable, hence they have been considered as finite in the present context. Accordingly, the development plan is based on draft from tubewells for their life period considered to be 25 years. The ground water storage in a confined aquifer is governed by its Storativity. The ground water resources of the study area, have been explored down to the depth of 282 m bgl. So the resources are assessed for the granular zones encountered down to the explored depth using Storativity concept in respect of all blocks falling in the study area. The resources estimated based on storativity concept is summarized for the study area in **Table 22**. The total ground water resources assessed down to the depth of 282 m for the entire study area is 170.94 MCM.

Table 29 Development Plan for Confined Aquifer Storativity Based Assessment

PARTS OF US NAGAR DISTRICT CONFINED AQUIFER (STORATIVITY CONCEPT) DEVELOPMENT PLAN AND FINANCIAL ASPECT				**Confined Aquifer Unit Draft (mcm/yr)* Life of Well**		
				2.5		
Sl. No	**Name of District**	**Area (sq. km.)**	**GW Resources Confined Aquifer upto explored**	**No. of Additional Wells Required to Develop Additional Potential**		
			Fresh Water	**No. of Wells**	**Unit cost**	**Total Cost**
				(Cost in Lacks)		
1	**U S Nagar**	**888**	171	68	15	1020
TOTAL (MCM)		**888**	**171**	**68**		**1020**
TOTAL (BCM)			**0.171**			

For development of the fresh ground water resources a total of **68**tubewells can be constructed in different blocks down to the depth of 282m bgl. This will require an investment of about Rs. 1020 Lakhs. The details of the number of tubewells and the cost of construction are given in **Table 29.**

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

The study area encompassing an area of 888 sq. Km. Comprises 3 blocks. Mor4e than 85% percent area of the district is underlain by Tarai formation (Tarai formation chiefly comprises clays & slits with subordinate sand-pebble beds. In the south this belt gently merges with the Gangetic alluvium.) The Tarai formation is separated by a spring line. Bhabar a thick pile of quaternary sediments (boulders, pebbles, cobbles, clay and sand) lying all along the Siwalik foothills.

1. The population of the district as per 2011 census is 3,93,405constituting roughly 40% percent of the total population of Udham Singh Nagar district.
2. Climate of the Study is subtropical & sub humid with an annual normal rainfall in Kashipur & Bazpur is1279.4 and 1289.9 (IMD data 2005-2015).
3. The chief occupation in the district is agriculture. The main crops are paddy, wheat, sugarcane, maize, pulses and oilseeds. Out of the total geographical area of 888 Km^2 of study, the Net sown area is 523.33 Km^2 andarea sown more than once in the year is 446.4 Km^2. Area under Rabi and Khariff crops are 438.39 Km^2 and 430.75 Km^2, respectively. The highest net sown area, the gross cropped areas is in Kashipur block. The principal source of assured irrigation is by wells and tube wells, which together account for about 90% of the total irrigation. Only 61.8 Km^2 (6%) of the studyarea is irrigated by canal irrigation.
4. The depth to water level in the study area shows a great variation due to the presence of different geomorphological units. The groundwater in the Tarai formation occurs both under unconfined and confined conditions. In the unconfined aquifer the pre-monsoon water level ranges from 1 mbgl to 16.72 mbgl and in the post-monsoon, the water level ranges from 0.42 mbglto 14.1 mbgl with an average fluctuation of 0.42 m to 13.1 m. In Bhabar the groundwater occurs in unconfined conditions & at places perched groundwater conditions are also observed e.g. the water level being 5.25 mbgl.
5. In the Tarai zone autoflowing conditions, due to confinement of aquifer, are abundant. The past extent of the Autoflow zone have been established by the author in the west the boundary was marked by the ‘Dhela River’, in the east the boundary was marked by the Dabka river which also forms natural block boundary for the Bazpur block in east,

in the south it extended outwards up to village Bosina, Rampur district, UP, and in the north it was limited by the spring line.

6. The present extent of the Autoflow zone has been established in the west up to the Dhela river as in the past, otherwise the zone has shrunk. In the south the zone has receded northwards up to the north of Kashipur –Sitarganj-Nankmatta roadin the north the zone remains limited by the spring line as in the past.

7. In Bazpur block the piezometric head during the pre-monsoon ranges from 1.75 magl to 5.3 magl and free flowing discharge ranges from 600 lpm to 3000 lpm. During the post-monsoon the piezometric head ranges from 2.50 magl to 6.50 magl. The potential artesian aquifers have been established to exist between a)76.0 to 85.0 mbgl b) 199.0 to 214.0 mbgl and either or all the three zones subject to confirmation categorised as (1) 282.0 to 288.0 mbgl (2) 300.0 to 318.0 mbgl & (3) 345.0 to 351.0 mbgl.

8. In Kashipur block the piezometric head during the pre-monsoon ranges from 3.0 magl to 6.0 magl& free flowing discharge ranges from 1575 lpm to 2729 lpm. During post-monsoon, the head ranges from 6.0 magl to 8.0 magl& free flowing discharge varies from 2729 lpm to 2900 lpm. The artesian granular zones have been established to exist between a)49.0 and 63.0 mbgl b) 70.0 and 107.0 mbgl & c) 172.0 and 222.0 mbgl.

9. In the past, about 40 years back, the wells drilled by the ETO had exhibited piezometric heads ranging from 6.6 magl (Pipalsana) to 10.81 magl (Munshi farm) which over the years have depleted to present levels.

10. Tarai formation which is chiefly the intercalation of clay beds with permeable granular beds of sand, grave, pebble etc. exhibits artesian conditions in almost all the blocks falling in the Tarai zone. Among the various factors & causes giving rise to artesian conditions. The main area listed below:

(I) The granular beds in Tarai are connected with the Bhabar zone at higher elevations and the latter forms the recharge area for the former.

(II) The difference in elevation of the Bhabar & Tarai together with slope of the beds appear to build the artesian head in Tarai aquifers.

(III) Permeability of the Tarai aquifers which is comparatively less than the Bhabar also plays a vital role in building up the pressure as it offers hindrance to the groundwater flow.

(IV) A very high hydraulic gradient of the order of 4-16 m/km in Bhabar in the central part of the district also works towards building up hydrostatic pressure.

(V) Thickness & width of the Bhabar wherever appreciable plays an important role in the development of artesian conditions e.g. in central part of Tarai zone, while in the eastern & western portions of the zone lesser incidence of artesian conditions can be attributed to lesser thickness & width of the Bhabar.

(VI) Most importantly besides above, it is the subsurface aquifer geometry wherever conforming to the ideal configuration of permeable aquifer confined by thick impervious clastic clay layer leads to artesian conditions.

11. The artesian head appear to have no relationship with depth as well as discharge in the Tarai zone.

12. It has been established that the autoflow zone has shrunk in south & west by atleast 5-8 km over the past 40 years & similarly there is down trend in the artesian heads and free flowing discharges. The possible reasons for the same may be attributed to the following:-

(I) Massive deforestation in the Bhabar zone, consequently deforestation has caused more run off resulting in declining recharge.

(II) Increase in agricultural land due to deforestation where intensive agricultural practices are employed. Rapid increase in the number of tubewells in the region consequent upon increase in agricultural land.

(III) Increase in population over the last 20-30 years resulting in more groundwater consumption.

(IV) Most of the flowing well in the study area are devoid of any mechanism to control and regulate their flow. In other words, their non capping has led to decrease in pressure heads and wastage of the valuable groundwater resource.

(V) General downward trend in the rainfall in the region, and

(VI) Faulty construction and designing of the tubewells.

13. Based on the present and past studies certain recommendations are made to augment the artesian wells for further future needs and development.

(I) It is recommended that to lessen the strain on artesian aquifers occurring in shallow depth range, the deeper artesian aquifers should be tapped.

(II) Massive afforestation in the Bhabar belt should be undertaken since this would arrest runoff and also help restore the past climatological order. The deforestation has adversely affected the rainfall in the district over the past resulting into greater runoff and lesser recharge.

(III) Artificial recharge in the Bhabar, which serves as the recharge zone, by building successively bigger bunds at suitable distance on the stream channels flowing through the Bhabar. This will check the rum off and allow the water to stay for a greater period of time leading to percolation downwards.

(IV) Change of cropping pattern also to be adopted, which helps to augment the groundwater.

(V) Battery of tube wells can be constructed at the flood plains of the river, instead of drilling cluster of tube wells in the different areas.

(VI) It is recommended that the free flowing wells be equipped with sluice valve so that the yield is fully controlled.

(VII) Further to augment the recharge,

14. The quality of groundwater in the study area is invariably good to excellent in condition. All the constituents present in the groundwater are well within the permissible limits for both drinking as well as from irrigation purposes.

15. The total ground water resource potential as on 2011, is calculated 28959.2 ham. The net annual ground water draft is 23786.54 ham and the balance available for future ground water development is 4195.82 ham.

16. The area can be more development for irrigation through ground water, thus. The Bhabar, which is the recharge area and has deeper water levels, can be developed by using 'Percussion Cum Rotary' drill rigs by drilling up to 300.0 mbgl yielding 2000 lpm to 3000 lpm at economic drawdown.

17. Since, the Dynamic Groundwater Stage of Development in the study area already reaches crosses 80 % and there 2 critical blocks also. So, no new Ground Water based industry should be allowed in the study area.

Annexure 1- Lithologs of Borewells Drilled by CGWB and State Government Agencies within the study area, Parts of Udham Singh Nagar District, Uttarakhand

Well Id **Aspur**
Latitude 29° 18´ 45"
Longitude 78° 45´ 47"
RL 237m

Depth Range (m bgl)		Thickness (m)	Lithology
To	**From**		
0	7	7	Surface Soil
7	56.36	49.36	Clay
56.36	61.55	5.19	Fine to medium grained sand
61.55	93.65	32.1	Clay
93.65	116.9	23.25	Fine to medium grained sand with gravels
116.9	124	7.1	Clay
124	259.41	135.41	Medium to coarse grained sand with Gravels
259.41	282.81	23.4	Clay
282.81	300.36	17.55	Fine to coarse grained sand
300.36	396.99	96.63	Clay
396.99	402.84	5.85	Fine grained sand with gravels
402.84	417.39	14.55	Clay

Well Id **Jaspur**
Latitude 29° 17´ 05"
Longitude 78° 49´ 04 "
RL 238m

Depth Range (m bgl)		Thickness (m)	Lithology
To	**From**		
0	6	6	Boulders
6	18	12	Coarse sand with pebbles and cobbles
18	22	4	Clay
22	26	4	Coarse to medium sand with gravels
26	42	16	Clay
42	47	5	gravels and pebbles
47	62	15	Clay
62	71	9	coarse sand with Gravels and boulders
71	87	16	Clay
87	88	1	sand + gravel
88	94	6	Clay

Well Id	**Basai**
Latitude	29° 11´ 45"
Longitude	78° 56´ 00"
RL	224m

Depth Range (m bgl)		Thickness (m)	Lithology
To	**From**		
0	6	6	Surface Soil
6	14	8	Clay
14	27.5	13.5	Medium grained sand with boulder
27.5	54.9	27.4	Clay
54.9	61	6.1	Medium grained sand with boulder
61	68	7	Medium to fine grained Sand with boulder
68	81	13	Clay
81	99	18	Medium grained sand with boulder
99	104.3	5.3	Clay
104.3	113.2	8.9	Medium grained sand with a little clay

Well Id	**Sultanpur Patti**
Latitude	29° 09´ 45"
Longitude	79° 02´ 60"
RL	224m

Depth Range (m bgl)		Thickness (m)	Lithology
To	**From**		
0	3	3	Surface Soil
3	5.7	2.7	Clay
5.7	10.99	5.29	Sand + Gravel
10.99	17.87	6.88	Sand + Gravel mixed with clay
17.87	38.85	20.98	Clay with sand and gravel
38.85	46.05	7.2	Sand + gravel
46.05	52.9	6.85	Gravel with little clay
52.9	84.75	31.85	Clay with v. little gravel
84.75	91.73	6.98	Clay
91.73	94.73	3	Coarse grained sand and gravel
94.73	101.69	6.96	Gravel
101.69	129.43	27.74	Clay with small amount of gravel
129.43	133.37	3.94	Clay
133.37	216.71	83.34	Clay with small amount of gravel and pebbles
216.71	226.6	9.89	Gravel with pebbles and v. little clay
226.6	243.2	16.6	clay with gravel and pebbles

243.2	268.37	25.17	Clay

Well Id **Bazpur**
Latitude 29° 04´ 48"
Longitude 79° 09´ 11"
RL 240m

Depth Range (m bgl)		Thickness (m)	Lithology
To	From		
0	1.83	1.83	Clay
1.83	2.75	0.92	Fine sand
2.75	4.88	2.13	Sand with pebbles and cobbles
4.88	8.23	3.35	Clay
8.23	15.85	7.62	Sand with pebbles
15.85	32.92	17.07	Clay
32.92	36.58	3.66	Sand with gravels
36.58	43.1	6.52	Clay
43.1	43.94	0.84	Fine grained sand
43.94	51.81	7.87	Coarse grained sand with gravels and pebbles
51.81	67.66	15.85	Clay
67.66	71.93	4.27	Coarse grained sand with gravels
71.93	73	1.07	Clay

Annexure 2 - Lithologs of Borewells Drilled by CGWB and State Government Agencies Outside the study area, Parts of Udham Singh Nagar District, Uttarakhand

Well Id **Khempur**
Latitude 29° 05´ 53"
Longitude 79° 14´ 52"
RL 227 m

Depth Range (m bgl)		Thickness (m)	Lithology
To	From		
0	40	40	Clay
40	74	34	Gravel with Boulder
74	78	4	Clay
78	80.5	2.5	Gravel with Boulder
80.5	83.77	3.27	Clay
83.77	84.92	1.15	Coarse grained sand with gravel
84.92	92	7.08	Coarse grained sand with gravel & pebbles, Cobble and boulders
92	93	1	Clay

Well Id **Ramnagar**
Latitude 29° 23´ 53" "
Longitude 79° 07´ 52
RL 227m

Depth Range (m bgl)		Thickness (m)	Lithology
To	From		
0	6	6	Boulders
6	18	12	Coarse sand with pebbles and cobbles
18	22	4	Clay
22	26	4	Coarse to medium sand with gravels
26	42	16	Clay
42	47	5	gravels and pebbles
47	62	15	Clay
62	71	9	coarse sand with Gravels and boulders
71	87	16	Clay
87	88	1	sand with gravel
88	94	6	Clay

Well Id **Himmatpur**
Latitude 29° 13´ 09"
Longitude 79° 29´ 30"
RL

Depth Range (m bgl)		Thickness (m)	Lithology
To	From		
0	2.1	2.1	Fine sand with silt
2.1	11.3	9.2	Pebbles and coarse sand
11.3	23.2	11.9	Clay to v. coarse sand with boulders
23.2	28.3	5.1	Clay
28.3	29	0.7	Coarse to v. coarse sand
29	32.9	3.9	Clay with pebbles
32.9	48.7	15.8	fine coarse sand with cobbles and boulders
48.7	63.4	14.7	Fine to medium sand with little gravel, pebbles, cobbles and occorinal boulders
63.4	82.3	18.9	cobbles with pebbles and little boulders

Well Id **Pipalsana**
Lattitude 29° 16´ 56"
Longitude 79° 02´ 21"
RL

Depth Range (m bgl)		Thickness (m)	Lithology
To	From		
0	1.8	1.8	Surface soil with little brown clay
1.8	10.8	9	Medium to coarse sand with pebbles
10.8	14.3	3.5	Pebbles with little coarse sand
14.3	30.4	16.1	Boulders and pebbles with little clay
30.4	55.5	25.1	Medium to fine grained sand with pebbles
55.5	64.3	8.8	Pebbles with little fine sand
64.3	71.3	7	Pebbles with little clay
71.3	84.4	13.1	Boulders and pebbles with small quantity of medium to coarse sand

Well Id **Dhela**
Lattitude 29° 24´ 57"
Longitude 79° 00´ 12"
RL

Depth Range (m bgl)		Thickness (m)	Lithology
To	**From**		
0	9	9	Surface soil, clay with boulders and gravels.
9	19	10	Angular chips, coming through boulders of quartzite.
19	34	15	Clay, yellowish and hard
34	42	8	Sand, medium mixed with chips of quartzite boulders and gravel
42	45	3	Sand fine to medium mixed with pebbles
45	55	10	Clay, yellowish and hard
55	65	10	Angular pieces of boulders, cobbles and pebbles
65	69	4	Sand, coarse, consisting of quart, feldspar pieces and chips of boulders
69	75	6	Sand, medium to coarse yellowish mixed with quartz
75	88.9	13.9	Pieces of cobbles, pebbles mixed with gravel

Annexure 3 - Monthly and Annual Rainfall in the study area, Parts of Udham Singh Nagar District, Uttarakhand (Based on 2005 -2015 data)

S. No	Name of Rain Gauge Station	Rainfall in mm												Annual Rainfall	Monsoon Rainfall	Non-Monsoon Rainfall
		Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec			
1	Kashipur	34.3	36.6	16.8	9.4	21.1	148	361	373	212	51.7	4.7	10.9	1279.4	1093.9	185.5
2	Bazpur	37.6	30.4	17.1	7.9	17	118	391	388	222	49.8	2.6	9	1289.9	1118.5	171.4

Annexure 4- Depth to water levels (mbgl) of the GWMS in the study area, Parts of Udham Singh Nagar District, Uttarakhand

S.NO.	BLOCK	LOCATION	STRUCTURE	WATER LEVEL	
				May-15	Nov-15
1	Bazpur	Bazpur	DW	2.78	1.58
2		Jharkhandi	HP	2.07	1.26
3		Jogipura	HP	4.59	2.45
4		Banna Khera	DW	5.25	3.78
5		Pritpur	HP	7.91	3.21
6		Badaripur	HP	5.36	4.22
1	Kashipur	Barkhare Pande	HP	9.62	0.42
2		Sultanpur Patti	HP	8.78	1.74
3		Kashipur	DW	5.68	5.23
4		Bharatpur	HP	11.31	6.95
5		Dhanauri Patti	HP	4.86	2.71
6		Shankhera	HP	10.51	5.68
1	Jaspur	Jaspur	HP	12.72	13.1
2		Patrampur	HP	9.51	8.83
3		Angadpur	HP	15.2	12.7
4		Durgapur	HP	5.01	4.44
5		Missarwala	HP	14.4	7.44

Annexure 5 A- Long term Premonsoon depth to water levels (mbgl) of the GWMS in the study area, Parts of Udham Singh Nagar District, Uttarakhand (May 2005-2015)

S. No.	***Location***	***May-14***	***May-13***	***May-12***	***May-11***	***May-10***	***May-09***	***May-08***	***May-07***	***May-06***	***May-05***	***SUM***	***AVG.***	***May-15***	**Fluct.**	**Rise**	**Fall**
1	***Bazpur DW***	2.68	2.94	2.56	2.74	2.36	2.63	2.84	2.42	2.35	2.28	25.80	**2.58**	2.78	**-0.20**		0 to 2
2	***Banna Khera DW***	6.25	6.14	5.35	4.11	4.96	4.74	4.85	4.48	4.92	5	50.80	**5.08**	5.25	**-0.17**		0 to 2
3	***Barkhare Pande HP***	8.57	9.96	10.14	7.67	7.49	6.77		7.5	5.24	5.24	68.58	**7.62**	9.62	**-2.00**		2 to 4
4	***Kashipur DW***	7.33	7.57	7.53	6.03	6.1	5.79	7.08	5.84	5.63	3.7	62.60	**6.26**	5.68	**0.58**	0 to 2	
5	***Bharatpur HP***	10.05	11.45	11.35	9.05	8.88	9.05	3.72	3.76	3.45	3.13	73.89	**7.39**	11.31	**-3.92**		2 to 4
6	***Dhanauri Patti HP***	5.76	4.46	5.06	3.92	4.68	4.58	4.61	4.27	4.07	4.72	46.13	**4.61**	4.86	**-0.25**		0 to 2
7	***Jaspur HP***	15.18	17.58	17.52	2.5	5.51	5.55	5.55	5.51	5.2	4.87	84.97	**8.50**	16.72	**-8.22**		>4
8	***Patrampur HP***	10.43	10.99	9.45	7.63	23.95	8.77	7.75	7.5	7.08	7.8	101.35	**10.14**	9.51	**0.63**		0 to 2
9	***Angadpur HP***	6.25	7.58	-	5.1	5.11	4.94	4.89	4.45	4.17	4.2	46.69	**5.19**	15.20	**-10.01**		0 to 2
10	***Jogipura HP***	8.30	8.58	-	7.41	7.2	8.53	6.94	7.06	6.79	6.62	67.43	**7.49**	4.59	**2.90**	2 to 4	

Annexure 5 B- Long term Post monsoon depth to water levels (mbgl) of the GWMS in the study area, Parts of Udham Singh Nagar District, Uttarakhand (November 2005-2015)

S. No.	*Location*	*Nov-14*	*Nov-13*	*Nov-12*	*Nov-11*	*Nov-10*	*Nov-09*	*Nov-08*	*Nov-07*	*Nov-06*	*Nov-05*	*SUM*	**AVG.**	*Nov-15*	**Fluct.**	**Rise**	**Fall**
1	***Bazpur DW***	1.65	0.47	1.63	1.5	1.5	1.18	1.36	1.75	2.5	1.36	14.90	**1.49**	1.58	**-0.09**		0 to 2
2	***Banna Khera DW***	3.89	3.85	3.46	3.52	3.09	3.63	3.22	3.2	3.99	3.72	35.57	**3.56**	3.78	**-0.22**		0 to 2
3	***Barkhare Pande HP***	5.77	1.79	6.16	3	5.21	4.47	3.19	-	4.64	4.4	38.63	**4.29**	0.42	**3.87**	2 to 4	
4	***Kashipur DW***	5.97	5.83	5.85	4.05	3.57	2.93	3.41	3.51	3.65	2.61	41.38	**4.14**	5.23	**-1.09**		0 to 2
5	***Bharatpur HP***	8.29	6.15	9.32	6.15	5.45	7.89	2.1	3.89	3.36	0.92	53.52	**5.35**	6.95	**-1.60**		0 to 2
6	***Dhanauri Patti HP***	2.74	2.5	2.87	0.63	3.03	2.36	3.01	3	3	3.1	26.24	**2.62**	2.71	**-0.09**		0 to 2
7	***Jaspur HP***	9.17	8.84	14.53	5.68	4.37	14.42	4.42	4.21	4.33	2.8	72.77	**7.28**	13.10	**-5.82**		>4
8	***Patrampur HP***	7.08	7.58	11.03	1.46	5.43	7.12	5.56	7.6	8.16	5.12	66.14	**6.61**	8.83	**-2.22**		2 to 4
9	***Angadpur HP***	5.14	4.41	5.07	3.85	3.68	3.85	3.35	3.85	4.51	2.22	39.93	**4.44**	12.70	**-8.26**		>4
10	***Jogipura HP***	2.73	2.39	6.69	6.32	5.46	1.82	5.07	4.95	4.52	4.64	44.59	**4.46**	2.45	**2.01**	2 to 4	

Annexure 6- Seasonal Fluctutations (May 2015 vs November 2015) in the depth to water levels (mbgl) of the GWMS in the study area, Parts of Udham Singh Nagar District, Uttarakhand (November 2005-2015)

Sr. No	Block	Location	Type	DTWL (m bgl)		Seasonal Fluctuation	Rise	Fall
				May-15	Nov-15			
1	Bazpur	Bazpur	DW	2.78	1.58	1.2	0 to 2	
2		Jharkhandi	HP	2.07	1.26	0.81	0 to 2	
3		Jogipura	HP	4.59	2.45	2.14	2 to 4	
4		Banna Khera	DW	5.25	3.78	1.47	0 to 2	
5		Pritpur	HP	7.91	3.21	4.7	>4	
6		Badaripur	HP	5.36	4.22	1.14	0 to 2	
1	Kashipur	Barkhare Pande	HP	9.62	0.42	9.2	>4	
2		Sultanpur Patti	HP	8.78	1.74	7.04	>4	
3		Kashipur	DW	5.68	5.23	0.45	0 to 2	
4		Bharatpur	HP	11.31	6.95	4.36	>4	
5		Dhanauri Patti	HP	4.86	2.71	2.15	2 to 4	
6		Shankhera	HP	10.51	5.68	4.83	>4	
1	Jaspur	Jaspur	HP	16.72	13.1	3.62	2 to 4	
2		Patrampur	HP	9.51	8.83	0.68	0 to 2	
3		Angadpur	HP	15.2	12.7	2.5	2 to 4	
4		Durgapur	HP	5.01	4.44	0.57	0 to 2	
5		Missarwala	HP	14.4	7.44	6.96	>4	

Annexure 7- Chemical Quality data of the study area (May 2014), Parts of Udham Singh Nagar District, Uttarakhand

Sl. No.	Location	Well ID	pH	E.C. (µ S/cm at 25°C)	Concentration(mg/l)											
					CO_3	HCO_3	Cl	F	NO_3	SO_4	TH as $CaCO_3$	Ca	Mg	Na	K	SiO_2
Jaspur Block																
1	Jaspur HP	W-1	8.30	650	0	403	7.1	1.4	0.38	3.9	90	20	9.7	113	1.06	23
2	Patrampur HP	W-2	7.96	520	0	317	14	0.68	0.09	1.8	180	32	24	41	0.89	29
3	Angadpur HP	W-3	8.03	400	0	244	7.1	0.35	0.26	4.7	180	56	9.7	12	0.92	35
4	Missarwala HP	W-4	8.19	500	0	293	7.1	0.27	1.46	8.9	200	64	9.7	27	1.7	31
Kashipur Block																
1	Barkhare Pande HP	W-5	8.06	450	0	256	7.1	0.36	NIL	11	170	28	24	31	1.87	30
2	Sultanpur Patti HP	W-6	8.15	369	0	207	7.1	0.14	NIL	0	160	36	17	9.5	1.38	26
3	Kashipur DW	W-7	7.80	750	0	342	43	0.25	0.68	43	230	44	29	63	2.57	29
4	Bharatpur HP	W-8	8.27	570	0	342	7.1	0.93	0.28	4.2	120	24	15	77	1.53	23
5	Dhanauri Patti HP	W-9	8.25	500	0	293	7.1	0.43	0.06	5.8	200	52	17	27	1.34	29
6	Durgapur HP	W-10	8.10	685	0	256	85	0.4	0.68	23	260	52	32	39	1.96	28
7	Shankhera HP	W-11	8.14	399	0	207	7.1	0.17	2.3	2	170	32	22	9.6	1.23	30
Bazpur Block																
1	Bazpur DW	W-12	7.80	725	0	366	21	0.25	0.11	50	280	52	36	40	1.54	33
2	Jharkhandi HP	W-13	7.70	680	0	390	7.1	0.16	9.8	14	320	48	49	8.9	1.24	30
3	Jogipura HP	W-14	7.80	6.2	0	366	14	0.27	NIL	1	270	40	41	16	1.53	30
4	Banna Khera DW	W-15	7.90	650	0	390	7.1	0.18	0.02	5	290	48	41	16	1.5	30
5	Kanawra HP	W-16	8.18	597	0	342	14	0.32	2.31	0	260	56	29	15	1.56	31
6	Pritpur HP	W-17	7.90	627	0	354	7.1	0.21	0.12	20	270	52	34	17	1.6	31
7	Badaripur HP	W-18	8.14	740	0	390	14	0.21	0.12	26	320	40	54	29	3.26	24

Annexure 8- Long term Chemical Quality data of the study area (May, 2005 - 2014) , Parts of Udham Singh Nagar District, Uttarakhand

S. No	Year	E.C. (µ S/cm at 25°C)	Flouride	Chloride
			(mg/l)	
Jaspur Block				
1	2005	1217	0.24	184
2	2006	580	0.2	162
3	2007	330	0.28	53
4	2008	272	0.31	12
5	2009	683	0.22	7.1
6	2010	350	0.28	14
7	2011	465	0.98	13.6
8	2012	623	1.23	14
9	2013	590	0.89	8.9
10	2014	650	1.4	7.1
Kashipur Block				
1	2005	410	0.05	14
2	2006	616	0.3	206
3	2007	613	0.08	149
4	2008	325	0.26	6.7
5	2009	363	0.08	7.1
6	2010	280	0.3	14
7	2011	295	0.33	7.1
8	2012	916	0.95	5.3
9	2013	780	0.56	56
10	2014	750	0.25	43
Bazpur Block				
1	2005	840	0.03	7.1

2	2006	770	0.01	13.5
3	2007	462	0.06	1.1
4	2008	486	0.22	12
5	2009	494	0.22	17
6	2010	530	0.14	28
7	2011	482	0.18	24
8	2012	525	0.51	60
9	2013	654	0.14	47
10	2014	725	0.25	21