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Government of India

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES

UTTARKASHI DISTRICT, UTTARAKHAND

उत्तराखंड क्षेत्र, देहरादून

Uttarakhand Region, Dehradun

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Central Ground Water Board

REPORT ON AQUIFER MAPPING AND MANAGEMENT PLAN IN UTTARKASHI DISTRICT, UTTARAKHAND
(AAP 2017 - 2018)

Uttaranchal Region
February 2019
Dehra Dun

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देहरादून

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REPORT ON AQUIFER MAPPING AND MANAGEMENT PLAN IN UTTARKASHI DISTRICT, UTTARAKHAND
(AAP: 2017-2018)

Submitted By:

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CHAPTER 1
INTRODUCTION

1.1. GENERAL

This report deals with work carried out under National Aquifer Mapping (NAQUIM) project in parts of Uttarkashi district, Uttarakhand during the AAP: 2017-2018. Aquifer Mapping can be defined as a scientific process, wherein a combination of geologic, geophysical, hydrologic and chemical field and laboratory analyses are applied to characterize the quantity, quality and sustainability of ground water in aquifers. Results of an aquifer mapping programme can contribute significantly to resource management tools such as developing a long-term aquifer monitoring network and formulating conceptual and quantitative groundwater flow models that can be used by planners, policy makers and other stakeholders.

Aquifer mapping aims at defining hydrogeology and establish a framework of background information on geology, hydrology and geochemistry of the important aquifer systems. The main objective of the present work is to prepare thematic maps on 1:50000 scale and thereafter to prepare an Aquifer Management Plan and develop an Aquifer Information System, preferably under a Web based Geographic Information System (GIS) platform. In this platform, components of aquifer mapping on 1:50000 or larger scale will be made available for use by various stakeholders. Development of an Aquifer Management Plan in the hilly terrain of Uttarkashi District may also aid various institutions/stakeholders to effectively understand and manage groundwater resources, both at regional and local levels.

1.1.1 Scope of Present Study

The aquifer mapping study was carried out keeping in mind preparation of thematic maps like geology, geomorphology, drainage, land use land cover etc. and establishing the groundwater occurrence (depth range) by study of bore wells (hand pump wells) in accessible terrain, which is characterized by presence of crystalline meta-sedimentary and metamorphic rocks of Lesser Himalaya and Central Himalaya.

1.1.2 Methodology

In this work, micro-level subsurface hydrogeological data was generated by inventory of hand pump wells, along all-weather motorable roads that connect various villages and habitations.

Ground Water Prospect Maps of National Remote Sensing Centre, Hyderabad, topographic maps of Survey of India, Quadrangle Map (53J) and geological reports of Geological Survey of India were used. Available strata charts of Uttarakahnd Jal Sansthan, Uttarkashi Division were also studied to know the subsurface geology of the area. Few satellite images (IRS, LISS-III in optical multi-spectral band) and GoogleMap images were also studied. Thematic maps on 1:50000 scale were mostly prepared in a GIS platform using ***ArcGIS (v. 10.2.1)*** software suite and ***CorelDraw (v. XVII)*** software was also used to prepare few maps.

1.2 STUDY AREA

The study area falls in Dunda, Chinyalisaur and Bhatwari blocks, covering an area of 2000 km^2 under the aquifer mapping programme, AAP: 2017-18. The area falls under Survey of India topographic sheet nos. 53J/2, 53J/5, 53J/6, 53 J/9 and 53 J/10. As per latest available Census data, the civil area viz. area excluding the forest area, of Bhatwari block is 188 km^2, for Dunda block – it is 185 km^2 and for Chinyalisaur block – it is 138 km^2. However, during the present study, out of the total area (2000 km^2), the following areas were covered under the three Developmental Blocks as given below:

Chinyalisaur Block: 410 km^2

Dunda Block: 567 km^2

Bhatwari Block: 1023 km^2

A base map of Uttarakhand State, showing the location of Uttarkashi District as well as the area covered under Aquifer Mapping (2000 km^2) is given in ***Fig. 1.1*** whereas the disposition of the study area – including the coverage under the toposheet numbers 53J/2, 53J/5, 53J/6, 53J/9 and 53J/10, is shown in ***Fig. 1.2***. ***Fig. 1.2*** also shows the regional aquifer-wise distribution with standard Aquifer Mapping Codes. From the map, it is clearly seen that quartzite (Aquifer Code: QZ02) and schist (Aquifer Code: SC01) are the major aquifer types in the study area. This is followed by the occurrence of phyllite aquifer system (Aquifer Code: SC02) whereas the gneissic aquifer system has the smallest areal extent in the study area. However, this scenarios changes substantially when ground hydrogeological mapping was carried out on a much larger scale (1:50000) in parts of Chinyalisaur, Dunda and Bhatwari blocks. The details are given in **Chapter 5.**

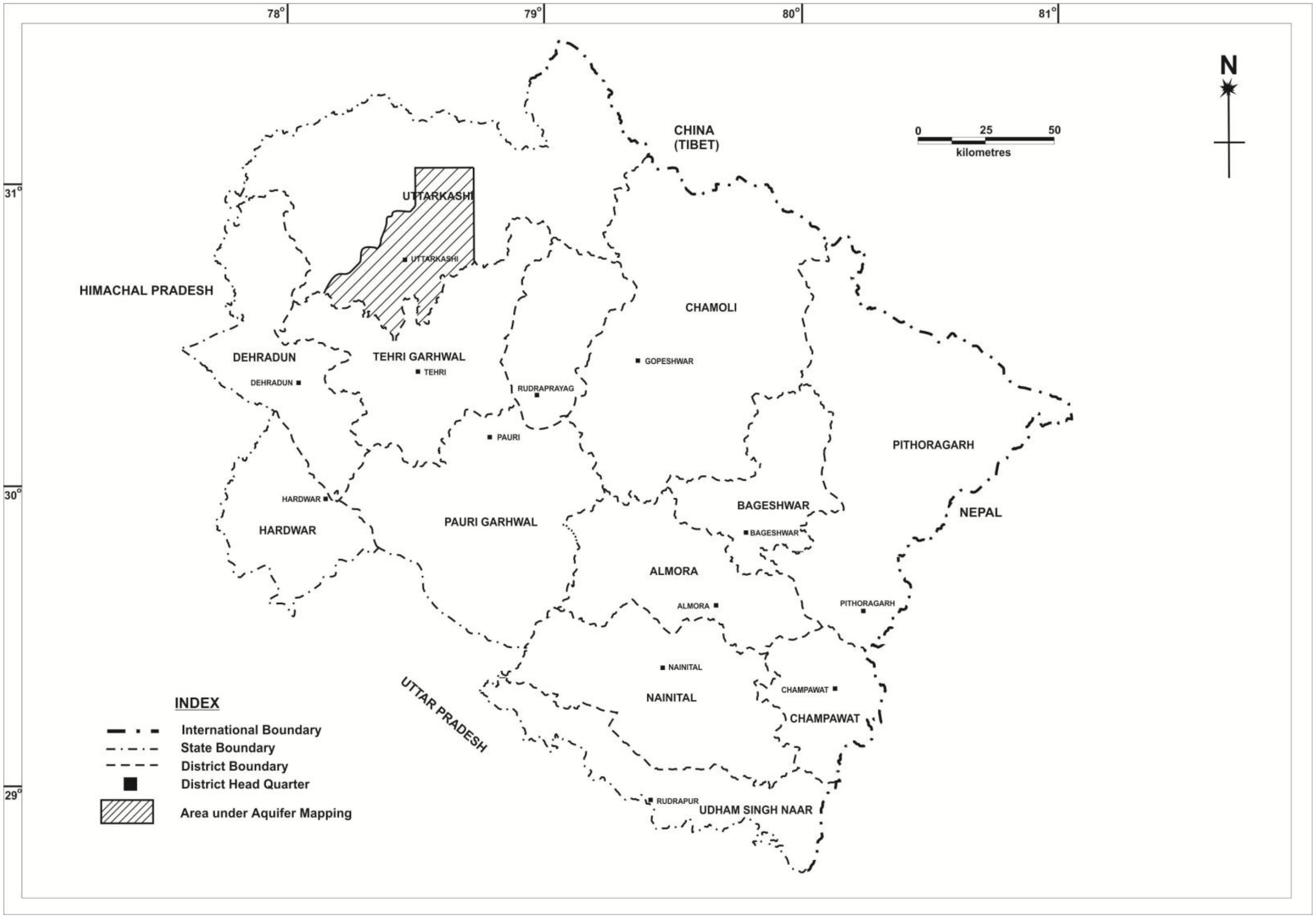


Fig. 1.1 Base map of Uttarakhand State showing Uttarkashi District and area covered under Aquifer Mapping (2000 km^2)

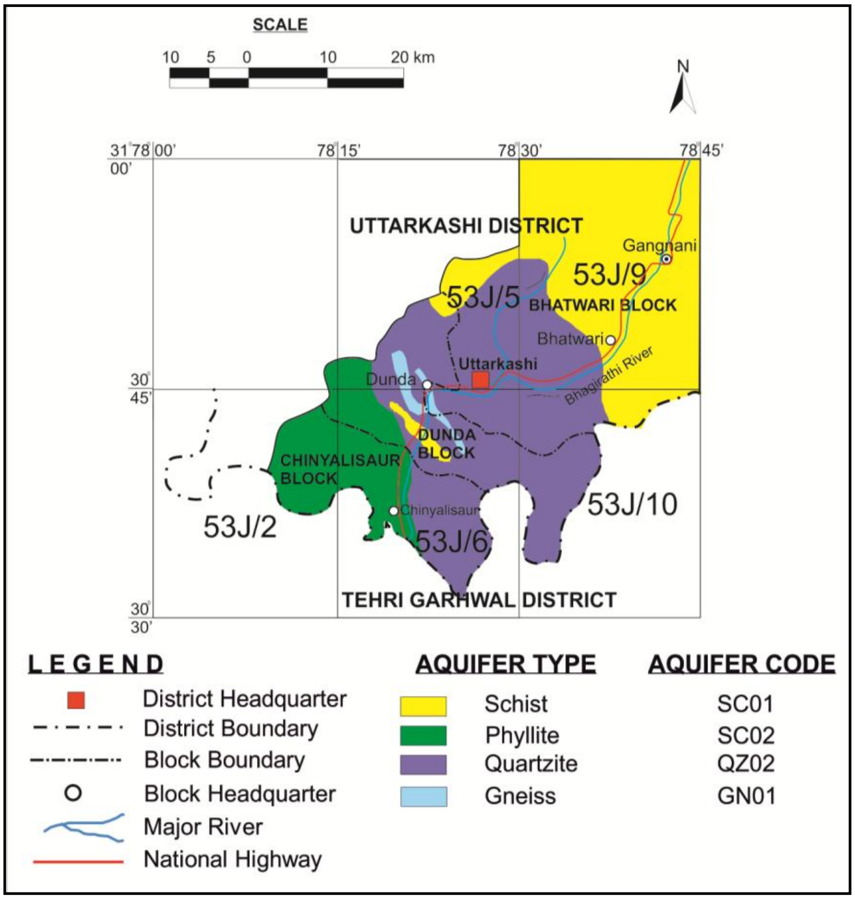


Fig. 1.2 Study area showing Principal Aquifer Systems

1.3. PREVIOUS WORK

Systematic geological mapping in the area was carried out by G. Kumar, N.C. Agarwal and A. Mukerjee from the Geological Survey of India (GSI) during Field Season 1969-1970. Srivastava and Pant from GSI carried out geological mapping near Maneri in connection with the Maneri-Bhali Hydel Project during the Field Season 1963-1964 and confined their work within the project area. Reappraisal Hydrogeological Survey (District Ground Water Management Study) was carried out in parts of Bhatwari, Dunda and Chinyalisaur blocks by Sh. Kartik P. Dongre during the Annual Action Plan: 2005-2006. Apart from these, engineering geologic studies for Lohari-Nag-Pala Hydel Project was carried out by the National Hydro Electric Power Corporation Limited in Bhatwari block.

1.4 DEMOGRAPHY

As per latest available data (Census 2011), the total population of Uttarkashi district is 330090, out of which male population was 168600 and female population was 161490. Out of the total population, 305780 persons lived in rural areas whereas only 24300 lived in urban areas. Population of Scheduled Caste was 80570 while that of Scheduled Tribe was 3540. Density of population (Census 2011) was 41 persons per sq. km and the male-female sex ratio was 1000:958. The overall literacy rate in the district was 75.81%, and the number of habitated and inhabited villages was 667 and 8, respectively. The overall literacy rate in Uttarkashi district was 75.81%.

1.5 ACCESSIBILITY

The study area is well connected with Dehradun, the capital city of Uttarakhand, by a network of all weather roads. National Highways like NH-94 (Rishikesh-Yamunotri road), NH-108 (Rishikesh-Chamba-Uttarkashi-Gangotri road) and NH-123 (Dehradun-Mussoorie-Barkot road). Besides, few State Highways and numerous smaller, feeder roads – many of which are difficult to navigate during the monsoon season, connect the major places and semi-urban areas as well as villages in the study area. Total length of roads in the district is 1189 km, out of which 1030 km road was constructed and maintained by the state Public Works Department. The nearest airport is at Jolly Grant which is at a distance of 181 from Uttarkashi, the district headquarter. The nearest railway station is at Rishikesh, which is situated at a distance of 171 km from Uttarkashi, the district headquarter. Public transport is mainly in the form of private jeeps and buses (mainly during the Yatra Season, viz. from April/May to September/October) and government buses operated by Uttarakhand Transport Corporation Limited, connecting important locations like Dharasu, Barkot, Dunda, Uttarkashi, Bhatwari, Harsil and Gangotri, run throughout the year.

CHAPTER 2
HYDROMETEOROLOGY

2.1 Climate:

Climate of the study area (Bhatwari, Dunda and Chinyalisaur blocks) depends on the summer monsoon currents and associated cyclone system, westerly disturbances and local orographic and conventional thunderstorms that occur in the afternoon during pre and post-monsoon. The variation in temperature and rainfall conditions along the ridge and the valley areas is very prominent. The slope and aspect also play an important role in determining the climate as north facing slopes are much cooler and damp compared to south facing slopes due to insolation effect. Besides this, alignment of ranges in leeward and windward directions, proximity of water bodies and large stretch of forest cover and proximity to snow cover are important factors in determining spatial variation in rainfall and temperature.

The area under aquifer mapping is covered by Lesser Himalaya and Central (Higher) Himalaya. In general, the Lesser Himalaya experiences humid climate with maximum and minimum temperatures of 40ºC and 0.4ºC respectively. Central Himalaya experiences cold, arid climate having minimum temperature below freezing point during the winter season. Higher reaches and mountainous areas are snow covered throughout the year. During winter season the district experiences very cold climate.

2.2 Rainfall

Rainfall is highly variable in space, depending on the altitude. As large part of the study area is situated on the southern slopes of the Outer Himalaya, the monsoon currents penetrate through entrenched valleys. The area gets maximum rainfall during the months of July, August and September. About 90% of the total rainfall is received during the southwest monsoon season during the period June to September. The remaining 10% of rainfall occurs as winter and summer rainfall. Winter precipitation is in association with the passage of the western disturbances and is mostly in the form of snowfall, particularly at higher elevations. The precipitation during the pre-monsoon month is frequently associated with thunderstorms. The average annual rainfall at Dharasu, Uttarkashi, Dunda and Bhatwari was 1095.0, 1552.8, 1631.2, and 2092.9 mm, respectively.

In the study area, neither any Rainfall Observatory nor any Automatic Weather Station of the India Meteorological Department exists. During the present study, only very limited rainfall data was made available by the District Disaster Management Authority (DDMA), Uttarkashi. The daily rainfall data in the monsoon period (June to August, 2012) at four locations viz. Bhatwari, Dunda, Chinyalisaur and Uttarkashi, is given in ***Table 2.1***. Similarly, daily rainfall data for the pre-monsoon and part of monsoon period (April to June, 2017) - provided by the DDMA, Uttarkashi is given in ***Table 2.2***.

Table 2.1 Rainfall data of four Rain Gauge Stations (June to August, 2012)

Month: June 2012				
Date	**Rainfall (mm)**			
	Bhatwari	**Dunda**	**Chinyalisaur**	**Uttarkashi**
01-6-2012	0	0	0	0
02-6-2012	0	0	0	0
03-6-2012	0	0	0	0
04-6-2012	0	0	0	0
05-6-2012	0	0	0	0
06-6-2012	7.0	3.0	18.0	9.0
07-6-2012	0	0	0	0
08-6-2012	0	0	0	0
09-6-2012	0	0	0	0
10-6-2012	0	0	0	0
11-6-2012	0	0	0	6.0
12-6-2012	0	0	0	0
13-6-2012	0	0	0	0
14-6-2012	0	0	0	0
15-6-2012	0	0	0	0
16-6-2012	0	0	0	0
17-6-2012	0	0	0	0
18-6-2012	0	0	0	0
19-6-2012	0	0	0	0
20-6-2012	0	0	0	0
21-6-2012	0	0	0	0
22-6-2012	0	0	0	0

23-6-2012	20.0	16.0	21.0	34.0
24-6-2012	5.0	0	0	0
25-6-2012	2.0	0	2.0	0
26-6-2012	2.0	0	0	13.0
27-6-2012	5.0	0	0	6.0
28-6-2012	0	0	0	5.0
29-6-2012	0	0	0	0
30-6-2012	10.0	0	0	16.0
Monthly Total	***51.0***	***19.0***	***41.0***	***91.0***
Month: July 2012				
01-7-2012	0	0	0	0
02-7-2012	0	6.0	2.0	28.0
03-7-2012	2.0	96.0	8.0	63.0
04-7-2012	14.0	3.0	0	82.0
05-7-2012	2.4	0	0	9.0
06-7-2012	0	0	0	0
07-7-2012	9.0	9.0	32.0	30.0
08-7-2012	2.0	0	4.0	3.0
09-7-2012	2.0	2.0	11.0	14.0
10-7-2012	1.0	15.0	2.0	6.0
11-7-2012	10.0	12.0	9.0	24.0
12-7-2012	18.0	10.0	26.0	82.0
13-7-2012	7.0	0	0	0
14-7-2012	3.0	16.0	7.0	15.0
15-7-2012	2.0	0	0	0
16-7-2012	6.0	0	0	0
17-7-2012	0	0	0	0
18-7-2012	0	0	0	0
19-7-2012	0	0	0	0
20-7-2012	0	0	0	0
21-7-2012	2.0	0	0	0
22-7-2012	0	0	0	0
23-7-2012	2.0	0	0	0
24-7-2012	13.0	0	0	0
25-7-2012	63.0	5.0	26.0	42.0
26-7-2012	20.0	14.0	17.0	24.0
27-7-2012	10.0	24.0	9.0	9.0
28-7-2012	15.0	5.0	1.0	20.0
29-7-2012	46.0	2.0	0	7.0

30-7-2012	45.0	10.0	6.0	62.0
31-7-2012	30.0	36.0	22.0	43.0
Monthly Total	***324.4***	***265.0***	***182.0***	***563.0***
Month: August 2012				
01-8-2012	4.0	16.0	4.0	10.0
02-8-2012	22.0	5.0	1.0	8.0
03-8-2012	45.0	0	0	11.0
04-8-2012	81.0	60.0	34.0	75.0
05-8-2012	61.0	60.0	65.0	22.0
06-8-2012	29.0	80.0	36.0	22.0
07-8-2012	0	0	0	0
08-8-2012	6.0	0	0	0
09-8-2012	1.0	6.0	7.0	24.0
10-8-2012	6.0	18.0	3.0	18.0
11-8-2012	0	0	0	0
12-8-2012	4.0	23.0	42.0	15.0
13-8-2012	18.0	1.0	0	3.0
14-8-2012	4.0	1.0	2.0	8.0
15-8-2012	0	15.0	7.0	8.0
16-8-2012	0	17.0	0	48.0
17-8-2012	20.0	5.0	0	7.0
18-8-2012	0	5.0	0	9.0
19-8-2012	30.0	64.0	22.0	98.0
20-8-2012	7.0	6.0	0	25.0
21-8-2012	20.0	19.0	11.0	28.0
22-8-2012	22.0	23.0	57.0	20.0
23-8-2012	14.0	13.0	0	6.0
24-8-2012	7.0	14.0	7.0	7.0
25-8-2012	10.0	25.0	32.0	14.0
26-8-2012	14.0	16.0	26.0	6.0
27-8-2012	8.0	37.0	26.0	36.0
28-8-2012	13.0	0	1.0	12.0
29-8-2012	4.0	0	0	2.0
30-8-2012	6.0	0	0	0
31-8-2012	5.0	9.0	27.0	27.0
Monthly Total	***461.0***	***538.0***	***410.0***	***569.0***

Table 2.2 Rainfall data of four Rain Gauge Stations (April to July, 2017)

Month: April 2017				
Date	**Rainfall (mm)**			
	Bhatwari	**Dunda**	**Chinyalisaur**	**Uttarkashi**
01-4-2017	0.0	0.0	0.0	0.0
02-4-2017	0.0	0.0	0.0	0.0
03-4-2017	0.0	0.0	0.0	0.0
04-4-2017	0.0	0.0	0.0	0.0
05-4-2017	12.0	4.0	8.0	7.0
06-4-2017	35.0	8.0	59.0	45.0
07-4-2017	9.0	10.0	5.0	7.0
08-4-2017	0.0	0.0	0.0	0.0
09-4-2017	0.0	0.0	0.0	0.0
10-4-2017	0.0	0.0	0.0	0.0
11-4-2017	0.0	0.0	0.0	0.0
12-4-2017	0.0	0.0	0.0	0.0
13-4-2017	0.0	0.0	0.0	0.0
14-4-2017	0.0	0.0	0.0	0.0
15-4-2017	0.0	0.0	0.0	4.0
16-4-2017	0.0	0.0	0.0	0.0
17-4-2017	0.0	0.0	0.0	0.0
18-4-2017	0.0	0.0	0.0	0.0
19-4-2017	0.0	0.0	0.0	0.0
20-4-2017	0.0	0.0	0.0	0.0
21-4-2017	0.0	0.0	0.0	0.0
22-4-2017	0.0	0.0	2.0	0.0
23-4-2017	0.0	0.0	0.0	0.0
24-4-2017	0.0	0.0	0.0	0.0
25-4-2017	0.0	0.0	0.0	0.0
26-4-2017	0.0	0.0	0.0	0.0
27-4-2017	0.0	0.0	0.0	0.0
28-4-2017	0.0	0.0	0.0	0.0
29-4-2017	0.0	0.0	0.0	0.0
30-4-2017	7.0	2.0	4.0	6.0
Monthly Total	***63.0***	***24.0***	***78.0***	***69.0***
Month: May 2017				
01-5-2017	16.0	6.0	8.0	15.0
02-5-2017	4.0	0.0	0.0	2.0

03-5-2017	0.0	0.0	0.0	0.0
04-5-2017	0.0	0.0	0.0	0.0
05-5-2017	0.0	0.0	0.0	0.0
06-5-2017	0.0	0.0	0.0	0.0
07-5-2017	0.0	0.0	0.0	0.0
08-5-2017	0.0	0.0	0.0	0.0
09-5-2017	7.0	0.0	0.0	12.0
10-5-2017	0.0	0.0	0.0	0.0
11-5-2017	32.0	14.0	6.0	35.0
12-5-2017	6.0	1.0	0.0	3.0
13-5-2017	27.0	7.0	2.0	35.0
14-5-2017	5.0	0.0	0.0	0.0
15-5-2017	4.0	0.0	4.0	1.6
16-5-2017	0.0	0.0	0.0	0.0
17-5-2017	2.0	6.0	0.0	1.0
18-5-2017	5.0	2.0	7.0	2.0
19-5-2017	25.0	4.0	0.0	23.0
20-5-2017	3.0	9.0	7.0	1.0
21-5-2017	0.0	0.0	0.0	0.0
22-5-2017	2.0	0.0	0.0	1.0
23-5-2017	4.0	0.0	0.0	3.0
24-5-2017	5.0	0.0	3.0	5.0
25-5-2017	0.0	0.0	0.0	0.0
26-5-2017	3.0	2.0	2.0	1.0
27-5-2017	2.0	23.0	17.0	67.0
28-5-2017	2.0	7.0	0.0	9.0
29-5-2017	0.0	0.0	4.0	2.0
30-5-2017	1.0	0.0	0.0	0.0
31-5-2017	8.0	5.0	20.0	11.0
Monthly Total	***163.0***	***86.0***	***80.0***	***229.6***
Month: June 2017				
01-06-2017	0.0	0.0	0.0	0.0
02-06-2017	0.0	2.0	0.0	0.0
03-06-2017	0.0	0.0	0.0	0.0
04-06-2017	0.0	0.0	0.0	0.0
05-06-2017	0.0	0.0	0.0	0.0
06-06-2017	35.0	5.0	2.0	30.0
07-06-2017	31.0	32.0	18.0	27.0
08-06-2017	2.0	2.0	3.0	3.0

09-06-2017	0.0	0.0	0.0	0.0
10-06-2017	13.0	0.0	0.0	2.0
11-06-2017	0.0	0.0	0.0	0.0
12-06-2017	3.0	0.0	0.0	0.0
13-06-2017	4.0	8.0	0.0	20.0
14-06-2017	0.0	0.0	1.0	5.0
15-06-2017	0.0	0.0	0.0	0.0
16-06-2017	5.0	0.0	8.0	4.0
17-06-2017	0.0	2.0	13.0	9.0
18-06-2017	0.0	0.0	0.0	0.0
19-06-2017	1.0	22.0	0.0	12.0
20-06-2017	5.0	0.0	0.0	0.0
21-06-2017	10.0	7.0	14.0	9.0
22-06-2017	5.0	0.0	1.0	3.0
23-06-2017	0.0	0.0	0.0	2.0
24-06-2017	0.0	0.0	0.0	0.0
25-06-2017	0.0	0.0	0.0	0.0
26-06-2017	4.0	19.0	32.0	60.0
27-06-2017	0.0	0.0	4.0	0.0
28-06-2017	10.0	0.0	0.0	3.0
29-06-2017	10.0	15.0	36.0	25.0
30-06-2017	3.0	3.0	15.0	4.0
Monthly Total	***141.0***	***117.0***	***147.0***	***218.0***
Month: July 2017				
01-07-2017	6.0	0.0	5.0	4.0
02-07-2017	3.0	0.0	0.0	31.0
03-07-2017	30.0	21.0	8.0	55.0
04-07-2017	0.0	0.0	0.0	0.0
05-07-2017	17.0	0.0	0.0	1.0
06-07-2017	19.0	22.0	7.0	31.0
07-07-2017	9.0	7.0	10.0	8.0
08-07-2017	3.0	3.0	5.0	4.0
09-07-2017	0.0	0.0	0.0	1.0
10-07-2017	3.0	0.0	0.0	2.0
11-07-2017	10.0	17.0	12.0	16.0
12-07-2017	10.0	10.0	19.0	35.0
13-07-2017	17.0	8.0	0.0	25.0
14-07-2017	0.0	0.0	0.0	0.0
15-07-2017	11.0	7.0	0.0	20.0
16-07-2017	36.0	32.0	7.0	60.0
17-07-2017	10.0	40.0	5.0	41.0

18-07-2017	14.0	4.0	8.0	13.0
19-07-2017	26.0	7.0	12.0	13.0
20-07-2017	14.0	13.0	12.0	43.0
21-07-2017	0.0	2.0	0.0	0.0
22-07-2017	19.0	17.0	0.0	30.0
23-07-2017	7.0	0.0	0.0	1.0
24-07-2017	0.0	0.0	6.0	7.0
25-07-2017	22.0	8.0	31.0	37.0
26-07-2017	33.0	21.0	16.0	46.0
27-07-2017	0.0	0.0	0.0	0.0
28-07-2017	0.0	0.0	0.0	0.0
29-07-2017	13.0	8.0	14.0	12.0
30-07-2017	29.0	26.0	69.0	35.0
31-07-2017	15.0	34.0	14.0	32.0
Monthly Total	***376.0***	***307.0***	***260.0***	***603.0***

A perusal of data in ***Table 2.1*** indicates that August is the month having maximum rainfall, which coincides with the peak monsoon period in the study area. During August, maximum monthly rainfall of 569.0 mm was recorded at Uttarkashi, followed by 538.0 mm at Dunda. At Chinyalisaur, the least monthly rainfall of 410.0 mm was recorded. Also, the highest cumulative rainfall (from June to August) of 1223.0 mm was recorded at Uttarkashi whereas the least monsoon rainfall of 633.0 mm was recorded at Chinyalisaur.

Rainfall data during the pre-monsoon (summer) period and part of the monsoon period (year: 2017), as given by DDMA, Uttarkashi (***Table 2.2***), indicates that in the study area, pre-monsoon rainfall (April and May, 2017) was least at Dunda (110.0 mm) whereas it was highest (298.6 mm) at Uttarkashi. At Bhatwari, pre-monsoon rainfall was 226.0 mm whereas at Chinyalisaur, rainfall was much lower (158.0 mm). The rainfall shows wide variation in the spatial distribution in the study area, which is a typical feature of mountainous terrain. In absence of rainfall data during the months of August and September, the complete monsoon rainfall pattern cannot be delineated. However, cumulative rainfall data of four months (April to July, 2017) indicates that the highest rainfall of 1119.6 mm was recorded at Uttarkashi whereas the lowest rainfall of 534.0 mm was observed at Dunda rain gauge station.

CHAPTER 3
GEOMORPHOLOGY

3.1 PHYSIOGRAPHY

Within the study area, two distinct physiographic-cum-tectonic units are exposed viz. the Lesser Himalaya and the Central (Higher) Himalaya. The Lesser Himalaya is represented by mountains having average elevation ranging from 1000 to 3000 m above Mean Sea Level (amsl). The Central Himalaya is represented by mountains with average elevation ranging from 3000 to 4500 m amsl. The study area is characterized by rugged, mountainous terrain with narrow valleys and deep gorges with high variation in surface relief within a short distance. Bhagirathi River is the most prominent natural drainage in the study area. The catchment of Bhagirathi River comes under Himadri or Central Himalayan zone. Average altitude of this zone varies from 4800 to 6000 m. The mountain peaks are separated by transverse gorges of Bhagirathi River. Glacial and interglacial moraines occupy the valleys.

Bhagirathi River originates from Gangotri Glacier at Gaumukh on the western slope of Chaukhamba Peak at an elevation of 3892 m. The river initially flows with a northwesterly course and meets River Jahnvi (Jadh Ganga) at the tip of Bhaironghati, where it flows with an east-west trend. This river has carved out deep gorges and many smaller tributaries join it at almost right angle. From Harsil onwards, the river flows towards south west and then further downstream along south. The whole catchment area of Bhagirathi River has very scanty vegetation. The valley side slopes are steep and are covered with moraine deposit. Depositional terraces with Quaternary sediments are developed along Bhagirathi River, between Harsil and Gangnani, around Uttarkashi town and around Dunda. The river has developed an antecedent gorge, which is deep, narrow and sinuous. In the upstream side, the narrow gorge becomes highly sinuous and the channel shows meandering. This is attributed to presence of several faults. The valley becomes wide around Uttarkashi with 2-3 distinct sets of terraces, both paired and unpaired. Beyond Uttarkashi, the valley again becomes wide. Beyond Maneri, about 13 km from Uttarkashi on Uttarkashi-Gangotri road, it appears to occupy a glaciated valley. Fossil valley and epigenetic gorge were identified at Maneri by the GSI. Beyond Bhatwari, about 25 km from Uttarkashi on Uttarkashi-Gangotri road, after crossing the Main Central Thrust (MCT), the valley losses its sinuosity, but continues as a meandering channel. Beyond Sukhi and up to Harsil and through Bhaironghati, the river forms a narrow glaciated valley, with its tributaries forming meandering courses and forming waterfalls at regular intervals.

3.2 SLOPE CONDITIONS

Stream profiles of Bhagirathi River and its tributaries give a general idea about slope conditions in the study area. In the catchment area, due to the presence of Central Crystallines, the valley side slopes are usually well cohesive, cliff type. The tributaries show a very steep gradient, but owing to the presence of moraine deposits, concave aggradational slopes are also commonly found. At places like Dabrani, Gangnani and Bhatwari, the slopes are of repose type. Towards the south of the Central Crystallines, in the Lesser Himalayan zone, the valley side slopes are generally of repose type or aggradational. The presence of fault/shear zones appears to have widened the valleys with remnants of old landslides as observed at Hinna, Uttarkashi and Dunda.

3.3 GEOMORPHOLOGICAL SET UP

Various land system classes in the study area are: structural hills (highly dissected, moderately dissected and less dissected), valley-fill sediments, weathered hill top, river terrace, intermontane valleys and recent slided mass. Geomorphological maps of the study area of about 2000 km^2 and falling in toposheet nos. 53J/2, 53J/5, 53J/6, 53J/9 and 53J/10, are prepared using ArcGIS software. While preparing the maps, due emphasis was given to published maps of GSI and Resourcesat-I LISS-III images, with spatial resolution of 23.5 m and ground swath of 141 km. A mosaic of all geomorphological maps was created using ERDAS Imagine and ArcGIS software, which is given in ***Annexure-I.*** A study of the combined image (map) indicates that highly dissected structural hills predominate in the southern and south eastern parts of the study area, covering toposheet nos. 53J/6 and 53J/10. In other parts, moderately dissected structural hills are the main landform units. Low dissected structural hills are predominantly exposed in the south central part of toposheet no. 53J/5, in and around Uprikot, Bharangaon and Panjala. In toposheet no. 53J/9, such hills are exposed in and around Sainj, Jagthu, Maror, Darsu and Gairsu. Shallow valley fill deposits are exposed in the south western part of the area. River terrace, both paired and unpaired, was developed along the course of Bhagirathi River, which is the principal natural drainage in the study area. Apart from this, small river terraces with valley fill material at places are developed in some of the perennial rivers like Khurmola Gad, Nagun Gad, Assi Ganga and Jadh Ganga Rivers. A very small outcrop of weathered hill top is exposed to the north of Dunda. Recent Slided Mass (RSM), which is a result of active landslides and neotectonic activity, was developed in the Central Himalayan zone, to the north of MCT. One such prominent slided mass (with colluvial deposits) is found 4 km south west of Loharinag village in Bhatwari block. Small outcrops of RSM are also observed to the west of Uttarkashi, the district headquarter.

3.4 LAND USE LAND COVER (LULC)

Land cover type is a natural differentiation, which describes how much of an area is covered by forest, wetland, agriculture, impervious surface and other land and water types. Land cover of an area can be determined by analyzing satellite and aerial images. Land use shows how people use the landscape – whether for development, conservation or mixed uses, and therefore, cannot be determined by satellite or aerial remote sensing techniques.

In the study area, land cover map of toposheet nos. 53J/2, 53J/6 and 53J/9 were made available by the Geological Survey of India, State Unit, Dehradun. Based on type of use of a natural land system type, the land use pattern was determined and demarcated in the mosaic of the combined Land Use Land Cover (LULC) map, which is shown in ***Annexure-II.*** A perusal of the LULC map, based on the latest available database (Survey Period: 2014 to 2016), shows that 11 different types of units can be categorized in the map. However, for sake of simplicity, these LULC classes are combined into five broader subdivisions, a brief description of which is given below:

3.4.1 Barren Land: Such type of land, devoid of any vegetation, is exposed in the north eastern, south eastern and north western parts of toposheet no. 53J/9, covering Bhatwari block. Aerial extent of this land cover type is not much, and it is predominantly associated with Barren Land having Snow Cover. In the north western part of toposheet no. 53J/9, extensive snow covered areas are developed, which can be distinctly identified. The third type of barren land, having River Bed Material (RBM) being the geomorphic unit, is not conspicuous in a scale of 1:50000, as seen from ***Annexure-II.***

3.4.2 Cultivated Land: Cultivated land, with extensive slope cut, is exposed in isolated areas in the southern part of toposheet no. 53J/2. However, this land cover type is most well developed in the north central part of toposheet no. 53J/6, covering areas around Geunla, Asthal, Sera and Matli along the course of Bhagirathi River. In the north western part of 53J/6, locally well developed cultivated land is observed in and around Nag, Naugaon, Majhgaon and Chhamrali. Cultivated area is also well developed to the east of Chinyalisaur, in and around Pujargaon, Badsi and Hadiari.

3.4.3 Vegetation: Thick, moderate and sparse vegetation is found to occur extensively in the study area. Thick vegetation type (dense forest cover) is by far the most extensive, followed successively by the moderate and sparse vegetation type, as observed from the LULC map. The moderately and sparsely vegetated land cover – combined together, occupies about 95% of the geographical area of toposheet no. 53J/6 and about 75% of that of toposheet no. 53J/9.

3.4.4 Settlement: The settlements are very limited in aerial extent, except around Chinyalisaur, Barethi, Dunda, Matli, Gyansu and Uttarkashi. In the north eastern part of toposheet no. 53J/6, settlements are traceable in and around Joshiyara, Manera, Jokani and Tiloth, both to the north and south of the course of Bhagirathi River.

3.4.5 Pasture Land: Pasture land is closely associated with cattle grazing. In toposheet no. 53J/6, isolated patches of this land use class is observable to the north of Kumrara, to the south east of Hadiari and to the west of Bhetiara. In toposheet no. 53J/9, relatively bigger parcels are observed in and around Pilgau and Pilang in the south eastern part, in and around Tiara and Helgu, to the south of Sunagar and to the west of Gangnani in the central part and in and around Jamni Thathar in the northern part. In most of the cases, the pasture land is developed in the form of Alpine or Sub-alpine Meadows, locally known as *Bugyals.*

3.5 DRAINAGE

The principal natural drainage in the study area is Bhagirathi River, which initially flows with NE-SW trend in Harsil-Bhatwari section. In the catchment area of Bhagirathi River, initially in the Gangotri-Badrinath-Kedarnath complex, the river shows radial drainage pattern. This is attributed to strong tectonic influence and structural control on the drainage pattern. In Netala-Uttarkashi-Maneri-Bandarkot area, Bhagirathi River flows with an E-W trend due to strong structural control. In Khattukhal-Dunda-Dharasu area, the river again starts flowing with almost north-south direction, before taking a sharp turn south of Chinyalisaur and continues further downstream with a NW-SE trend. The tributaries are often referred locally as *Gad*, *Nadi* or *Gadhera*. The tributaries form a trellis drainage pattern, with almost all of them meeting Bhagirathi River at a high angle. This indicates that the overall drainage pattern is rectangular having a strong structural and tectonic control. A mosaic of drainage maps of toposheet nos. 53J/2, J/5, J/6, J/9 and J/10 was prepared, which is given in ***Annexure-III.*** Generally, tributaries of Bhagirathi River flow along the regional strike direction. Prominent among the tributaries are: Assi Ganga, Jalkur River, Indravati Gad, Khurmola Gad, Banari Gad, Nagun Gad, Daski Gad, Chamar Gad, Nagun Gad, Dhanari Gad, Ghatu Gad, Gair Gad, Dogadda Gad, Malogi Gad and Kol Gad. During the present study, it was observed that generally second or third order streams are perennial while almost all the first order streams, originating near hill tops with ground slope of >30° are seasonal.

CHAPTER 4
GEOLOGY

4.1 GENERAL

Geology of Uttarkashi district is very complex with rocks types ranging in age from Precambrian to Recent. The rocks are highly metamorphosed, ranging from greenschist to almandine-amphibolite facies. The country rocks are predominantly folded, faulted, jointed, thrusted and sheared. Regionally metamorphosed Proterozoic rocks are emplaced by granites of variable age. The granitoids, associated with volcano-sedimentary sequences, are emplaced along with predominantly metamorphic and meta-sedimentary rocks forming large-scale nappe, e.g. the Garhwal nappe. The Central (or Higher) Himalaya consists of thick slabs of crystallines rocks thrusted along the Main Central Thrust (MCT), overriding the rocks of Lesser Himalaya. This zone consists of 10-15 km wide sequence of metamorphic and granitic rocks. The metamorphic rocks show progressive regional metamorphism ranging from greenschist to upper amphibolite facies. Presence of garnet followed by gradual appearance of staurolite, kyanite and sillimanite from SW to NE in Bhagirathi Valley indicates progressive increase in metamorphic grade. Strain effect is seen in quartz grains, which increases from SW to NE in the Bhagirathi Valley. The area has been subjected to retrograde metamorphism indicated by presence of chlorite and oxides of iron around the margins of biotite grains. The intrusion of dolerite dyke across the MCT is the last magmatic activity in Bhagirathi Valley.

4.2 LOCAL GEOLOGY

Detailed lithological and structural mapping was carried out by workers of the Geological Survey of India (GSI), wherein area falling in toposheet no. 53J/5, 53J/6, 53J/9 and 53J/10 was covered (Kumar et al., 1970). Rocks of the area around Uttarkashi were grouped under the “Barahat Series” (after the old name of Uttarkashi) by Auden (1937), which he later renamed as the “Garhwal Series” (Auden, 1949). Pant (1964) carried out geological mapping near Maneri in connection with the Maneri-Bhali Hydel Project and confined his work within the project area.

Rocks of the study area have been grouped into Garhwal Group and Central Crystalline Group, also loosely referred as Central Crystallines. A generalized tectonic succession of the area is given in ***Table 4.1.***

Table 4.1 Generalized tectonic succession of the area (after Kumar et al., 1970)

? Fault	
Central Crystallines (Central Crystalline Group)	Kyanite-garnet-mica schist and interbedded augen and porphyritic gneiss Banded augen gneiss and garnet-mica schist, containing tourmaline Migmatite zone of mica schist, gneiss, granite, amphibolite and marble/calc silicate
Fault (Main Central Thrust)	
Garhwal Group	Upper massive quartzite – white to light grey and green, fine grained to gritty, occasionally schistose, current and graded bedded and with ripple marks Metavolcanics occasionally bearing pillow structure Lenticular limestone/Dolomite with slate and minor quartzite Lower quartzite and slate

On the basis of published maps, a mosaic of all geological maps has been prepared and is shown in ***Annexure-IV.*** The major geological units are described on the basis of three broad stratigraphic units viz. Jaunsar Group, Garhwal Group and Central Crystalline Group. A brief description of the local geology is given below:

4.2.1 JAUNSAR GROUP

The Jaunsar Group comprises rocks of Mesoproterozoic to Neoproterozoic II (ca. 1600-750 Ma), and has been categorized as Supersequence III by some workers (Kumar, 2005). The Jaunsar Group of rocks is subdivided into five formations viz. Nagthat Formation, Chandpur Formation, Mandhali Formation, Morar Chakrata Formation and Sauli Formation. Basic intrusive (epidiorite and less commonly dolerite) was found to occur in close association with the rocks of the Jaunsar Group. A brief description of the formations and the basic intrusive is given hereunder.

1. Nagthat Formation: The arenaceous facies of Jaunsar Group unconformably overlying the Chandpur Formation is named Nagthat Formation. This formation comprises purple and green coloured sandstone, quartzite, conglomerate, clay-slate and phyllite. The quartzite/sandstone shows current bedding and ripple marks. The conglomerate contains pebbles of vein-quartz, often stained red or purple, purple and pale quartzite, purple or green slate or phyllite.

2. Chandpur Formation: This unit consists of laminated, greenish grey to khaki laminated phyllite/slate interbedded with thin, finely interbanded siltstone and white to brownish, purplish greywacke. In Bhagirathi Valley, the contact between Chandpur Formation and overlying Nagthat Formation is conformable.

3. Mandhali Formation: The Mandhali Formation consists of slate, limestone, quartzite, greywacke and siltstone and has a gradational contact with the overlying Chandpur Formation in the Bhagirathi Valley.

4. Morar Chakrata Formation: Rocks of the Morar-Chakrata Formation consist of slate, phyllite, quartzite, greywacke, shale and siltstone. Primary sedimentary structures like ball and pillow structure, convolute bedding, load cast and flute cast are well developed in greywacke.

5. Sauli Formation: This formation consists of a thick sequence of dolomitic limestone, dolomite, calc-arenite, slate and quartzite. In Bhagirathi Valley, the Sauli Formation is overlain conformably by the Morar Chakrata Formation. Dolomite is typically light grey to bluish black and massive. Stormatolites like *Collenia symmetrica* has been identified in the dolomitic limestone.

6. Basic Intrusives (Epidiorite): The epidiorites have intrusive relationship with the host rocks, are massive or weakly foliated and medium to coarse-grained and occur as dykes and sills. In Bhagirathi Valley, epidiorites are best developed between Maneri and Jakhol. Another body was mapped at Hina, which extends to Paithani enclosing thin bands of quartzite. Some workers (Kumar et al., 1970) believed the epidiorites are the metamorphic derivatives of dolerites.

4.2.2 GARHWAL GROUP

The Garhwal Group of rocks comprises thick pile of metamorphosed arenaceous, argillaceous and calcareous sediments with thick beds of metabasic rocks and chlorite schist. The Bhagirathi valley sediments (arenaceous, argillaceous and calcareous) have been subjected to consolidation by subsidence and vertical pressure resulting in bedding schistosity. The Garhwal Group consists of metavolcanic rocks, rocks of Nagnithank Formation, Lameri Formation and Uttarkashi Formation.

1. Metavolcanics: Metavolcanic rocks of the Garhwal Group consist of drab-green chlorite schist and related rocks, amygdaloidal at places (Kumar et al., 1970). These rocks have been subjected to varying degrees of weathering and alteration, giving rise to chlorite schists at places and fine-grained, massive rocks showing pillow structures. The best development of metavolcanics in the study area is between Dhanpur and 2 km NNW of Bamangaon, on Uttarkashi-Lambgaon road.

2. Nagnithank Formation: Rocks of this formation comprises quartzites, slates and penecontemporaneous basic flows and is found to occur extensively to the east of Chinyalisaur, south of Dunda and Uttarakshi and around Uprikot-Bamangaon and Bhakoli-Agora section. Dolerite intrusives, often metamorphosed to epidiorite, are found to occur as dykes and sills at many places.

3. Lameri Formation: In Bhagirathi Valley, rocks of the Lameri Formation are restricted to the NW of Dunda. This formation consists of black, grey and purple slates, phyllites intercalated with chert and stromatolite-bearing dolomitic limestone and dolomite.

4. Uttarkashi Formation: A thick succession of quartzite, limestone, slate and phyllite occurs along the lower elevation of Bhagirathi Valley around Uttarkashi. The axe shaped outcrop of this formation measures 6.5 km across strike at its widest expanse and runs for more than 14 km from Sada to Baun. It is subdivided into five lithostratigraphic Members viz.

4.1 Netala Quartzite: The lowest unit is predominantly arenaceous with buff-grey-green, thinly bedded (10-60cm) quartzite and phyllite. It is well exposed near Netala village and Maneri village.

4.2 Lower Uttarkashi Limestone: The Netala Quartzite is conformably overlain by nearly 200 m thick grayish, friable, slaty limestone containing many thin yellowish quartzite and grey phyllite intercalation.

4.3 Pokhari Slate: The succeeding unit consists of greenish-grey-black, friable, laminated and thinly bedded and occasionally carbonaceous slate and phyllite. The Pokhari Slate is exposed into three NW-SE trending outcrops between Hina and Nair, between Gangori and Iwain and between Matli and Sada.

4.4 Upper Uttarkashi Limestone: The overlying limestone (150 m thick) succession shows typical fawn-blackish coloured rugged weathered surfaces. Bluish grey and dark greyish black, fine grained, thinly bedded limestone is frequently intercalated with greyish black slate and phyllite.

4.5 Barethi Quartzite: Barethi Quartzite, the uppermost unit of Uttarkashi Formation is predominantly arenaceous with minor slate, limestone and metabasic rocks. Quartzites are greyish buff to purplish black and greyish green in colour. The quartzite is about 250 m thick near Barethi.

4.2.3 CENTRAL CRYSTALLINE GROUP

The Garhwal Group of rocks has been thrust over by the Main Central Thrust (named as Baijnath Thrust in toposheet no. 53J/10), which separates them from the rocks of Central Crystalline Group, often referred as the *Central Crystallines*. The name *Central Crystallines*, though a misnomer, has been retained as it is entrenched in literature and has been given the status of a Group (Kumar, 2005). In the study area, rocks of the Central Crystalline Group are exposed in parts of toposheet nos. 53J/5, 53 J/9 and 53J/10. A perusal of ***Annexure-IV*** indicates that in Sainj-Loharinag area, the *Central Crystallines* are grouped into Wazri Formation and Yamunotri Formation whereas in the eastern part of toposheet no. 53J/10, Baijnath Formation and Badrinath Formation were recognized by the workers. Within the study area, the Central Crystallines are exposed in the Bhagirathi Valley upstream of Sainj to Sukhi. The rocks show considerable migmatization giving rise to various types of gneisses and schists up to Bhatwari. A brief description of the four lithologic formations of the Central Crystalline Group is described below.

4.2.3.1 Baijnath Formation: The Baijnath Formation is part of the Central Himalaya of Proterozoic age. This formation, also referred as the *Baijnath Crystallines*, tectonically overlies the Berinag Formation and consists of gneiss, quartzite and phyllite. Geologists of the GSI have divided the Baijnath Formation into two members: Lower and Upper. Lower Member of Baijnath Formation consists of schist, augen gneiss, quartzite and amphibolite whereas the Upper Member comprises quartz-sericite-chlorite schist and limestone. The granitoids associated with Baijnath Crystallines occur as klippe in the Lesser Himalaya, forming parts of the Baijnath-Askot Nappe. The regionally metamorphosed rocks of Baijnath Formation occur in the core of a broad open major synform (Garhwal Synform) of the Lesser Himalaya.

4.2.3.2 Wazri Formation: The Wazri Formation is part of the *Central Crystallines* of Paleoproterozoic age which is best exposed in Yamuna Valley. Within the study area, rocks of the Wazri Formation are exposed to the north of Main Central Thrust in Kumrara-Bhatwari-Phola-Thind section. This formation is further classified into three members, viz. lower Guptkashi Member, middle Soundergarh Member and upper Dodital Member. The Guptkashi Member lithologically consists of white to grey quartzite, quartz garnetiferous schist and grey to green phyllite. Rocks of the Soundergarh Member comprise porphyroblastic augen gneiss with bands of leuco to melanocratic gneiss and partings of mica schist, sillimanite gneiss and amphibolite. The uppermost Dodital Member consists of leucocratic to mesocratic gneiss with bands of augen gneiss and quartz mica schist.

4.2.3.3 Yamunotri Formation: The Yamunotri Formation is best exposed in the Yamuna Valley and is a part of the Central Crystalline Group of Paleoproterozoic age. In the Bhagirathi Valley, within the study area, rocks of this formation are exposed in Sunagar-Bhujkot-Loharinag-Jhala-Harsil area. This formation has been classified into the lower Dabrani Member and the upper Loharinag Member. Rocks of the Dabrani Member comprise garnetiferous gneiss with bands of marble whereas rocks of the upper Loharinag Member include kyanite schist, leucocratic to melanocratic gneiss and quartz-mica schist. In the study area, rocks of the Yamunotri Formation are restricted to toposheet no. 53J/9 only.

4.2.3.4 Badrinath Formation: Badrinath Formation of Paleoproterozoic age is best exposed in the Kali Valley. It is classified into three members. The lower Bauling Member comprises garnetiferous schist, quartz-mica schist, kyanite-sillimanite schist, calc gneiss and porphyroblastic augen gneiss. The middle Sela Member comprises garnetiferous schist, quartz-mica schist, bands of para-gneiss, amphibolite and quartzite. The upper Nagling Member consists of gneiss, garnetiferous schist, kyanite-sillimanite schist, quartz schist, migmatite, calc-silicate rocks, granite and pegmatite. This is the youngest formation of Central Crystalline Group and is found in the eastern part of toposheet no. 53J/10.

A detailed geological map mainly covering the area under toposheet no. 53J/6 and 53J/9, is shown in ***Fig. 4.1.*** Two geological cross-sections (along A-B and X-Y of the geological map) are shown in ***Fig. 4.2.***

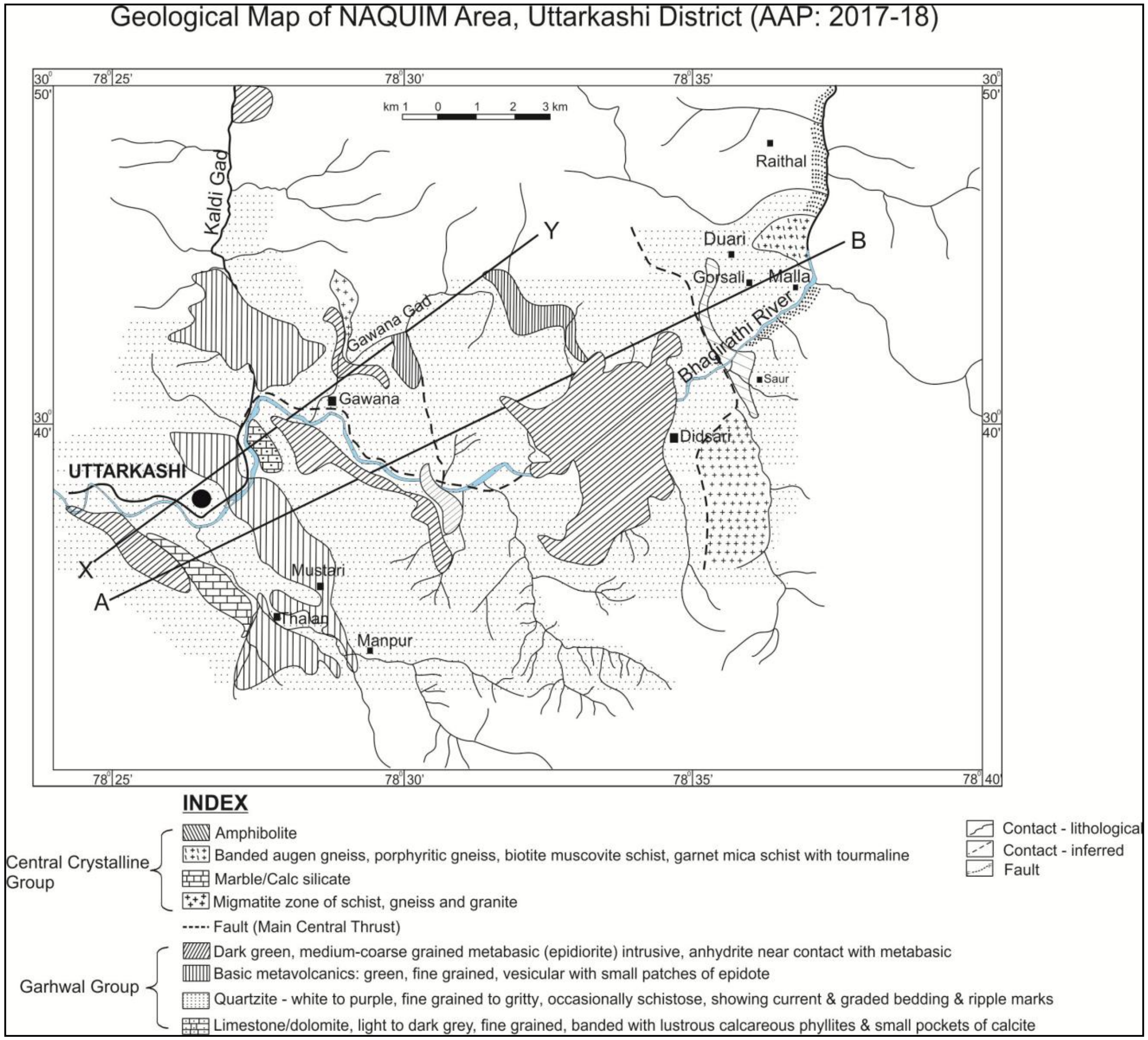


Fig. 4.1 Detailed geological map of the study area (after Kumar et al., 1970)

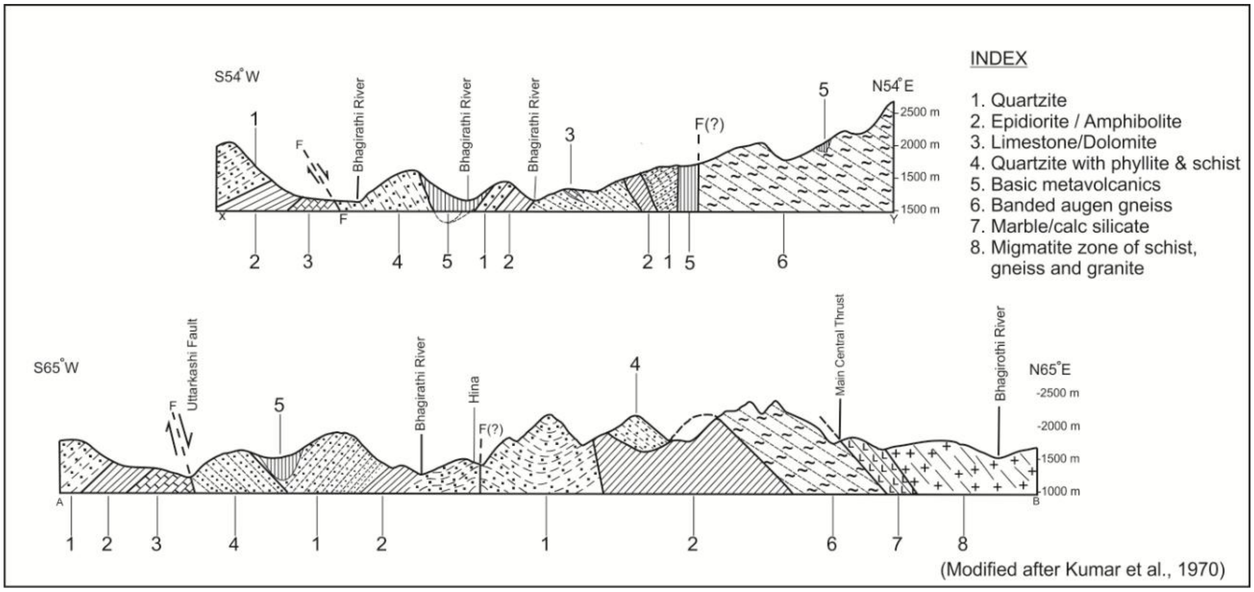


Fig. 4.2 Geological cross-sections along X-Y (above) and A-B (below)

A perusal of ***Fig. 4.1*** and ***Fig. 4.2*** indicates the complexity of local geological conditions in the study area. Kumar et al. (1970) identified the interbedded sequence of quartzite and slate as the oldest member of Garhwal Group in the area. The quartzite is fine to medium grained, generally greyish buff to light green in colour and less commonly white. It is interbedded with argillaceous intercalations varying in thickness from one millimeter (mm) to nearly 50 centimeter (cm) and shows ripple marks to the north of Neganri. The limestone and dolomite, with interbedded slates and occasional quartzites, overlying the lower quartzite and slate sequence, occur in the form of narrow, linear, impersistent bands. This unit has been mapped on the right bank of Bhagirathi River between Matli and Basong. On the left bank, this unit is exposed between north of Pokhri and west of Thalan. The other exposure of limestone/dolomite is near Tekhla, about 1 km south of Neganri. The limestone is light to dark grey in colour, interbedded with thin bands of grey slate/phyllite, and quite massive to the east of Tekhla.

The metavolcanic rocks exposed in the area include drab-green chlorite schist and related rocks, amygdaloidal at places. Kumar et al. (1970) identified them to be pene-contemporaneous with the upper quartzite and showing varying degrees of weathering and alteration, with the result that at places, the metavolcanics have given rise to chlorite schists or occur as find-grained massive rocks showing pillow structures. The best development of the metavolcanics is observed on Uttarkashi-Lambgaon road, between Dhanpur and 2 km NNW of Bamangaon, underlying the quartzite. In the north, it is delimited by the Baragadi Fault (along Baragadi Gad) and in the west, it is offset by another N-S trending fault along a stream 1.5 km SE of Bonga. In the east, the outcrops of the metavolcanics take a swing and join with similar rocks seen at Manpur, and continue towards the north-west in the area around Mastari, Silyara and Kot. Basic metavolcanics are also exposed between Utiaun and Nairad in the Kaldi Gad section. About 2 km north-east of Netala, the metavolcanics are exposed below the lower quartzites due to overturning. Towards the east, the metavolcanics are cut-off by the Hina Fault (***Fig. 4.2***).

The main lithologic member of the Garhwal Group in the study area, according to Kumar et al., is the upper massive quartzite. The quartzite is in general white to dirty white, at places purplish, fine to coarse-grained. The coarser varieties show graded bedding, current bedding and ripple marks. The quartzite is massive to schistose, depending on the percentage of mica (sericite) present in it. This upper quartzite also encloses lenses of limestone, partly metamorphosed to marble at about 1.2 km NE of Mandwa. In the study area, this quartzite is well developed between Hina and Sainj, enclosing a thick intrusion of dolerite (metamorphosed to epidiorite) between Maneri and Jakhol. The quartzite is cut-off in the east near Sainj and comes in contact with the rocks of the *Central Crystalliunes* due to a major fault (thrust) – the Main Central Thrust. Kumar et al. mapped the quartzite in the Kaldi Gad section, between Utiaun and Gajoli. In its southern continuation, the quartzite forming precipitous slopes of Andri Gad and Gamar Gad, was mapped up to Manpur, where it comes in contact with the basic metavolcanics.

Epidiorites in the study area shows intrusive relationship with the host rocks and occur as sills and dykes. The epidiorite is massive or weakly foliated and medium to coarse-grained. At places, the foliation is parallel to the bedding of the host rocks. Kumar et al. postulated that the epidiorites are the metamorphic derivatives of some basic igneous rocks (possibly dolerites) which have undergone a low-grade regional metamorphism. Epidiorites are best exposed between Maneri and Jakhol in the Bhagirathi Valley and continues southwards in the area lying between Baman Gad and Andri Gad. Another outcrop was mapped at Hina, which extends to Paithani in the south enclosing thin bands of quartzite between Khaini and Paithani. In the Kaldi Gad section, epidiorites are seen around Saku. Kumar et al. (1970) observed that in the road section about 1.5 km ENE of Aungi, due to development of feldspar porphyroblasts, the rock has the appearance of a diorite/gneiss.

Rocks of the Central Crystalline Group are exposed in the Bhagirathi Valley upstream of Sainj to Suki. Immediately north of Bhatwari to 1.5 km north of Lohari Nag, a sequence of banded augen gneiss, porphyritic gneiss and garnet-mica schist was mapped by Kumar, Agarwal and Mukerjee. They also mapped a band of calc-silicate rocks about 1 km north of Bhatwari and basic rocks (amphibolite) about 800 m SSW of Sunagar. The rocks show considerable migmatization giving rise to various types of schists and gneisses up to Bhatwari. Further mapping revealed that in the north western part of the study area, the *Central Crystallines* occupy an area between Bhatwari and west of Martoli. Eastwards, the migmatites are exposed beyond Sila in the Pilang Gad section and their southern extension was mapped beyond Chunna in the Dugadda Gad section, the area being covered mostly by talus. Granitic rocks are exposed to the south-east of Siab and about 1 km west of Jaunkani. A band of marble, about 500 m wide, was mapped at Sila. Near the fault contact of the MCT, quartz-biotite schist with bands of porphyritic gneiss was mapped. Meta-sedimentary rocks exposed from north of Suki to 3 km east of Dharali were considered by Kumar et al. (1970) as possible equivalent of Martoli Formation (Algonkian age) of the eastern Kumaon Himalaya. They observed that after crossing the landslide zone at Suki, banded augen gneiss is exposed before reaching the bridge on Bhagirathi River. The banded augen gneiss is reported to be overlain by garnet-mica schist, which continues up to Jhala, where quartz-biotite schist appears. The assemblage of quartz-biotite schist and garnet-mica schist continues from east of Harsil to about 3 km east of Dharali, where a biotite granite was mapped by the authors. They considered the landslide zone as the tectonic boundary between the meta-sedimentary rocks (Martoli Formation?) and the underlying *Central Crystallines.* However, recent geological literature defines this tectonic contact as a major thrust (Vaikrita Thrust) and excludes the existence of Martoli Formation. Instead, the rocks are classified under the Yamunotri Formation whereas the underlying rocks (*Central Crystallines*) were grouped into the Wazri Formation.

4.3 STRUCTURE

The area shows a complex structural and tectonic set up. Multiple phases of deformation and metamorphism are evident from the patterns of folding, faulting, many criss-cross lineaments, numerous fractures and joint planes and foliation in high-grade metamorphic rocks. The structural map of toposheet no. 53J/6 is shown in ***Fig. 4.3.***

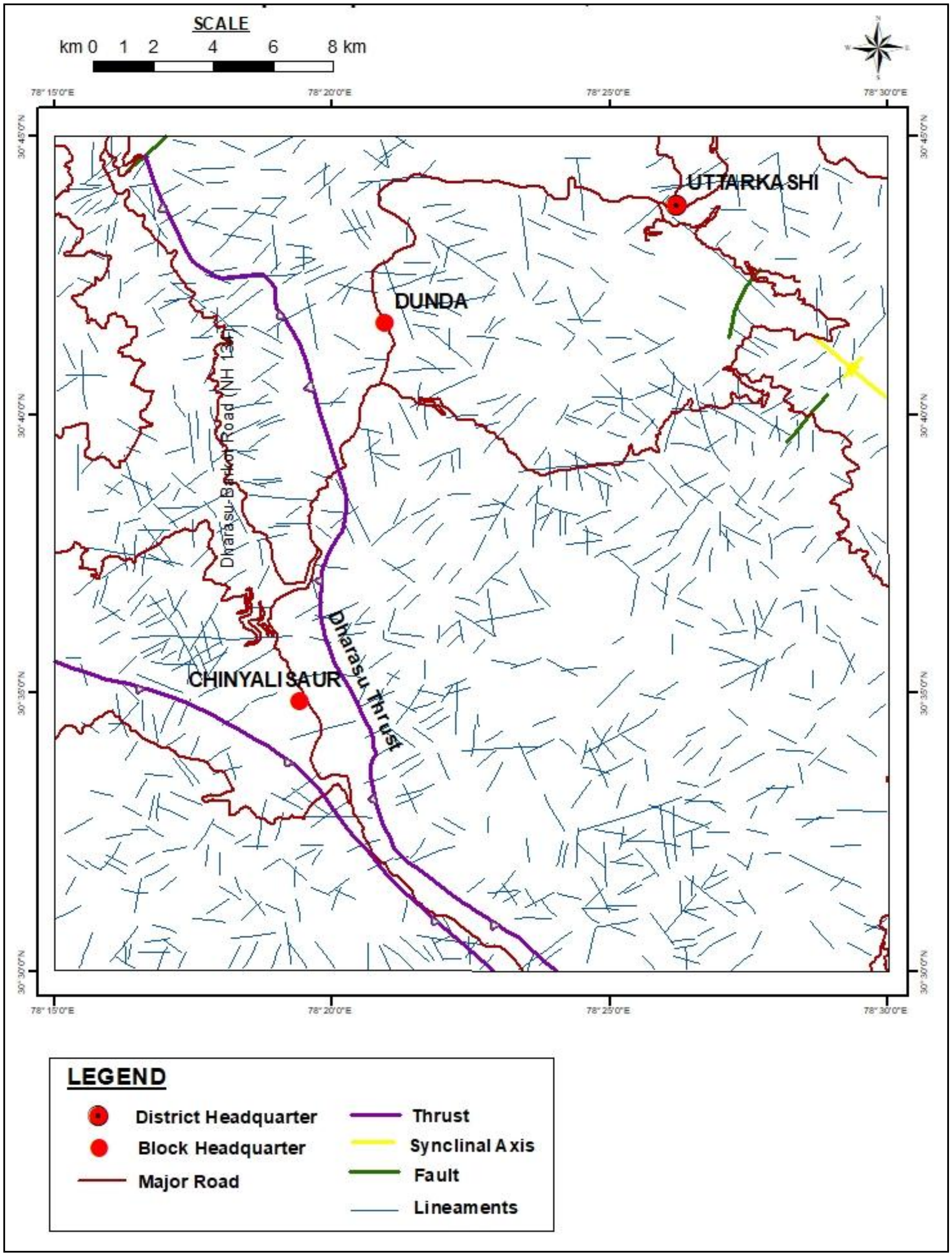


Fig. 4.3 Structural map of Toposheet No. 53J/6, NAQUIM Area

On the basis of the structural map and published literature of the Geological Survey of India (Kumar et al., 1970), a brief description of the structural characteristics of the study area is given below.

4.3.1 Folds and Faults

Within the study area, the Garhwal Group of rocks (including the intrusive basic rocks) is intricately folded into WNW-ESE and ENE-WSW trending folds. A major anticline, trending NW-SE, was mapped between Ladari and Thalan along the Baragadi Gad. Near Uttarkashi, this anticline takes a westerly swing and was traced up to Matli. Along the axial plane of this anticline (antiform), a steeply dipping reverse fault trending NE-SW has resulted in the concealment of the Lower Quartzite Member (of Uttarkashi Formation) in the southern limb and truncation of Sialam Gad fault and Sankuni Khal fault. The sudden widening of the Bhagirathi Valley near Uttarkashi and the crushed white quartzite exposed on the Uttarkashi-Lambgaon road near Thalan are indications of this fault. Due to plunging nature of the Baragadi anticline, the lower quartzite and metavolcanics close south of Manpur.

The Sialam Gad fault, trending NW-SE cuts off the limestone (of Uttarkashi Formation) exposed to the west of the fault, while the Sankuni Khal fault truncates the axis of the minor syncline to the east. A minor fault exposed near Bonga has caused the local off-set in the rock units. The axial trace of another major anticline, running almost parallel to the Bhagirathi River for about 14 km between Sainj and Neganri, was found to be re-folded (Kumar et al., 1970). Due to re-folding, the NW-SE trending axis between Neganri and Saror, swerves to ENE between Lata and Sainj. A sub-vertical fault, running parallel to the axial trace between Neganri and Jamak, has considerably reduced the thickness of rocks. Near Netala, Jamak and Maneri, the rocks are highly sheared. The fault dies out near Utiaun after running along Kaldi Gad for some distance. Along the Gawana Gad, a local overturning of the eastern limb of a minor anticline has brought the metavolcanics below the lower quartzite at about 2 km NNE of Netala. Further to the east, both the units abut against the N-S trending Hina Fault and come in contact with the upper quartzite.

The upper extremity of the Garhwal Group of rocks is marked by a steep, northerly dipping fault, where they come in faulted contact with the tectonically overlying mica schists and gneisses of the Central Crystalline Group. This fault is referred to as the Main Central Thrust (MCT). The MCT has been traced from 1.5 km west of Gorsali to 500 m north of Sailu, trending in NNW-SSE direction. North of Sainj, the MCT runs almost parallel to a perennial stream. Southwards, the MCT follows Dugadda Gad through Siab. The faulted contact is nowhere clearly exposed and is covered by heavy landslides, especially in the area east and north of Sainj and south of Siab. The mica schist and gneiss of the Central Himalaya, north of Sainj, are uniformly north-easterly dipping without any major structural variation. Kumar et al. (1970) identified another fault at Suki separating the meta-sedimentary rocks (equivalent to Martoli Formation) from the underlying rocks of the Central Crystalline Group. Heavy landslides are common in this area. The crushed nature of the rocks along the faulted contact could be seen on the slopes opposite Suki. Kumar et al. (1970) found a close resemblance of the meta-sedimentary rocks with the rocks exposed in the basal part of Martoli Formation in the Gauriganga Valley in Pithoragarh District. On the basis of this correlation, they considered the fault at Suki to be equivalent to the Dar-Martoli Fault in the eastern Kumaon Himalaya. However, Valdiya (1980) has identified this faulted contact as a major thrust, the Vaikrita Thrust (VT). This thrust trends almost NW-SE along Kelaun-Sahgara area (in toposheet no. 53J/9) and swerves to almost E-W further eastwards. To the north of Helga and passing through Delpura, the VT continues eastwards with a WNW-ESE trend. The VT separates rocks of Wazri Formation (in the south) from the rocks of Yamunotri Formation, both being sub-units of the Central Crystalline Group, as shown in ***Annexure-IV***.

4.3.2 Joints and Foliation

The strike of the upper quartzite (Uttarkashi Formation) is variable due to folding. Three sets of joints are well developed in the massive quartzites (Kumar et al., 1970). The attitudes of these sets are:

1. Strike N50°E, dipping at 65° - 70° towards north-east
2. Strike N65°W, dipping at 45° - 70° towards east
3. Strike N10°W, dipping at 60° - 70° towards either north-east or south-west

The authors have reported other less developed joint sets in rocks of the Garhwal Group. The attitudes of such joints are as follows:

1. Strike N30°E, vertical
2. Strike N25°W, dipping 80° towards north
3. Strike N65°E, dipping 70° towards north
4. Strike N85°E, dipping 79° towards south.

In the rocks of Central Crystalline Group, the general strike of foliation is NW-SE with variable dip of 15° to 33° towards north-east in the area west of the Bhagirathi River. The foliation takes an anticlinal swing in the eastern part with strike direction of NNW-SSE with dip amount ranging 27° to 45° towards east. Three prominent joint sets are identified in the granite gneiss and/or granites of the *Central Crystallines*, whose attitude is as follows:

1. Strike NW-SE dipping at 80° towards north-east
2. Strike NNW-SSE with variable dip of 67° - 70° towards the west
3. Strike N75°W with variable dip of 75° - 86° towards south.

According to Kumar et al., the huge landslides, found to the east of Lata (Lata Sera) and to the north of Pakhi, are possibly connected with the first set of steeply dipping (sub-vertical) joints.

To the north of Bhatwari, the general strike of foliation is NW-SE with dips towards north-east direction. However, near Sunagar, the strike of foliation becomes north-south. Between Lohari Nag and Suki, the foliation planes strike N80°W with variable dips of 45° to 50° towards the north.

CHAPTER 5

HYDROGEOLOGY

5.1 GENERAL

Groundwater scenario in the study area comprising Chinyalisaur, Dunda and Bhatwari blocks, is quite complex due to the peculiar geological and structural set up. Groundwater in the crystalline rocks of Lesser and Central Himalaya occurs in the secondary porosity of joints, fractures and fissures. In some places, groundwater also occurs in limestone and dolomitic limestone country rocks depending upon the local lithological and geomorphological controls. The occurrence and movement of groundwater depend not only on the host rock but also on the nature of the structures in which secondary porosity is developed. The vertical and horizontal extent of joints, fractures, faults and/or shear zones and the control of local and regional geomorphology are the principal factors for determining groundwater potential in the Lesser and Central Himalaya. Moderately high groundwater potential exists in the well vegetated and gently sloping tracts of Bhagirathi Valley.

In the hilly terrain of the district, groundwater often emerges as springs and seepages (locally called *chhani* or *naula*) along the valley floor, formation contact and fracture zones. A spring is a concentrated discharge of groundwater appearing at the ground surface as a current of flowing water whereas seepage is slower movement of groundwater to the ground surface. A considerable amount of groundwater also occurs in the thin veneer of soil developed due to weathering of rocks, in alluvial terraces, valley fill etc. Such features are well developed along Barethi-Neri-Baldogi section, falling in Chinyalisaur block. The potential zones of groundwater recharge in the study area are flat ridges, hills, saddles, spurs, river terraces on Bhagirathi River, fault zones and shear zones. The discharge/infiltration of springs takes place through the hill slopes where structurally weak and saturated zones intercept the topography.

Depth to water level in the localized and discontinuous aquifers can be measured in selected bore wells fitted with India Mark-II hand pumps, which are almost always installed along all-weather roads. The aquifers are recharged through precipitation, comprising rainfall and snowfall at higher reaches. However, due to steep ground slope, the immediate surface runoff or overland flow is very high. This is also caused by relatively impervious nature of the crystalline meta-sedimentary, metamorphic and igneous rocks. The high slope condition results in steep hydraulic gradient, which causes relatively less recharge to the fractured aquifers. Most of the surface run off flows down slope and contributes as base flow to the rivers and streams located at lower elevations.

5.2 PRESENT WORK

In the Bhagirathi Valley, aquifers can be broadly divided into four types viz. sandy and gravelly aquifers consisting of semi-consolidated and unconsolidated sediments, basin fill (or valley fill) aquifers and aquifers of the crystalline, consolidated rocks, also known as hard rock aquifers. Groundwater in the shallow aquifer system is under unconfined condition. However, presence of thin clay beds creates semi-confining condition at few places. Most of the water from rainfall entering this aquifer system moves quickly along short flow paths and appears as base flow to the first and second order streams. Along Bhagirathi River, basin-fill/ valley fill aquifers are formed in depressions caused by either faulting or erosion or both. Fine-grained deposit of silt and clay form local confining units in such aquifers, and thick sequences of unconsolidated sediments become more compact and less permeable with increasing depth.

5.2.1 SPRINGS

During the present study, 17 springs, including one thermal spring at Gangnani were inventoried. The spatial distribution of these springs indicates that various litho-tectonic units in the area represent variable discharge of springs and water temperature. The hot water (sulphurous) spring at Gangnani is the thermal effect of a granitoid pluton with high geothermal gradient. In the vicinity of this hot spring, garnet-mica schist is exposed with neddles of tourmaline. This spring is located in a thrust/shear zone with the Main Central Thrust passing to the south of it. In the study area, the springs located in Bhagirathi Valley occur in three distinct lithological types viz. a) phyllite-schist-slate assemblage, b) low-grade quartzite with associated schist and gneiss and c) high-grade quartzite, granite and gneiss in the Central Himalayan zone. The discharge, water temperature and other details of the springs inventoried and/or monitored during the present study are given in ***Table 5.1.***

Table 5.1 Details of Springs inventoried during Aquifer Mapping, Uttarkashi district

Sl. No.	Spring Location	Co-ordinates	Discharge (LPM)	Fluctuation (LPM)	Water Temp (^{0}C)
1.	KALYANI, on Dharasu-Brahmkhal road, LHS of road before reaching Phari village	30^{0}39'20" N 78^{0}18'14.3" E 1178 ± 3 m	Pre: 25.16 Post: 29.59	+4.43	14.0
2.	LODARA, about 1 km before reaching Dhauntri on Uttarkashi-Chaurangikhal-Lambgaon road.	30^{0}36'42.8' N 78^{0}30'26.7" E 1724 ± 3 m	Pre: 2.98 Post: 3.62	+0.64	10.0
3.	MANPUR, about 1 km away from the village towards Aleth village, on Uttarkashi-Lambgaon road	30^{0}41'38.5" N 78^{0}29'21.7" E 1665 ±3m	Pre: 0.96 Post: 1.98	+1.02	8.0
4.	NETALA, on Uttarkashi-Gangotri road, LHS of road, opposite Hotel Himshri Niwas	30^{0}45'04" N 78^{0}28'59" E 1240 ±3m	Pre: 4.26 Post: 4.35	+0.09	14.5
5.	RAITHAL, upslope of road from GMVN Tourist Rest House, Raithal, on Bhatwari-Raithal-Natin road	30^{0}49'04" N 78^{0}36'00" E 2175 ±3m	Pre: ~22 Post: ~20	-2.0	8.0
6.	SUKI, near Suki Top, LHS of road from Gangnani to Harsil, about 1 km after crossing the Army Camp	30^{0}00'21.5" N 78^{0}42'14" E 2682 ±3m	Pre: 1.14 Post: 3.49	+2.35	6.0
7.	DIWARIKHOL, about 4 km from Diwarikhol village and about 9 km from Banchaura on Pattharkhol road, RHS of jungle road	30^{0}38'15" N 78^{0}11'44" E 1876 ±3m	Pre: 0.08 Post: 0.24	+0.16	7.0
8.	JASTWARI, on LHS of Barethi –Banchaura road, about 10 m upslope of motorable road, about 0.5 km before reaching Jastwari village	30^{0}37'48" N 78^{0}15'01" E 1451 ±3m	Pre: 3.17 Post: 2.50	-0.67	8.0
9.	CHAMYARI, on Barethi-	30^{0}38'04" N	Pre: 24.15	-2.95	13.0

	Margaon-Gamri road, LHS of road towards Gamri, about 1 km before village	$78^0$20'27" E 1151 ±3m	Post: 21.20		
10.	TILPAR, about 1.6 km from Chamyari spring, downslope of road, near twin temples & UREDA solar post	$30^0$37'25.5" N $78^0$21'09.5" E 1205 ±3m	Pre: 15.20 Post: 16.13	+0.93	12.0
11.	MASTARI, on Ladari-Mustiksaur road, LHS of road, about 1 km before reaching Mustiksaur HP	$30^0$42'42" N $78^0$27'44.5" E 1575 ±3m	Pre: 0.47 Post: 0.59	+0.12	13.0
12.	BAGSARI, RHS of Fold-Bamangaon-Pipli Dhanari road, about 3 km SW of Chakon village	$30^0$39'13" N $78^0$25'7.5" E 1395 ±3m	Pre: 0.78 Post: 0.58	-0.20	12.5
13.	SUNARGAON, on Dharasu-Tulyara-Baldogi road, LHS of road towards Baldogi, about 2 km south of Tulyara village	$30^0$34'24" N $78^0$20'10" E 847 ±3m	Pre: 3.97 Post: 4.62	+0.65	15.0
14.	BADHANGAON, about 1 km SSE of Haldiari village on Dharasu-Hadiari-Baldogi road, LHS of road towards Baldogi	$30^0$33'02.5" N $78^0$20'56" E 894 ±3m	Pre: 3.31 Post: 2.86	-0.45	10.0
15.	RATODI SAR, on the LHS of Dharasu-Uttarkashi road, about 6 km from Dunda, near Sarthak Cement Trading and Relax Restaurant	$30^0$44'38" N $78^0$21'33" E	Pre: 8.10 Post: 5.43	-2.67	12.0
16.	BARETHI, on the LHS of Chamba-Dharasu road, about 0.5 km before reaching Barethi market	$30^0$36'02" N $78^0$18'54" E	Pre: 3.32 Post: 1.95	-1.37	13.0
17.	GANGNANI (THERMAL SPRING), on the RHS of Uttarakshi-Gangotri road, about 6-7 m upslope of main road, locally known as *Rishi Kund*	$30^0$54'11.5" N $78^0$40'48.5" E 1911±3m	Pre: 26.22 Post: 6.67	-19.55	58.0

A perusal of the above table indicates that during pre-monsoon, the highest discharge of 25.16 LPM was recorded at Kalyani whereas the lowest discharge (0.08 LPM) was recorded at Diwarikhol, both located in Chinyalisaur block. However, if the thermal spring is also taken into consideration, then the highest pre-monsoon discharge was 26.22 LPM at Gangnani, falling in Bhatwari block. In the post-monsoon and during detailed studies, the highest spring discharge of 29.59 LPM was measured again at Kalyani whereas the lowest discharge (0.24 LPM) was again recorded in Diwarikhol spring. The spring at Diwarikhol is located at topographic high, near a water divide where groundwater potential is very low. In such a terrain, even the very low discharge can also be utilized gainfully by constructing suitable water harvesting/conservation structure (like *hauj*) along the motorable road.

On the basis of pre and post-monsoon discharge data, discharge fluctuation for 17 springs (16 cold water springs and one thermal/hot spring) was calculated, which reveals that 9 out of 17 springs have shown positive fluctuation in discharge. This is a normal situation wherein post-monsoon discharge exceeds that of pre-monsoon discharge. However, a substantial 47% of the springs inventoried has revealed anomalous discharge pattern, wherein the post-monsoon discharge is reduced compared to the pre-monsoon value. This anomalous discharge pattern may be attributed to natural causes like landslides (during monsoon period) and anthropogenic causes, particularly the large-scale widening of roads in Chinyalisaur, Dunda and Bhatwari blocks under the *Char Dham Yatra Project.* Widening of roads, combined with landslides has resulted in de-stabilization of rocks in the recharge area of the affected springs, e.g. at Ratodi Sar, Chamyari and Raithal. Landslide hazard is a prime factor in affecting the primary and/or secondary orifices of the mountain springs, whose discharge was measured at the road head. The highest and the lowest positive fluctuation in spring discharge were observed at Kalyani (+4.43 LPM) and at Netala (+0.09 LPM), respectively. Among the cold water springs, the minimum negative fluctuation in discharge was 0.45 LPM at Badhangaon, whereas the maximum negative fluctuation was 2.95 LPM at Chamyari, both located in Chinyalisaur block. The highest negative fluctuation in discharge was 19.55 LPM at the Gangnani hot spring, which may be attributed to tapping of the spring water in a small pond (*garam kund*), from where the hot spring water flows through separate outlets. The main flow of hot spring had a very high discharge, which was not measurable due to its non-channelized flow. However, when the pond was emptied for cleaning purpose (in March 2018), in situ measurements of two secondary flows indicated a discharge of

~100 LPM for the main source of this thermal spring. The temperature of cold water springs during post-monsoon was found to be varying from 6.0 °C at Suki Top to 14.5 °C at Netala. Interestingly, temperature of the Gangnani hot spring was found to be constant (58.0 °C) during the entire monitoring period from May 2017 to March 2018. This indicates the deep-seated (volcanic) origin of this spring.

All the cold water springs are of gravitational type whereas Gangnanai thermal spring is of volcanic type. The springs were classified into VI, VII or VIII order according to Meinzer's classification of spring discharge. Out of 17 springs, five springs (23.53% of total number) - including four cold water springs and Gangnani hot spring were categorized as of VI order with discharge varying from 6 to 60 LPM. Springs of VII order (discharge varying from 0.6 to 6 LPM) were nine in number and constitute 52.94% of the total number of springs inventoried. The VIII order springs have least discharge (0.06 to 0.6 LPM) and constitute 17.65% of the total number of springs inventoried during the present study.

5.2.2 HAND PUMPS

In the study area, hand pumps (or hand pump wells) serve as important source of groundwater, especially along the all weather, motorable roads. The bore wells, drilled by DTH Drilling Rigs with ODEX attachments, are mainly used for drinking and domestic work by the villagers, tourists and pilgrims. The hand pumps are mainly India Mark-II type and installed by Uttarakhand Jal Sansthan (UJS), Uttarkashi Division. During the micro-level hydrogeological study in the Aquifer Mapping Area, data of 23 India Mark-II hand pumps were collected from the office of Executive Engineer, UJS. Among the 23 hand pumps, 8 are located in Dunda block, 7 in Chinyalisaur block and 8 in Bhatwari block. Drilling data of two mini tube wells (10 inch or 254 mm dia.) were also collected, whose description is given in the next section. On the basis of available data, a detailed description of various aspects like drilled depth, static water level (SWL) and compressor discharge (yield) recorded during drilling operations are given in ***Table 5.2***.

Table 5.2 Drilling details of Hand Pumps in the Aquifer Mapping Area

I. DUNDA BLOCK

1. Location: Brahmkhal (on Kumarkot road, near house of Sh. Shyam Lal)
Drilled Depth: 82.70 m
Yield: 16 LPM
SWL: 44.0 m

2. Location: Chaurangikhal (Bayali Bend) – near NIM Camp
Drilled Depth: 85.30 m
Yield: 16 LPM
SWL: 47.20 m

3. Location: Fold (Dhanari) – near Deen Dayal tea shop
Drilled Depth: 59.52 m
Yield: 16 LPM
SWL: 32.10 m

4. Location: Pipli Dhanari – G.I.C. residential premises
Drilled Depth: 78.02 m
Yield: 16 LPM
SWL: 33.00 m

5. Location: Matli (Sainj) – near Sh. Sunder Lal Nautiyal's house
Drilled Depth: 99.50 m
Yield: 16 LPM
SWL: 48.00 m

6. Location: Baun (Khandwara) – track leading to *chhani*
Drilled Depth: 80.79 m
Yield: 17 LPM
SWL: 27.80 m

7. Location: Dunda (Tehsil Office)
Drilled Depth: 62.50 m
Yield: 16 LPM
SWL: 34.00 m

8. Location: Chakon (near bridge)
Drilled Depth: 75.30 m
Yield: 12 LPM
SWL: 27.00 m

II. CHINYALISAUR BLOCK

9. Location: Phari (on highway, near village gate and culvert)
Drilled Depth: 88.00 m
Yield: 10 LPM
SWL: 53.00 m

10. Location: Baldogi (near Basic School/Pathshala)
Drilled Depth: 82.35 m
Yield: 16 LPM
SWL: 21.00 m

11. Location: Barimani (Tholdhar) – near shop of Sh. Deewan Chandra
Drilled Depth: 95.00 m
Yield: 16 LPM
SWL: 31.70 m

12. Location: Morgi (Baretha) – near Girl's Junior High School
Drilled Depth: 83.00 m
Yield: 15 LPM
SWL: 48.00 m

13. Location: Jestwari (Laldhar) – near shop
Drilled Depth: 82.30 m
Yield: 16 LPM
SWL: 32.00 m

14. Location: Tulyara (near *Nala* & track leading to village)
Drilled Depth: 76.21 m
Yield: 16 LPM
SWL: 39.80 m

15. Location: Dharasu (near stairs of village & above NPCC Labour Colony)
Drilled Depth: 83.00 m
Yield: 16 LPM

SWL: 19.40 m

III. BHATWARI BLOCK

16. Location: Lata (near track leading to village)
Drilled Depth: 70.12 m
Yield: 15 LPM
SWL: 27.20 m

17. Location: Heena (near hotel)
Drilled Depth: 51.90 m
Yield: 17 LPM
SWL: 9.00 m

18. Location: Joshiyara (near Indravati jhula pul)
Drilled Depth: 78.90 m
Yield: 16 LPM
SWL: 24.00 m

19. Location: Mastari (Dubkiya) – near track leading to village
Drilled Depth: 100.00 m
Yield: 14 LPM
SWL: 67.00 m

20. Location: Mando (near Bharadi Devi Mandir)
Drilled Depth: 82.31 m
Yield: 16 LPM
SWL: 37.00 m

21. Location: Sera (Lata Sera)
Drilled Depth: 74.16 m
Yield: 16 LPM
SWL: 29.90 m

22. Location: NIM Premises (Joshiyara)
Drilled Depth: 85.40 m
Yield: 18 LPM
SWL: 27.00 m

23. Location: Manera (stadium premises)
Drilled Depth: 81.30 m
Yield: 16 LPM
SWL: 47.00 m

(Data Source: Office of the Executive Engineer, Uttarakhand Jal Sansthan, Uttarkashi)

A brief account of the drilled depth, discharge (or yield) and static water level of the above mentioned 23 hand pumps is given below.

5.2.2.1 *Drilled Depth*

The bore wells are drilled using the DTH function in the pure hard rock and ODEX method for drilling through the weathered/fractured overburden. The drilling records provided by UJS indicate that about 90 to 95% of the total drilled depth was through the ODEX method.

There is a wide variation in the drilled depth of the hand pumps, for which the data was collected from office of the Executive Engineer, Uttarkashi. In Dunda block, the drilled depth was found to be varying from 59.52 m (at Fold Dhanari) to a maximum of 99.50 m at Sainj (Matli) on Uttarkashi-Gangotri road. In Chinyalisaur block, the minimum drilled depth was 76.21 m at Tulyara, located on Dharasu-Lambgaon road, whereas the maximum drilled depth was 95.00 m at Barimani, located on the same road. The minimum drilled depth in Bhatwari block was 51.90 m, recorded at Heena on the right bank of Bhagirathi River on Uttarkashi-Gangotri road. Maximum depth of drilling was 100.00 m at Mastari, located on Uttarkashi-Ladari-Thalan road.

5.2.2.2 *Yield (Discharge)*

Yield or discharge of the hand pump wells were measured after drilling operations are over and air compressors of limited capacity are exclusively used for measurement of discharge. Available data indicates that in Dunda block, the minimum discharge was 12 LPM at Chakon on Devidhar-Pipli-Sankuni Dhar road whereas the maximum discharge was 17 LPM at Baun on Dharasu-Bandarkot-Geunla road. In Chinyalisaur block, discharge in hand pumps was found to be ranging from 10 LPM at Phedi (on Barkot-Brahmkhal-Dharasu road) to 16 LPM at several villages like

Baldogi, Barimani, Jestwari, Tulyara and Dharasu. In Bhatwari block, the maximum discharge was 18 LPM at Joshiyara whereas minimum discharge of 14 LPM was recorded at Mastari. The discharge data indicates that overall, discharge was ranging from about 12 to 18 LPM, which is sufficient to cater to the water requirement of a habitation.

5.2.2.3 *Static Water Level (SWL)*

Static Water Level (SWL) is the depth to water table (from ground surface) first encountered during the drilling operation. The SWL depends on the local topography, occurrence of springs/seepages near the hand pump, close proximity to a perennial river or stream and the local subsurface geology. These controlling factors have determined the deepest and the shallowest water level in this hilly terrain. For example, in Dunda block, at Sainj – where a structural ridge is passing nearby, the deepest water level condition (48.00 m bgl) was recorded. On the contrary, close proximity to a perennial stream (*gad*) at Chakon has resulted in shallowest depth to water table – only 27.00 m bgl. In Chinyalisaur block, the deepest water level of 53.00 m bgl was recorded at Phedi, which is again located on a structural ridge. The shallowest water level was only 19.40 m bgl at Dharasu, which is located in close proximity of the Bhagirathi River. Similar situation was observed at Heena (bhatwari block), where the shallowest water level of 9.0 m bgl was recorded by UJS during drilling operation. At Mastari, which is located on a highly dissected structural hill, far away from any perennial river/stream, the deepest SWL of 67.00 m bgl was observed.

5.2.3 MINI TUBE WELLS

Drilling details of two mini tube wells at Gyansu and Joshiyara, located in Bhatwari block, was collected from the office UJS, Uttarkashi. A perusal of the drilling data has revealed that mini tube wells have 10 inch (250 mm) diameter and were drilled by DTH rigs having ODEX attachment. The tube well at Gyansu is located adjacent to Joshiyara Lake (near Joshiyara Barrage) whereas at Gyansu, it is located on the bank of Bhagirathi River, near a hot mix-cum-crusher plant. Both the wells were drilled in December 2014. The subsurface geology and/or strata chart of these mini tube wells is not available. Other available drilling details are summarized in ***Table 5.3.***

Table 5.3 Drilling details of mini tube wells at Johiyara and Gyansu, Bhatwari block

Sl. No.	Location	Period of Drilling	Depth Drilled (m)	Yield/Discharge	Static Water Level
1.	Gyansu	From 02-12-2014 to 14-12-2014	ODEX: 50.0 DTH: 50.0 Total: 100.0	1540 LPM	27.30 m
2.	Joshiyara	From 17-12-2014 to 26-12-2014	ODEX: 0 DTH: 43.25 Total: 43.25	1730 LPM	13.60 m

The drilling data in ***Table 5.3*** indicates that proximity to the Bhagirathi River is responsible for the shallow depth to water table (<30 m) condition in both the mini tube wells. The high discharge (>1200 LPM) in such type of hilly terrain, located in the Lesser Himalaya is attributed to strong hydraulic connectivity between the river and the localized aquifers in these areas. The aquifers are undoubtedly fed by the Bhagirathi River, which acts as an influent river at Gyansu and Joshiyara. It was also found that at Joshiyara, thickness of the weathered zone/regolith, which overlies the basement (crystalline hard rock), is either nil or negligible. This is indicated as drilling of 43.25 m was completed totally with DTH and ODEX drilling was not used in this case. The above drilling details also indicate that high groundwater potential zones are generally confined to areas having gentler slopes and near the perennial Bhagirathi River.

5.2.4 HAND PUMPS INVENTORIED DURING MICRO-LEVEL HYDROGEOLOGICAL SURVEY

During the present aquifer mapping study, micro-level hydrogeological survey was carried out in parts of toposheet no. 53J/6 and continued in toposheet no. 53J/9. Inventory of hand pump wells was done along the right and left bank of Bhagirathi River, along the right bank of Dhanari Gad, along the right bank of Khurmola Gad, along the right and left banks of Gamri Gad and along the right bank of Indravati Gad. A total of 38 India Mark-II hand pumps and one tube well (at Mahi

Ka Danda, Bhatwari Block) were inventoried during the micro-level survey. The details of these hand pumps, used as Key Observation Wells (KOW) are summarized in ***Table 5.4.***

During the present work, depth to water levels (DTW) in pre-monsoon, monsoon and post-monsoon periods were measured. It was observed that generally these hand pumps are extensively used by the local populace. A perusal of data in ***Table 5.4*** indicates that the minimum DTW in the hand pump wells during pre-monsoon survey was 3.48 m at Chakon, followed successively by 6.44 m at Manera and 6.82 m at Pipli Dhanari. The deepest pre-monsoon DTW was 62.05 m at Baun, followed by 43.91 m at Mando and 43.17 m at Geunla. In the post-monsoon period, the shallowest water level was 4.92 m at Chakon followed by 5.62 m at Manera and 7.34 m at Pipli Dhanari. In the post-monsoon, the deepest DTW of 54.79 m bgl was recorded at Baun, falling in Dunda block. In post-monsoon, deeper water levels (>40 m bgl) were recorded at Geunla (45.14 m), Mando (42.73 m) and Aleth (40.67 m). A substantial variation in pre-monsoon and post-monsoon DTW condition was observed in the study area. This is attributed to local topographic, hydrological and subsurface geological conditions, where groundwater is restricted to localized zones like fractured rock aquifers and in weathered and/or fractured overburden, whose thickness is variable throughout the area.

In the relatively shallow water table conditions, the weathered and fractured overburden host groundwater whereas in deeper water table conditions, localized aquifers occur in the form of interconnected fractures in meta-sedimentary and metamorphic rocks like quartzite, amphibolite, granites and metabasic rocks. In the crystalline, hard rock of Garhwal Group and Central Crystalline Group, lithological contacts between quartzite and metavolcanics, schist and quartzite, granite and metabasic rock (amphibolite), quartzite and dolerite act as prominent zones of groundwater occurrence.

On the basis of surface geological data, including lithological characterization and structural/tectonic interpretation, a mosaic hydrogeological map of the aquifer mapping area was prepared using ArcGIS. The map is shown in ***Annexure – V.***

Table 5.4 Hand Pumps inventoried during Aquifer Mapping in Uttarkashi district, AAP: 2017-18

Sl. No	**Sample No./ Hand Pump No.**	**Location**	**Water Level (m bgl)**		**Atmospheric & Water Temperature (^{0}C)**		**Date of Instal lation ***	**Static Water Level* (m bgl)**	**Date of Survey**	**Discha rge* (LPM)**	**Remarks**
			PRM	POM	PRM	POM					
1.	53J/6-2A, Chinyalisaur-HP	At Chinyalisaur, near the bifurcation of main road and road leading to Hydel Colony, opposite office of Taxi Owner's Association. 30°34'48" N 78°19'41" E 851 m	MP: 0.35 **28.35**	**21.27** **23.79**	W: 21.0 A: 23.5	W: NA A: 16.0	NA	NA	PRM: 18.5.17 POM: 03.12.17 POM: 09.03.18	NA	HP No. G-04, installed by UJS Uttarkashi, normal & acid treated samples collected
2.	53J/6-1A, Brahmakhal-HP	About 14 km N of Dharasu via Dharasu Bend and about 1.2 km from Brahmakhal market, about 150 m from Mata Mandir towards Dharasu Bend, RHS of Barkot-Dharasu road. 30°41'32" N 78°18'11.5" E 1261 m	MP: 0.55 **21.40**	**17.21**	W: 16.5 A: 23.0	W: 10.5 A: 15.0	19.1.14	44.00	PRM: 18.5.17 POM: 29.11.17	16	HP No. Y-11, installed by UJS Uttarkashi, normal sample collected
3.	53J/6-2A, Pheri-HP	About 8 km north of Dharasu, & 5 km from Dharasu Bend, opposite the gate of Gram Panchayat Koda Pheri, LHS of Barkot-Dharasu road. 30°38'04" N 78°18'50" E 1142 m	MP: 0.70 **32.12**	**36.48**	W: 19.0 A: 23.0	W: 16.5 A: 15.0	8.7.14	53.00	PRM: 18.5.17 POM: 30.11.17	10	HP No. Y-1, installed by UJS Uttarkashi, marked as CGWB

4.	53J/9-3B, Lata Sera-HP	At village Lata Sera, about 5 km before Bhatwari, on the LHS of Uttarkashi-Gangotri road, near a bend, upslope of main road. 30°46'30" N 78°36'56" E 1467 m	MP: 0.90 **26.90**	**25.72**	W: 17.0 A: 19.0	W: NA A:14.0	5.4.10	27.20	PRM: 19.5.17 POM: 02.12.17	15	HP No. G-86, installed by UJS Uttarkashi, normal sample collected
5.	53J/9-2C, Sunagar-HP	At Village Sunagar, about 2 km before Gangnani on Uttarkashi-Gangotri road, LHS of road, opposite M/s. Arvind Traders, near an old, abandoned Jeep. 30°53'19" N 78°40'22" E 1856 m	MP: 0.50 **35.58**	**35.19**	W: NA A: 22.0	W: NA A:13.0	21.3.08	20.00	PRM: 19.5.17 POM: 02.12.17	21	HP No. H-92, chain broken, installed by UJS Uttarkashi, marked as CGWB
6.	53J/10-1A, Hina-HP	At Village Hina, about 11 km east of Uttarkashi en route Natala, RHS of Uttarkashi-Gangotri Road. 30°44'13" N 78°30'27" E 1277 m	MP: 0.50 **7.92**	**8.13** **8.34**	W: 15.5 A: 20.5	W: 14.0 A:11.5	26.2.11	9.00	PRM: 19.5.17 POM: 02.12.17 POM: 16.03.18	17	HP No. G-68, installed by UJS Uttarkashi, normal sample collected
7.	53J/5-3C, Mahidanda – TW	About 12 km from Tekhla, inside the ITBP campus at Mahidanda, in the open ground adjacent to Faith Park. 30°45'23" N 78°28'48" E 1813 m	MP: 0.15 **5.75**	2.08	W: 15.0 A: 21.0	W: 17.0 A:12.0	NA	-	PRM: 20.5.17 POM: 11.03.18	NA	Tube Well, drilled depth-211.90 m, normal & acid treated samples taken
8.	53J/6-1C, Joshiyara-HP	Near Joshiyara bus stand, on the left bank of Bhagirathi	MP: 0.70	**23.72**	W: 17.0 A: 24.0	W: 9.0 A: 8.0	9.8.14	24.00	PRM: 20.5.17 POM:	16	Installed by UJS

		River, about 1 km from Uttarkashi Market. 30°43'32" N 78°26'16" E 1139 m	**24.45**	**23.96**					01.12.17 POM: 13.03.18		Uttarkashi, marked as CGWB, normal & acid treated samples collected
9.	53J/6-1C, Mustik Saur-HP	At village Mustik Saur (Mastari) about 10 km from Tiloth via Uttarkashi-Lambgaon road, on the LHS of road, near a bend. 30°42'33" N 78°28'26" E 1856 m	MP: 1.02 **25.42**	**28.15**	W: 15.0 A: 25.0	W:13.0 A:12.0	25.11.09	67.00	PRM: 20.5.17 POM: 01.12.17	14	HP No. G-210, installed by UJS Uttarkashi, normal sample collected
10	53J/6-1C, Aleth-HP	About 13 km SE of Uttarkashi, on the LHS of Uttarkashi-Lambgaon road, near a seasonal stream and road bend. 30°41'24" N 78°29'00" E 1660 m	MP: 0.60 **39.85**	**40.67**	W: 14.0 A: 22.0	W: 9.0 A:2.5	27.11.11	37.00	PRM: 20.5.17 POM: 01.12.17	16	HP No G-124, installed by UJS Uttarkashi, marked as CGWB
11.	53J/6-2C, Chaurangikhal–HP	At Chaurangikhal, about 27 km SE of Uttarkashi on LHS of Lambgaon-Ghanshali road, near the Bio Toilets 30°38'42" N 78°29'20" E 2256 m	MP: 0.75 **25.98**	**21.47**	W: 10.0 A: 16.0	W: 8.0 A: 9.0	25.10.11 10.3.18	42.20	PRM: 20.5.17 POM: 10.03.18	16	HP No. G-131, installed by UJS, Uttarkashi
12.	53J/6-1C, Fold –HP	At village Fold Dhanari, about 22 km south of Uttarkashi, near board of Parivar Kalyan	MP: 0.75	**28.47**	W: 18.0 A: 25.0	W: 12.0 A: 11.0	7.12.10	33.10	PRM: 20.5.17 POM: 26.08.17	16	HP No. 18-610, installed by UJS

		Upa Kendra. 30°40'09" N 78°24'50" E 1815 m	**33.23**						POM: 15.03.18		Uttarkashi
13.	53J/6-2B Pipli Dhanari –HP	At Pipli Dhanari, ~34 km from Uttarkashi, RHS of Tiloth-Sankuni-Devidhar road, opposite Nitin Welding Workshop. 30°39'09" N 78°23'41" E 1288 m	MP: 0.25 **6.82**	**7.34**	W: 16.0 A: 25.0	W: 14.0 A: 16.0	5.12.10	33.90	PRM: 20.5.17 POM: 26.08.17 POM: 15.03.18	16	HP No. Nil, installed by UJS Uttarkashi, marked as CGWB
14.	53J/6-1C, Thalan-HP	At Thalan, about 9 km from Uttarkashi on Lambgaon-Kedarnath road, LHS of road 30°42'16" N 78°28'06" E 1516 m	MP: 0.60 **27.25**	**19.72**	W: 15.0 A: 22.0	W: 14.0 A: 10.0	12.12.10	29.90	PRM: 20.5.17 POM: 01.12.17	16	HP No. G-120, installed by UJS Uttarkashi, marked as CGWB
15.	53J/6-1B, Matli -HP	About 10 km west of Uttarkashi, opposite Angels International Academy, RHS of Dharasu–Uttarkashi road. 30°44'32" N 78°22'14" E 1065 m	MP: 0.55 **34.90**	**30.64** **40.48**	W: 19.0 A: 23.0	W: 13.0 A: 12.0	26.12.09	48.00	PRM: 21.5.17 POM: 01.12.17 POM: 10.03.18	16	HP No. H-35, installed by UJS, Uttarkashi, marked as CGWB
16.	53J/6-1B, Manera-HP	About 7 km from Uttarkashi, LHS of Joshiyara-Chamkot-Dunda road, left bank of Bhagirathi river, near Iron Bridge. 30°43'51" N 78°24'30" E 1088 m	MP: 0.50 **6.44**	**5.62**	W: 18.0 A: 21.0	W: 15.0 A: 11.0	23.12.11	47.00	PRM: 22.5.17 POM: 01.12.17	16	Installed by UJS, Uttarkashi, marked as CGWB

17.	53J/5-3B, Baun-HP	About 7 km from Matli on Geunla-Baun road, near a big tree and a road bend. 30°45'30" N 78°21'35" E 1281 m	MP: 0.50 **62.05**	**54.79**	W: 17.5 A: 20.0	W: 15.0 A:09.0	29.11.09	27.80	PRM: 21.5.17 POM: 01.12.17	17	Installed by UJS Uttarkashi, normal & acid treated samples collected in post-monsoon
18.	53J/5-3B, Geunla-HP	About 2 km from Matli and about 5 km before Baun village, on the RHS of road, near Bus Stand. 30°45'01" N 78°21'47" E 1177 m	MP: 0.55 **43.17**	**45.14**	W: 18.0 A: 20.5	W: 16.0 A:13.0	NA	NA	PRM: 21.5.17 POM: 01.12.17	NA	Installed by UJS Uttarkashi, normal sample collected in pre-monsoon
19.	53J/6-2B, Dunda-HP	In front of SDM office (Teshil), Dunda, up slope of road from main Dharasu-Uttarkashi road. 30°42'33" N 78°20'51" E 999 m	MP: 0.50 **32.96**	**35.68** **36.42**	W:17.0 A: 22.0	W: 15.0 A:13.0	18.12.09	34.00	PRM: 21.5.17 POM: 01.12.17 POM: 10.03.18	16	Installed by UJS Uttarkashi, normal sample taken in pre-monsoon
20.	53J/6-1B, Odalak-HP	About 5 km south of Dunda, on Dunda-Pipli Dhanari-Ckakon road, LHS of road towards Pipli Dhanari 30°40'29" N 78°21'30" E 1018 m	MP: 0.60 **24.15**	**25.64**	W:19.5 A: 25.0	W: 16.0 A: 17.0	NA	NA	PRM: 21.5.17 POM: 15.3.18	NA	Installed by UJS Uttarkashi, marked as CGWB
21.	53J/6-1C, Chakon-HP	About 20 km from Devidhar, on Pipli Dhanari-Fold-Sankuni Dhar road, on the right bank of	MP: 0.55	**4.92**	W:14.0 A: 23.0	W: 14.0 A: 15.0	5.8.14	27.00	PRM: 21.5.17 POM: 15.3.18	12	HP No. 14/620, installed by

		Dhanari Gad, in front of Sh. Darshan Lal's house. 30°40'42" N 78°26'30" E 1555 m	**3.48**								UJS Uttarkashi, marked as CGWB
22.	53J/6-2A, Barethi-HP	On Chinyalisaur-Dharasu-Uttarkashi road, LHS of road, about 3 km before Dharasu Bend, near Rajrajeshwari Mandir, Barethi. 30°35'59" N 78°19'02" E 892 m	MP: 0.40 **14.42**	**14.52**	W:20.0 A: 23.0	W: 16.0 A:10.5	NA	NA	PRM: 22.5.17 POM: 03.12.17	NA	HP No. G-12, installed by UJS Uttarkashi, marked as CGWB
23.	53J/6-3B, Hadiari-HP	At village Hadiari, about 12 km from Dharasu on Neri-Bandhangaon-Barimani road, on the left bank of Bhagirathi River, near a small Shiv temple. 30°33'32" N 78°20'36" E 869 m	MP: 0.65 **23.33**	**23.11**	W:19.0 A: 20.0	W: 13.0 A: 15.0	NA	NA	PRM: 22.5.17 POM: 30.11.17	NA	HP No. 3/7, installed by UJS Uttarkashi, normal sample collected
24.	53J/6-3B, Baldogi-HP	At village Baldogi, about km from Plalli Bend on Sunargaon-Hadiari-Thaula-Kumrara road, RHS of road. 30°31'04" N 78°23'04" E 971 m	MP: 0.40 **21.59**	**22.26** **21.09**	W:19.0 A: 21.0	W: 15.5 A: 20.0	16.6.11	21.00	PRM: 22.5.17 POM: 30.11.17 POM: 15.03.18	16	Installed by UJS Uttarkashi, normal sample collected
25.	53J/7-1B, Barimani -HP	At village Barimani, about 14 km from Hadiari Bend on Dharasu-Hadiari-Kumrara-Baldogi road, near village gate	MP: 0.50 **27.59**	**19.29**	W: NA A:20.0	W: NA A: 15.0	20.11.09	37.70	PRM: 22.5.17 POM: 30.11.17	16	Installed by UJS Uttarkashi, marked as

		(Shaheed Dwar) 30°29'52" N 78°24'33" E 970 m									CGWB
26.	53J/6-2A, Morgi-HP	About 12 km from Dharasu on Dharasu-Shrikot-Banchaura road, LHS of road, near Govt. Girls Primary School, Morgi. 30°37'31" N 78°17'55" E 1415 m	MP: 0.70 **36.72**	**24.32**	W:14.0 A: 21.0	W: 13.0 A: 24.0	19.12.13	48.00	PRM: 23.5.17 POM:14.3.18	15	Installed by UJS Uttarkashi, normal sample collected
27.	53J/6-2A, Tilari-HP	About 21 km from Dharasu on Morgi-Banchaura road, ~11 km before reaching Banchaura, in village Tilari, LHS of road. 30°37'31" N 78°15'36" E 1376 m	MP: 0.50 **37.50**	**19.30**	W:14.0 A: 22.0	W: 12.5 A: 20.0	28.11.09	32.00	PRM: 23.5.17 POM: 14.318	16	Installed by UJS marked as CGWB, normal sample collected in pre-monsoon
28.	53J/6-2B, Tulyara-HP	About 6 km SE of Barethi, on Dharasu-Neri-Baldogi-Lambgaon road, near a water tank (Hauj). 30°35'21" N 78°19'3486" E 907 m	MP: 0.62 **18.46**	**18.75**	W:22.0 A: 19.0	W: 12.0 A: 20.0	23.11.09	39.80	PRM: 23.5.17 POM: 30.11.17	16	Installed by UJS marked as CGWB, normal sample collected
29.	53J/6-2A, Dikoli-HP	Near village Dikoli, about 2 km from Barethi, on the RHS of Dharasu-Lambgaon road, left bank of Bhagirathi River. 30°36'51" N 78°19'07" E 864 m	MP: 0.65 **19.30**	**22.78** **22.90**	W:20.5 A: 22.0	W: NA A: 16.0	17.11.09	19.40	PRM: 23.5.17 POM: 30.11.17 POM: 15.03.18	16	Installed by UJS Uttarkashi, normal sample collected in pre-monsoon

30.	53J/6-1C, Gyansu-HP	At Gyansu, about 2 km West of Uttarkashi, on the RHS of road towards Uttarkashi 30°43'55.5" N 78°25'16" E 1118 m	MP: 0.60 **17.26**	**12.50** 17.09	W: 20.0 A: 21.0	W: 14.5 A: 21.0	NA	NA	PRM: 18.5.17 POM: 03.12.17 POM: 09.03.18	NA	Installed by UJS Uttarkashi, normal and acid treated sample collected
31.	53J/9-3B, Charethi-HP	At Charethi, about 1.5 km north of Bhatwari, on the LHS of Uttarkashi-Gangotri road, in front of Arti Tea Stall 30°49'16" N 78°37'3.5" E 1599 m	MP: 0.60 **5.69**	**16.95**	W:25.0 A: 25.0	W: 15.0 A: 14.5	NA	NA	PRM: 19.5.17 POM: 02.12.17 POM: 09.03.18	NA	Installed by UJS Uttarkashi, normal and acid treated samples collected
32.	53J/2-1C, Banchaura-HP	At Banchaura, near Kandar Devta Mandir, 32 km from Barethi, on Dharau-Jestwari-Pattharkhol road, near bifurcation of road 30°38'49" N 78°12'49" E 1504 m	MP: 1.0 **5.89**	**8.85**	W:17.0 A:22.5	W: 10.5 A: 12.0	NA	NA	PRM: 23.5.17 POM: 14.3.18	NA	Marked as CGWB, painted with green colour, normal and acid treated samples collected
33.	53J/10-2A, Dikholi-HP	At Dikholi bend, about 34 km from Uttarkashi & 9 km from Chaurangi Khal, near Chauhan Tourist Lodge, on the right bank of Ratnavati Nadi 30°37'08" N 78°30'04" E 1738 m	MP: 0.85 **19.15**	**10.78**	W:16.0 A:18.0	W: 12.0 A: 18.0	NA	NA	PRM: 23.5.17 POM: 10.3.18	NA	HP No. G-136, installed by UJS, norrmal sample collected
34.	53I/12-3C, Jhala-HP	At Jhala about 26 km from Gangotri road, near iron bridge, RHS of road, opposite	MP: 0.75	**15.75**	W:14.0 A:15.0	W: NA A: 14.0	NA	NA	PRM: 24.5.17 POM: 12.3.18	NA	HP No. G-95, Installed by UJS

		Police Chowki 31°00'55.5" N 78°42'43.5" E 2470 m	**14.09**								Uttarkashi, marked as CGWB
35.	53J/6-3B, Bhadkot-HP	At village Bhadkot, 3 km north of Hadiari bend, on the RHS of Dharasu-Hadiari-Jagat road, near Girls Junior School (Kanya Pathsala) 30°34'16" N 78°20'51" E 1104 m	MP: 0.40 **11.60**	**42.79**	W: NA A: 21.0	W: NA A: 16.0	NA	NA	PRM: 25.5.17 POM: 30.11.17	NA	Installed by UJS Uttarkashi, marked as CGWB, HP No. Nil
36.	53J/6-1C, Mando-HP	At village Mando, about 2.5 km north-east of Uttarkashi on Kedarnath by pass road, near a bus stand and electric pole 30°44'13" N 78°27'26.5" E 1185 m	MP: 0.62 **43.91**	**42.73**	W:17.0 A:26.0	W: 14.0 A: 10.0	NA	NA	PRM: 25.5.17 POM: 16.3.18	NA	Installed by UJS Uttarkashi, normal sample collected
37.	53J/6-1B, Hitanu-HP	At village Hitanu, ~1.2 km north-east of Devidhar bend, RHS of Devidhar-Hitanu-Ranari road, opposite Uniyal General Store, near bifurcation of road, on left bank of Bhagirathi River 30°41'16" N 78°21'23.5" E 989 m	MP: 0.50 **10.06**	**9.47**	W:22.0 A:23.0	W:18.0 A: 16.0	NA	NA	PRM: 25.5.17 POM: 01.12.17	NA	HP No. Nil, installed by UJS Uttarkashi, marked as CGWB
38.	53J/9-2B, Barsu-HP	At Barsu, about 12 km NW of Bhatwari on Pala-Barsu road; opposite of Dayara Hotel, near	MP: 0.60 **7.54**	**7.77**	W: 12.0 A: 11.0	W: 17.0 A: 16.0	NA	NA	PRM: 25.5.17 POM: 2.12.17	NA	HP No. Nil, installed by UJS

		village gate. 30°50'34.7" N 78°36'06.3" E 2214 m									Uttarkashi in 2011 (reported)
39.	53I/12-2A, Dharali-HP	At Dharali, on the LHS of Uttarkashi-Gangotri road, ~10 km from Harsil towards Bhaironghati, adjacent to Shiva Temple and Prakriti Hotel & Restaurant. 31°02'26.4" N 78°47'52.0" E 2536 m	MP: 0.60 **17.11**	**16.60**	W: 7.5 A: 9.0	W: 6.5 A: 6.0	NA	NA	PRM: 25.5.17 POM: 12.3.18	NA	HP No. G-98, installed by UJS Uttarkashi, marked as CGWB

*Data Source: Uttarakhand Jal Sansthan, Uttarkashi

5.2.5 HYDROGEOLOGY OF MAJOR ROCK TYPES

A perusal of ***Annexure-V*** indicates that this map may also be treated as a 2-D Aquifer Map of the study area. The Key Observation Wells (hand pumps) and springs are plotted in the map showing the spatial disposition in variable lithology (major rock types). Accordingly, the yield potential of major rock types (in a particular geological formation) has been categorized based on range of discharge in cold-water and hot springs. Similarly, depth to water level range (pre-monsoon and post-monsoon) in the hand pumps is also categorized. The hydrogeological characteristics of the study area are given in ***Table 5.5.***

Table 5.5 Hydrogeological characteristics of major rock types in the study area

Rock Types & Geological Formation	**Spring Discharge (LPM)**	
	Minimum	**Maximum**
1. Alluvium (Youngest Alluvium – Quaternary)	3.09	17.00
2. Slate and phyllite (Morar-Chakrata Formation)	5.67	27.38
3. Quartzite, slate, limestone (Uttarkashi Formation)	4.31	16.00
4. Metavolcanics (Garhwal Group)	0.53	16.00
5. Schist, gneiss, amphibolite (Wazri Formation)	16.00	
6. Gneiss, amphibolite, calc-silicates (Yamunotri Formation)	6.67	26.22
Rock Types & Geological Formation	**Depth to Water Level variation**	
	Pre-monsoon range (m bgl)	**Post-monsoon range (m bgl)**
1. Slate and phyllite (Morar-Chakrata Formation)	21.40 - 36.72	17.21 - 24.32
2. Quartzite and slate (Nagnithank Formation)	12.26 – 18.75	12.90 – 17.65
3. Quartzite, slate, limestone (Uttarkashi Formation)	15.31 – 19.20	11.10 – 17.20
4. Metavolcanics (Garhwal Group)	15.95 – 19.70	11.20 – 18.15

5. Schist, gneiss, amphibolite (Wazri Formation)	5.69 – 26.90	16.95 – 25.72
6. Gneiss, amphibolite, calc-silicates (Yamunotri Formation)	14.09 – 35.58	15.75 – 35.19

5.2.6 DEPTH TO WATER LEVEL ANALYSIS

Depth to water level data in the Key Observation Wells was analyzed and categorized into seven classes viz. 0-5 m, >5-10 m, >10-15 m, >15-20 m, >20-30 m, >30-50 m and >50 m bgl. The categorization of DTW data is given in ***Table 5.6*** and shown as a histogram in ***Fig. 5.1.***

Table 5.6 Analysis of depth to water level data in KOWs in the study area

Depth to Water (DTW) range (m bgl)	**No. of KOWs in pre-monsoon showing DTW in the specified range (m bgl)**	**No. of KOWs in post-monsoon showing DTW in the specified range (m bgl)**
0 to 5	1	2
> 5 to 10	7	6
>10 to 15	4	4
>15 to 20	4	7
>20 to 30	11	11
>30 to 50	10	7
>50	1	1
Total No. of KOWs	38	38

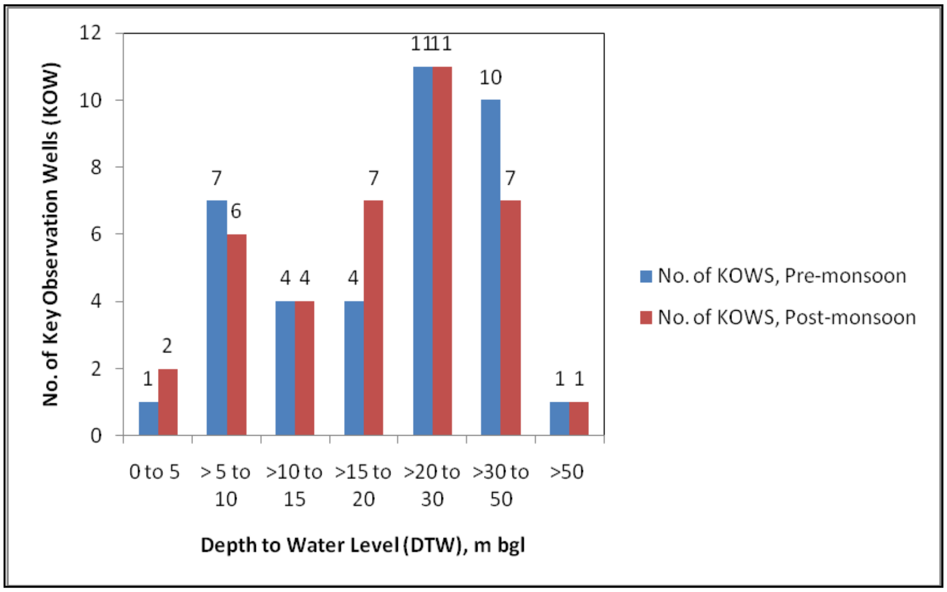


Fig. 5.1 Histogram of depth to water level data in Key Observation Wells

A perusal of ***Fig. 5.1*** indicates that both during the pre-monsoon and post-monsoon, maximum percentage (61.11%) of KOWs have shown depth to water level in the range >20-30 m bgl. This was followed by the DTW category of >30 to 50 m bgl, which was present in ten KOWs in the pre-monsoon period. Only 1 out of 38 (2.63% of total) KOWs have shown the deepest DTW condition viz. >50 m bgl, both during the pre-monsoon and post-monsoon. The shallowest DTW condition (0 to 5 m bgl) was observed in a single KOW at Chakon, Dunda block. During pre-monsoon 2017, only 2.63% (1 out of 38) of KOWs recorded this depth range whereas a slightly little higher percentage (5.25%) of KOWs have shown DTW ranging from 0 to 5 m bgl in the post-monsoon.

CHAPTER 6

GROUNDWATER EXPLORATION, GROUNDWATER MONITORING, GEOPHYSICAL AND HYDROCHEMICAL STUDIES

6.1 AVAILABILITY OF DATA

As per the Manual on Aquifer Mapping published by Central Ground Water Board (CGWB, 2013), there are four components on which the availability of data base in the study area needs to be categorized. These are (a) groundwater exploration data, (b) geophysical data, (c) groundwater monitoring data and (d) groundwater quality data. In this study, total five topographic sheets were covered, either in whole or in part, for analysis of the data requirement, present data availability and further additional data generation (quadrant wise). The present availability of data and the ideally suitable data coverage will be helpful in data gap analysis. A total of 28 quadrants were covered during the present study on Aquifer Mapping. A brief account of the quadrant-wise coverage of the five toposheets, covering an area of 2000 km^2, is given below.

1. Toposheet No. 53J/6: Nine quadrants (1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B, 3C).
2. Toposheet No. 53J/9: Nine quadrants (1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B, 3C).
3. Toposheet No. 53J/2: Two quadrants (1C, 2C)
4. Toposheet No. 53J/5: Five quadrants (2B, 2C, 3A, 3B, 3C)
5. Toposheet No. 53J/10: Three quadrants (1A, 1B, 1C)

The subsurface geometry and extent of the localized, fractured aquifers are not available due to unavailability of borehole logs. As a result, delineation of the Preliminary Aquifer Boundaries and Units (PABUs) is not possible. Due to the highly mountainous terrain (slope >20%) and non availability of parameters required for estimation of groundwater resources, assessment of groundwater resources is beyond the scope of the present study.

However, absence of mapped aquifer in an area does not necessarily means absence of aquifers, rather it indicates that sufficient and/or reliable subsurface data is not available to delineate and classify the fractured rock aquifers. Keeping this fact in mind, a point wise description of various components like groundwater exploration, geophysical studies, groundwater monitoring and hydrochemical studies are given below.

6.2 GROUNDWATER EXPLORATION

The area is characterized by highly undulating, mountainous terrain with high variation in surface relief over short distances. This is a characteristic of the Lesser and Central Himalayan zone. In such a terrain, groundwater exploration can be carried out by deploying a DTH Rig, preferably with an ODEX attachment. The DTH action of the hammer will drill through the un-weathered, crystalline hard rock while the ODEX attachment is most suitable for drilling through the weathered and fractured overburden, overlying the hard, crystalline basement.

No Exploratory Well of Central Ground Water Board exists in the study area. So from groundwater exploration point of view, the area remains a virgin terrain till date. Though numerous bore wells having drilled depth generally ranging from 70-90 m were constructed by state government organizations like Uttarakhand Jal Sansthan (UJS) and Uttarakhand Pey Jal Nigam (UPJN), the main problem faced during analysis of subsurface data is the unavailability of reliable subsurface geological data. Drilling data of 23 bore wells having 6 inch (150 mm) diameter, fitted with India Mark-II hand pumps were collected from UJS, Uttarkashi. In addition, drilling data of two mini tube wells having 10 inch (250 mm) diameter was also collected. In almost all the 6" diameter bore wells/hand pumps, the reported thickness of overburden was found to be variable between 75 and 95 m, below which the hard rock (basement) was exposed. The major problem in correlation of the subsurface geology, on the basis of drilling data of the UJS, is the high vertical and horizontal heterogeneity in the surface and subsurface geology. This is a characteristic of the Lesser and Central Himalayan zone. The available geological cross sections (shown in ***Fig. 5.3***), are also not much helpful in understanding the aquifer configurations due to the scale factor, wherein vertical depth interval was kept at 500 m, which far exceeds the drilled depth of the bore wells and the mini tube wells.

However, detailed subsurface geology is available for a tube well drilled inside the campus of Indo Tibetan Border Police (ITBP) at Mahi Ka Danda, located to the NE of Uttarkahsi, about 12 km from Tekhla. The drilled depth of this tube well was 695 feet (211.89 m). The litho log of this tube well is shown in ***Fig. 6.1.***

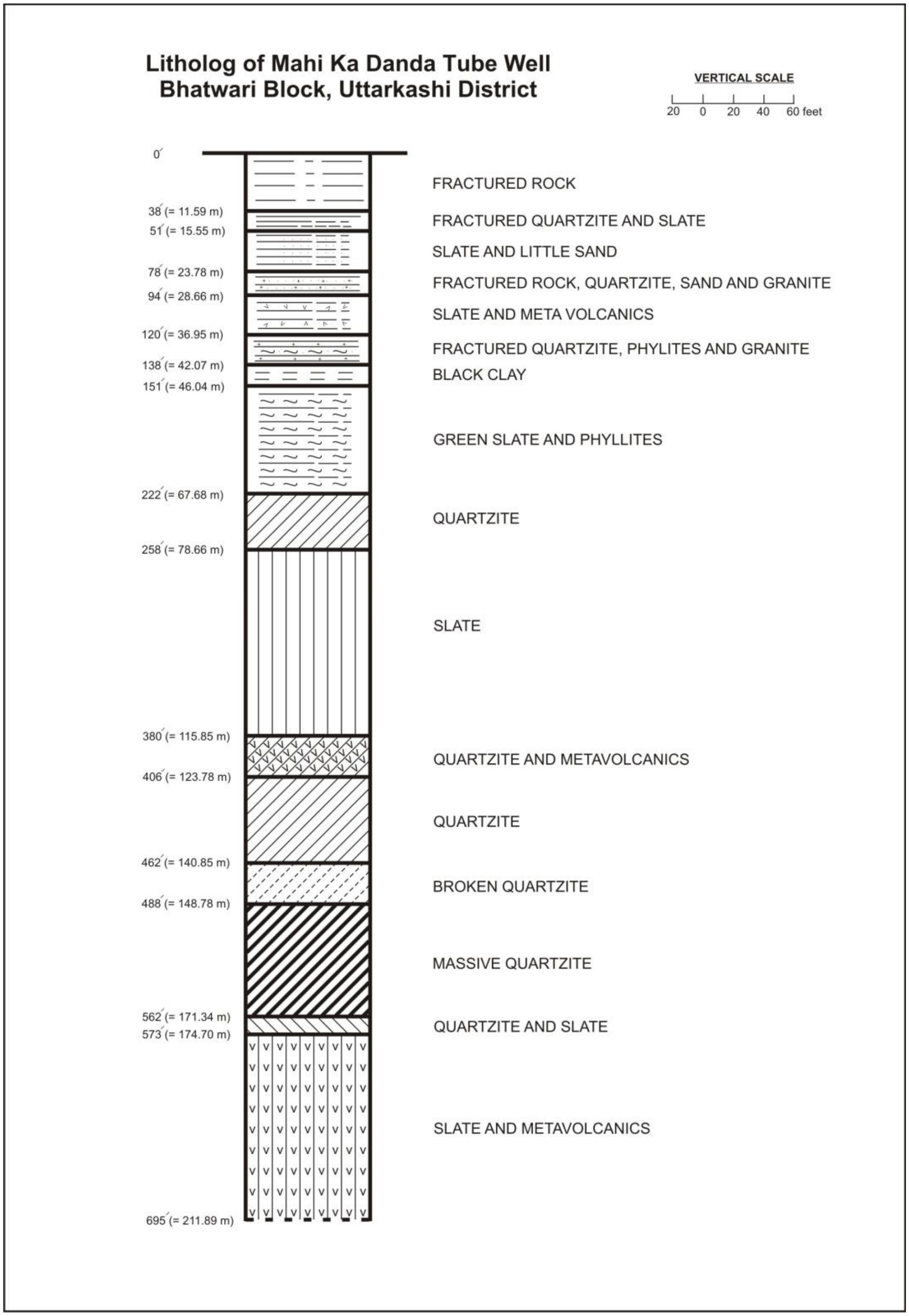


Fig. 6.1 Lithological Log of Tube Well at ITBP Campus, Mahi Ka Danda

A perusal of the litholog indicates that slate, quartzite, phyllite with a thin horizon of black clay (42.07 to 46.04 m) characterized the subsurface geology up to a depth of 100 m. It is also seen that limited groundwater potential exists in the fractured quartzite and slate in the depth ranges of ~11 to 15 m bgl and from ~37 to 42 m bgl. Hence, it can be inferred that the localized, fractured aquifers are confined to shallow or moderate depth range of ~10 to 40 m, below which mostly compact quartzite and slate was found. However, the contact between broken and massive quartzite at ~149 m depth may be another promising zone of groundwater occurrence, with an expected discharge of about 100-150 LPM.

It was observed that the only potential sites suitable for groundwater exploration are the locally well developed valleys of Bhagirathi River. Widening of the river valley near Uttarkashi, Chinyalisaur and Matli was observed, which may be suitable for construction of tube wells. In the event of strong hydraulic connectivity between the river and the localized, fractured aquifers, a high discharge (>1200 LPM) is possible. This is observed from the discharge data of two mini tube wells constructed at Gyansu and Joshiyara, located around Uttarkashi town and on the right and left bank of Bhagirathi River, respectively. The details are given in ***Section 5.2.3.***

On the basis of approachability of drilling rig, which is restricted mainly to the all weather motorable roads (Dharasu-Uttarkashi-Gangotri road, Uttarkashi-Lambgaon road, Badethi-Baldogi-Lamgaon road etc.) and the local geological and geomorphological conditions, it is found that three quadrants in toposheet no. 53J/6 are suitable for construction of exploratory tube wells (EWs) for carrying out test pumping and determination of aquifer parameters. Estimation of such parameters like transmissivity (T), hydraulic conductivity (K) and storage-coefficient (S) will greatly facilitate characterization of the fractured rock aquifers in the study area.

In toposheet no. 53J/6, the priority areas for groundwater exploration are at Chinyalisaur (quadrant no. 2A), Dunda and Matli (quadrant no. 1B) and in and around Uttarkashi like Gyansu, Joshiyara, Ladari and Manera (quadrant no. 1C). The rock types exposed in these areas are quartzite, limestone, phyllite and schist of the Garhwal Group. In toposheet no. 53J/9, due to (a) narrowing of Bhagirathi Valley and (b) presence of high-grade schist, varieties of gneiss including granite gneiss, amphibolite, calc silicate rocks (marble) etc. belonging to the Central Crystalline Group, the groundwater potential is very less compared to that in toposheet no. 53J/6. However, on the basis of gemorphological and geological map, it is recommended that pilot exploratory drilling may be carried out at Lata and Malla (quadrant no. 3B), about 100 m from the course of Bhagirathi River and on the right bank of it.

6.2.1 Site Selection Survey

During the aquifer mapping study, three sites were selected for construction of exploratory wells (EWs) on the basis of ground hydrogeological survey, local geology, hydrology, published maps and literature. All the sites are located in and around Uttarkashi town where the drilling rigs can approach easily. The location and other details of the sites are given in ***Table 6.1.***

Table 6.1 Details of sites selected for construction of Exploratory Wells, NAQUIM area

Sl. No.	Location of Site	Co-ordinates	Toposheet No. and Quadrant No.
1	Adjacent to the artificial lake formed on Bhagirathi River due to construction of Joshiyara Barrage (*Uttarkashi Jheel*), about 1 km west of market and about 200 m NW of iron bridge, on the right bank of Bhagirathi River, about 5 m down slope of Uttarkashi-Gangotri road	30°43'57" N 78°25'49" E	53J/6, 1C
2	At Joshiyara, in the compound of Police Lines, about 2 km west of Uttarkashi town and about 200 m west of Joshiyara Barrage, in the open ground and on the right bank of Bhagirathi River	30°43'44" N 78°25'19" E	53J/6, 1C
3	At Manera, inside the sports stadium, about 3 km west of Uttarkashi, approachable by Ladari-Joshiyara-Manera road, on the left bank of Bhagirathi River	30°43'55" N 78°24'42" E	53J/6, 1B

However, as per the guidelines given in Aquifer Mapping Manual, 10 exploratory wells (EW) and 10 observation wells (OW) should be constructed at suitable locations, preferably one in the central quadrant (quadrant no. 2B) and one each in the four corner quadrants (quadrant nos. 1A, 1C, 3A and 3C) for determining aquifer geometry and determining aquifer parameters. In the study area, the concept of first aquifer (up to 100 m depth) is not tenable for the reasons already explained. The possibility of construction of EW and OW in toposheet no. 53J/6 (quadrant wise) is described below.

In toposheet no. 53J/6, the central quadrant (quadrant no. 2B) falls in a highly mountainous terrain, which is covered by dense vegetation (Reserved Forest area) and absence of motorable roads. However, one Exploratory Well (EW) and one Observation Well (OW) may be constructed at Brahmkhal (quadrant no. 1A) as Barkot-Dharasu road (National Highway 34) passes through the area. In the north-east corner (quadrant no. 1C) sites for construction of EW and OW are already present as given in ***Table 6.1.*** However, in the other two corner quadrants (quadrant no. 3A and 3C) construction of EW or OW is out of question due to (a) absence of motorable roads, (b) very highly undulating topography with steep ground slopes (35° or more) and (c) thick forest cover. Thus, the standard guidelines for data gap analysis are not applicable in the mountainous terrain of the study area.

6.3 GEOPHYSICAL STUDIES

As the area is mountainous with rugged topography, geophysical studies like Vertical Electrical Sounding (VES) is helpful in delineating the subsurface geology in the Bhagirathi Valley. Along the hill slopes, outcrops are visible and an idea about possible subsurface geology can be made by surface geological and structural mapping. Hence, VES should be preferably done in proximity to river viz. in and around the locally well developed valleys, both on left and right bank of Bhagirathi. In such areas, thickness of alluvium (river bed material) is more as compared to pure hard rock terrain.

On the basis of four VES carried out at Nagun, Dharali and Chinyalisaur (AAP: 2005-06), 5 to 8 subsurface layers were interpreted. Interpretation of VES data in Dharali area (Bhatwari block) indicates that total thickness of loose unconsolidated/weathered/fractured formation is ~31 m. This is underlain by a basement which is expected to be massive schist/gneiss. The water level in this area is expected to be in the depth range of 5 to 10 m bgl. True resistivity of the formation overlying the basement ranges from 900 to 16000 ohm.m. The higher values of resistivity are indicative of dryness whereas lower values are attributed to occurrence of saturated formations. The basement in Dharali area is characterized by a resistivity of 280 ohm.m indicating presence of massive schist/gneiss.

In Nagun and Chinyalisaur areas (Chinyalisaur block) two VES were conducted in the marshy land NW of village Nagun and one VES was conducted in the premise of farm of

Horticulture Institute along the western side of Chamba-Uttarkashi road. The total thickness of loose unconsolidated/weathered/fractured formation in this area is estimated to be 90 m underlain by a basement which is expected to be massive quartzite/phyllite. The water level in Nagun area is expected to be in the depth range of 5 to 10 m bgl and at Chinyalisaur, it is expected to be in the range of 30 to 35 m bgl. True resistivity of the formation overlying the basement ranges from 250 to 24000 ohm.m. The basement in the area is characterized by resistivity of 980 ohm.m and is expected to be massive quartzite/phyllite.

During the present work, six sites were selected for conducting the VES. Among them, three sites are located in Bhatwari block, two in Dunda and one in Chinyalisaur block. The details of selected VES sites are given in ***Table 6.2.***

Table 6.2 Details of VES Sites selected in the study area

Sl. No.	**Name of Block**	**Toposheet No.**	**Location of Site for VES**	**Spread available**
1	Chinyalisaur	53J/6	At Chinyalisaur, in the campus of Krishi Vigyan Kendra, to the east of Chamba-Uttarkashi road, down slope of road, on the right bank of Bhagirathi River	About 300 m
2	Dunda	53J/6	At Nalupani, ~3 km from Dharasu Bend, on the LHS of Dharasu-Uttarkashi road, in the open land slightly up slope of main road, on the right bank of Bhagirathi River	About 200 m
3	Dunda	53J/6	At Dundagaon, on the LHS of Dharasu-Uttarkashi road, ~1 km before reaching Dunda market, in the open land slightly upslope of main road where a small temple is located	About 200 m
4	Bhatwari	53J/6	Inside the campus of Police Lines, Uttarkashi, in the open play ground, RHS of Dharasu-Uttarkashi road, before reaching Gyansu market, on the right bank of Bhagirathi River	About 160 m
5	Bhatwari	53J/6	At Manera, inside the ground of sports stadium, about 3 km west of Uttarkashi	About 300 m

			on Ladari-Joshiyara road, site located on the left bank of Bhagirathi River	
6	Bhatwari	53J/10	At Hina, ~12 km from Uttarkashi on Gangotri road, RHS of road, in open land slightly down slope of main road, on the right bank of Bhagirathi River	About 150 m

Once the result of VES surveys is available, it may be possible to obtain reliable subsurface geological data, which will enable analysis of geophysical data gap in the area. Field photographs of selected VES sites at Nalupani, Dundagaon and Hina are shown in ***Fig. 6.2, Fig. 6.3*** and ***Fig. 6.4***, respectively.

Fig. 6.2 VES Site at village Nalupani, Dunda block

Fig. 6.3 VES Site at village Dundagaon, Dunda block

Fig. 6.4 VES Site at village Hina, Bhatwari block (mosaic of three photos in Panorama Mode), Bhagirathi Valley in the background

With minimum half current electrode spacing (AB/2) of about 75 m at Hina and maximum AB/2 of about 150 m in the campus of Krishi Vigyan Kendra, Chinyalisaur, it is expected that subsurface geology may be investigated in the depth range varying from ~25 m to ~50 m. This is expected to demarcate the depth range of fractured rock aquifers in the study area.

6.4 GROUNDWATER MONITORING STUDIES

In the area under aquifer mapping, thirty four Key Observation Wells (including Hand Pump and one Tube Well at Mahi Ka Danda) are distributed in various toposheets as given below:

Toposheet No. 53J/2: 1 KOW

Toposheet No. 53J/5: 3 KOWs

Toposheet No. 53J/6: 25 KOWs

Toposheet No. 53J/9: 3 KOWs

Toposheet No. 53J/10: 2 KOWs

The quadrant wise distribution of the Key Observation Wells is shown in ***Fig. 6.5.***

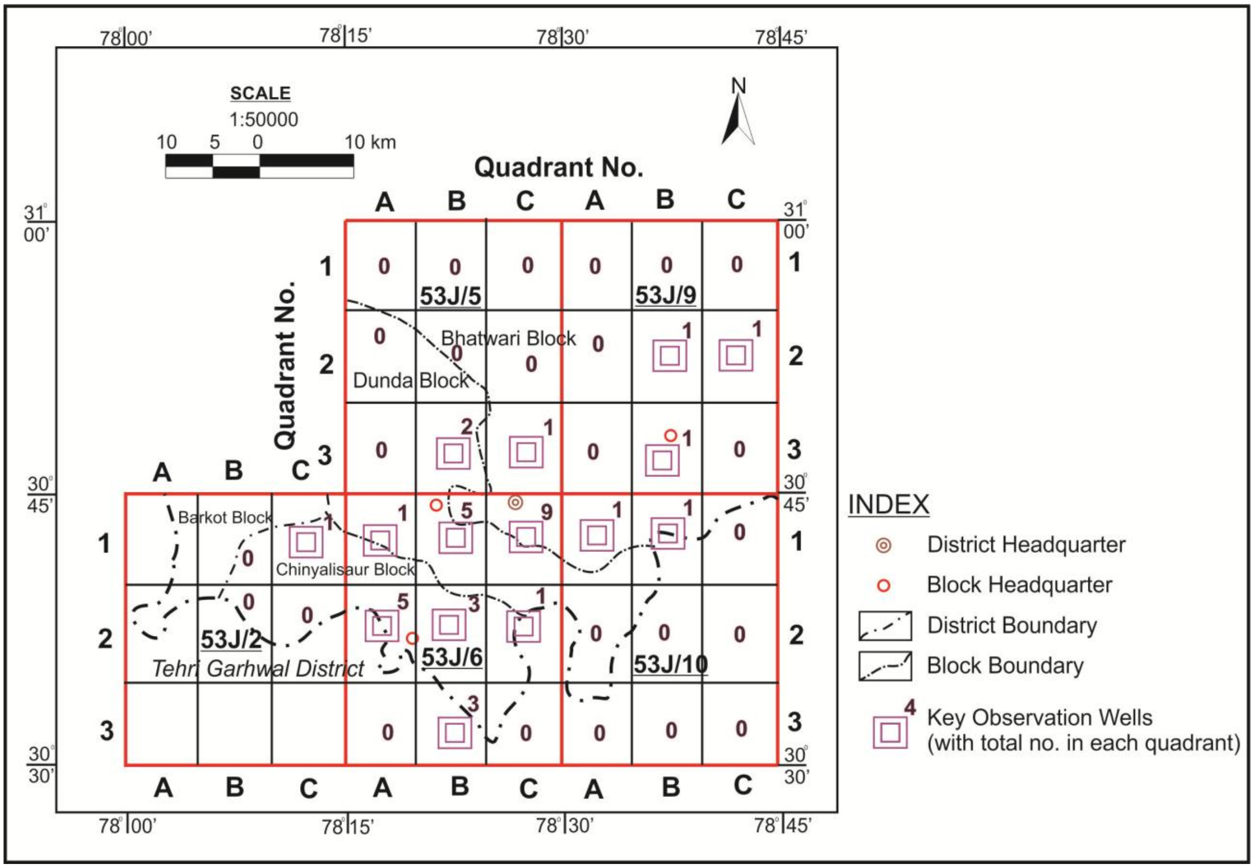


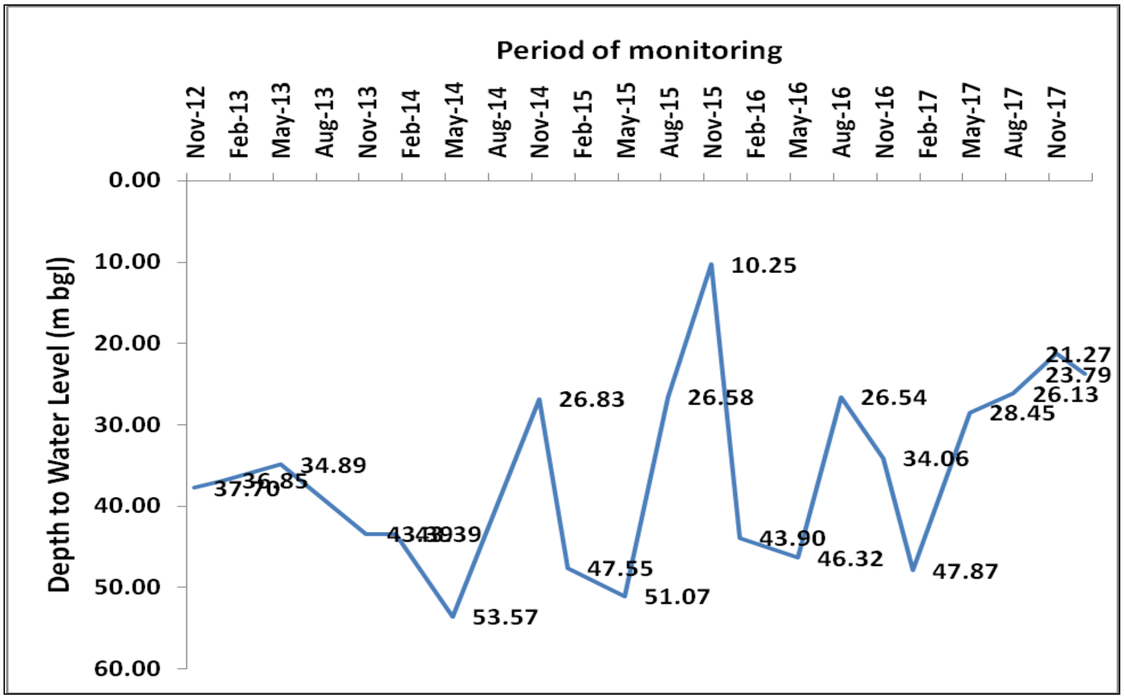
Fig. 6.5 Spatial distribution of Key Observation Wells in the area covered under Aquifer Mapping in Uttarkashi District (AAP: 2017-18)

6.4.1 Analysis of Depth to Water Level Data in Hand Pumps

In the study area, depth to water level (DTW) is monitored four times in a year since November 2012. The periodic monitoring data of six hand pumps has been analyzed to have an idea about the long-term variation in the DTW in parts of Chinyalisaur, Dunda and Bhatwari blocks, for the following Ground Water Monitoring Wells (GWMW):

Chinyalisaur, Devidhar (Nauliyasaur), Uttarkashi, Ganeshpur, Maneri and Charethi. Out of these, Ganeshpur, Maneri and Charethi fall in Bhatwari block and Devidhar falls in Dunda block.

Apart from the DTW data in the GWMWs, discharge of two cold water springs at Dharasu and Ratodi Sar and one thermal (hot) spring at Gangnani is also available, which has been collected over the years during groundwater regime monitoring in the area. These springs act as permanent Ground Water Monitoring Stations in the area. DTW data in the GWMWs and discharge data of springs are analyzed to know the local and regional groundwater regime and hydrogeological characteristics of major rock types like quartzite, schist, phyllite, slate etc. The



Well Hydrographs of the six GWMWs (bore wells fitted with hand pumps) are shown from ***Fig. 6.6*** to ***Fig. 6.11.***

Fig. 6.6 Well Hydrograph (GWMW) at Chinyalisaur (UK-HP-1)

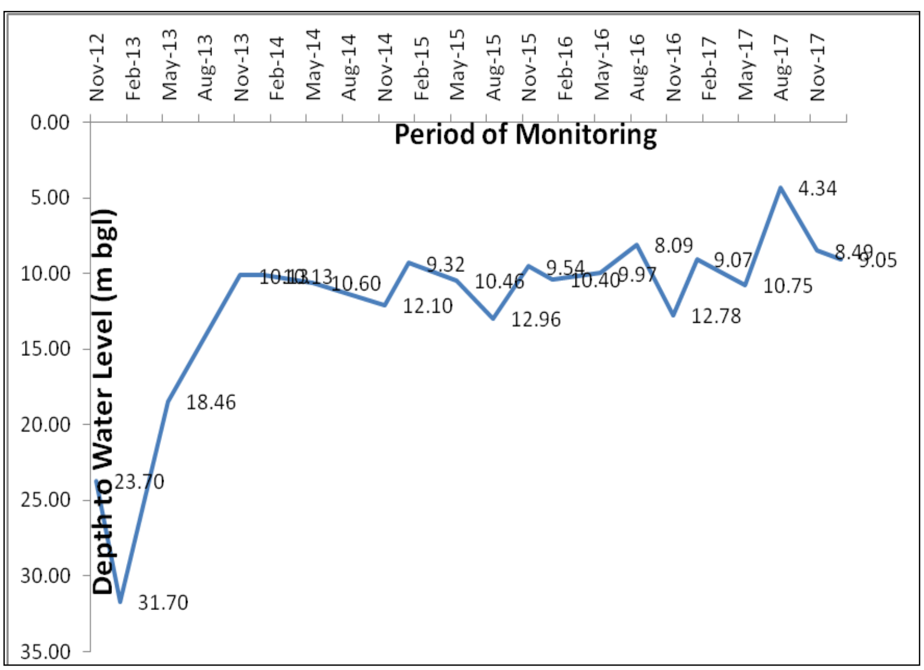
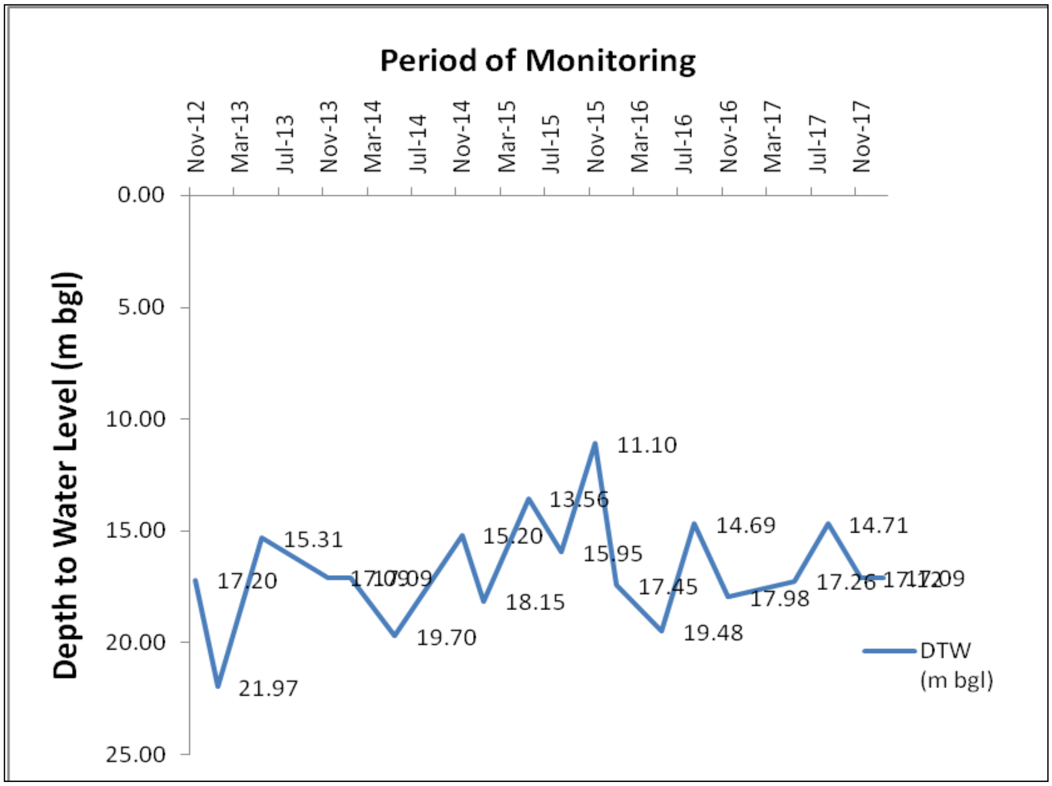


Fig.  *6.7 Well*

Hydrograph (GWMW) at Devidhar (UK-HP-2)

Fig. 6.8 Well Hydrograph (GWMW) at Uttarkashi (UK-HP-3)

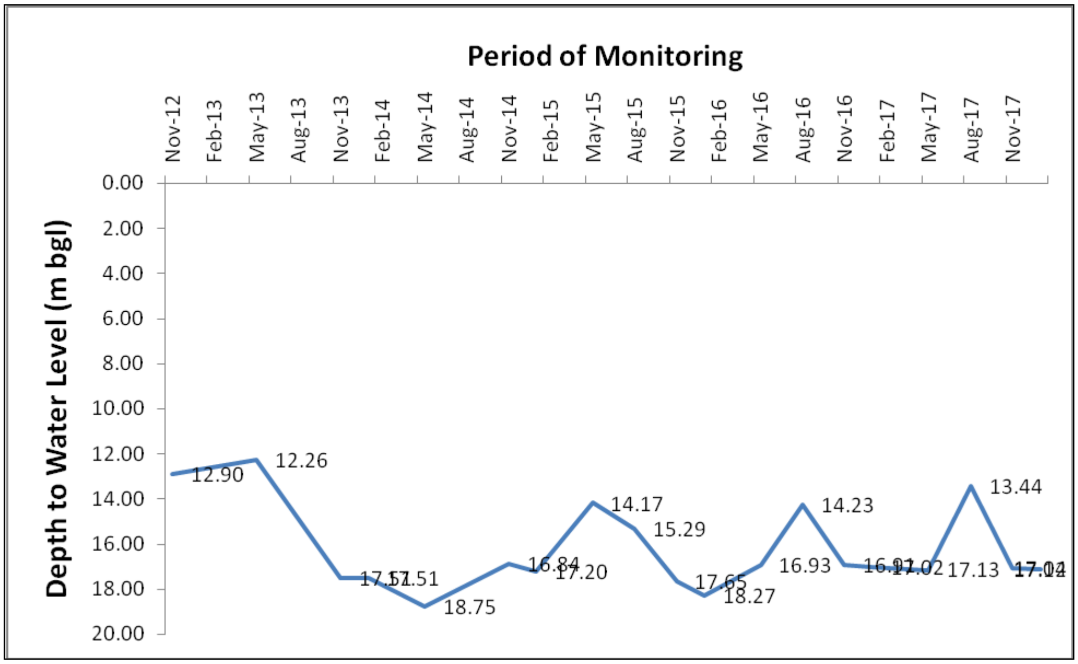


Fig. 6.9 Well Hydrograph (GWMW) at Ganeshpur (UK-HP-6)

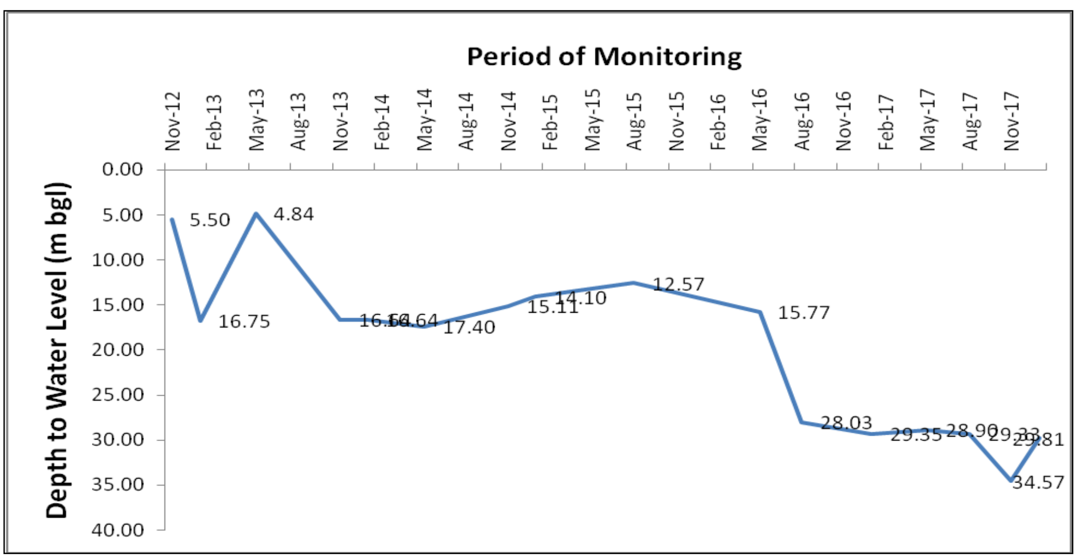


Fig. 6.10 Well Hydrograph (GWMW) at Maneri (UK-HP-7A)

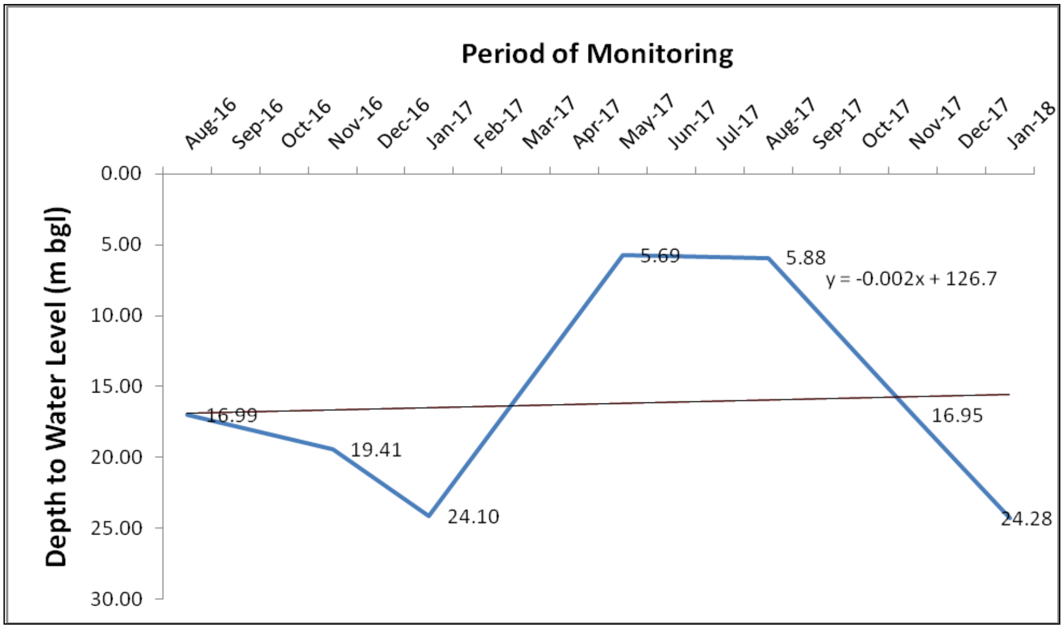


Fig. 6.11 Well Hydrograph (GWMW) at Charethi (UK-HP-8)

A perusal of the six Well Hydrographs reveals that at Chinyalisaur (***Fig. 6.6***), a fluctuating DTW trend is observed over the years, which can be best fitted with a 2 years moving average (MA) model of fit. From February 2017 onwards, a rapidly rising trend in DTW is observed, followed by a slightly declining trend in January 2018. At Devidhar (***Fig. 6.7***), the water level data shows that from November 2013 onwards, a more or less stable DTW condition is prevailing in the area, except for the short-term seasonal fluctuations in the pre-monsoon and post-monsoon periods. Similar DTW condition is also seen in the well hydrograph at Uttarkashi (***Fig. 6.8***), where no significant long-term rise or decline in groundwater table is observed. The Well Hydrograph of Ganeshpur (***Fig. 6.9***) shows an anomalous decline in DTW between pre-monsoon and post-monsoon 2013, which may be attributed to annual rainfall pattern and/or continuous use of the structure during post-monsoon monitoring, which may actually represent the Pumping Water Level in this hand pump. However, from November 2013 onwards, a regularly varying pattern in DTW, representing the seasonal water level fluctuation, is observed. The long-term trend in groundwater table does not show any rise or decline. Well Hydrograph at Maneri (***Fig. 6.10***) shows a typical condition wherein an existing hand pump had to be replaced with a new one in November 2016. The DTW variations clearly show two segments – from

November 2012 to November 2016 and from November 2016 onwards (till January 2018). Initially shallower DTW condition (~5 to ~15 m bgl) prevailed with no significant rise or decline in the DTW. However, due to deeper groundwater table in the replacement hand pump, there is sudden variation in DTW from ~15 m to ~30 m or so. Since then, the DTW shows very little variation in the groundwater table. Well hydrograph at Charethi (***Fig. 6.11***) is not quite representative of the long-term fluctuation in groundwater table as it was inventoried in August 2016. However, on the basis of linear regression of the DTW data, a slightly rising trend in the groundwater table is observed. More data points are required to establish the actual long-term variation at Charethi.

An important observation can be made from DTW variations in all the hydrographs, as the monitoring wells are located invariably in close proximity to Bhagirathi River (from 50 to 100 m) – all being situated on the right bank of the river. Due to the effect of Tehri Dam at Chinyalisaur area, wide variation in DTW in the Chinyalisaur hand pump was found from November 2012 onwards. This is attributed to periodic infillings of the reservoir (Tehri Dam), wherein high seasonal fluctuation is observed in the water level (stage) of the reservoir, which is hydraulically well connected with the fractured rock aquifers in the area. Such type of wide variation in DTW is absent in all the remaining well hydrographs. So it can be inferred that upstream of Chinyalisaur-Dharasu area, the localized, fractured aquifers do not have good hydraulic connection with Bhagirathi River.

6.4.2 Analysis of Discharge of Springs

Two cold-water springs at Dharasu (Chinyalisaur block) and Ratodi Sar (dunda block) and a hot spring at Gangnani (Bhatwari block) serve as the database for spring discharge analysis. The hydrographs, showing discharge variation in the springs at Dharasu, Ratodi Sar and Gangnani, are given in ***Fig. 6.12, Fig. 6.13*** and ***Fig. 6.14***, respectively. Out of these springs, Dharasu and Ratodi Sar are of cold-water type whereas the spring at Gangnani is of hot-water type. Due to absence of rainfall data at the respective locations, only the time series data on spring was used to prepare the spring hydrographs. A description of the spring hydrographs is given at the end of the figures.

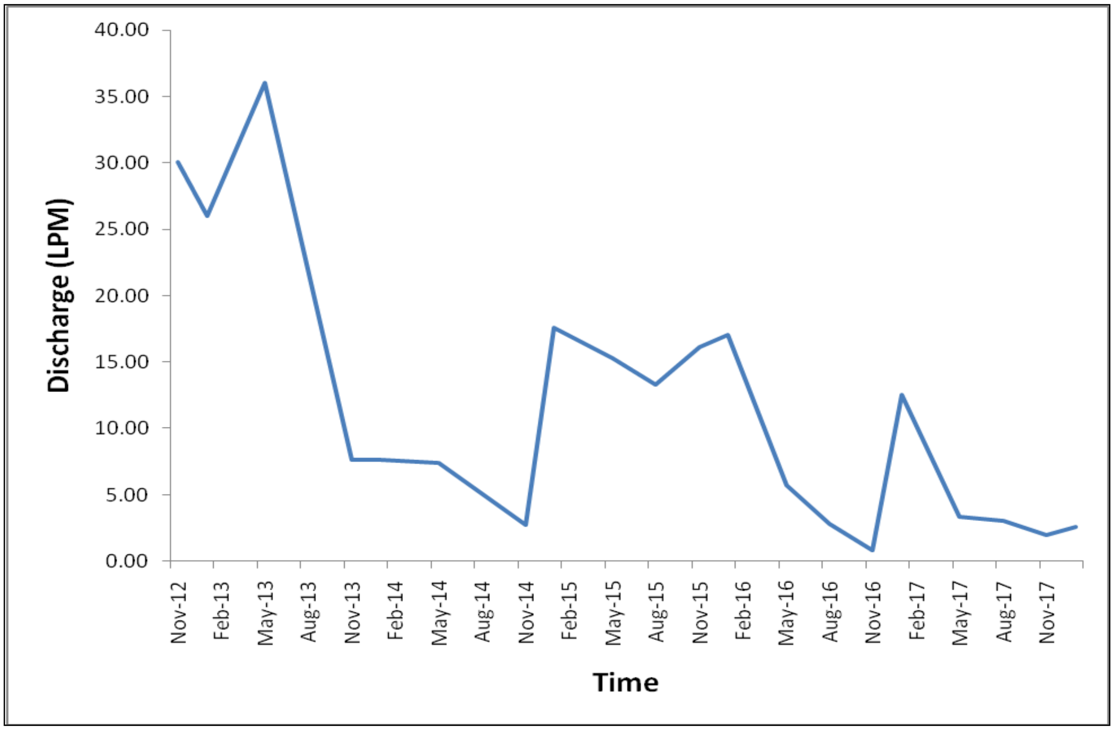


Fig. 6.12 Spring Hydrograph at Dharasu (UK-SP-1)

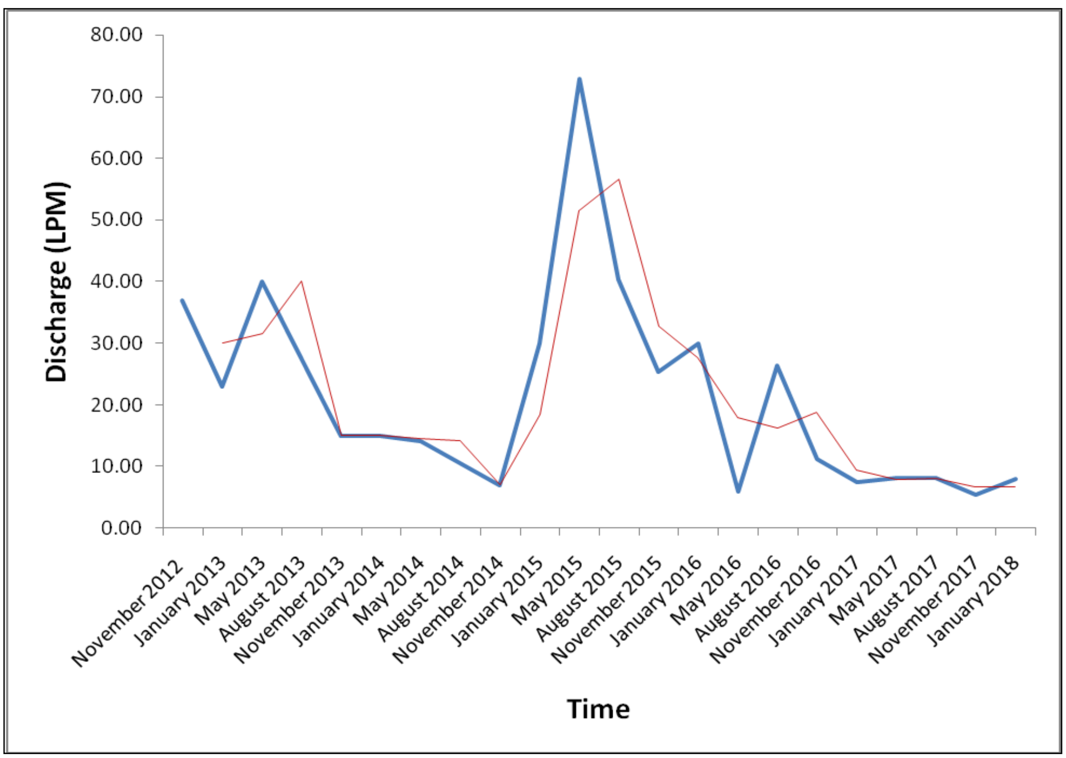


Fig. 6.13 Spring Hydrograph at Ratodi Sar (UK-SP-3)

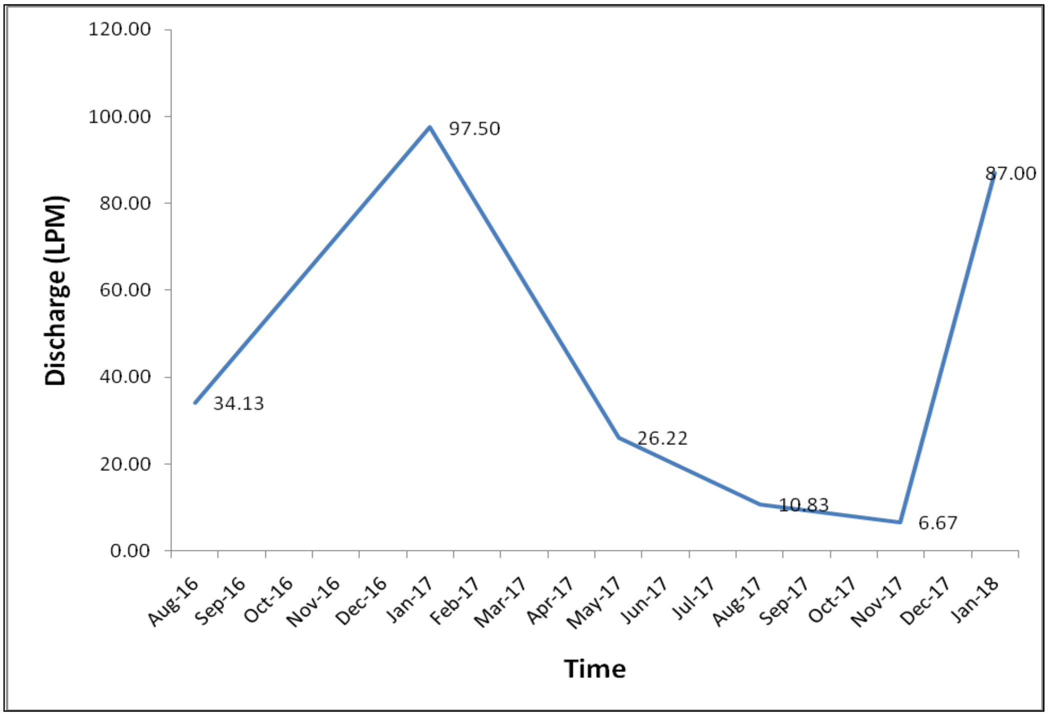


Fig. 6.14 Hydrograph of Hot Spring at Gangnani (UK-SP-4)

1. At Dharasu, the spring hydrograph (***Fig. 6.12)*** reveals that peak discharge was observed in the month of May, during the pre-monsoon period. Discharge was lowest invariably in the month of November, during the post-monsoon period. This is very surprising at first but may be attributed to isolation of the spring flow from the atmospheric system. In such case, rainfall does not directly contribute to increased discharge, rather it indicates that recharge area of this spring is possibly located far away from the outlet where discharge is currently measured.

2. The recharge area of Dharasu spring may also be affected due to anthropogenic cause like construction of roads, buildings etc. which disturbs the natural process of infiltration of rain water into the fractured rock aquifers.

3. Due to the proximity of Dharasu Thrust, the area is tectonically active. Hence landslides may occur near the discharge area (outlet) of the spring, which may block the major outlets and leads to emergence of the same spring in another location that is not being monitored presently.

4. Spring hydrograph at Ratodi Sar (***Fig. 6.13***) indicates a typical change in discharge (seasonal variation) but again the pre-monsoon discharge is invariably higher than the post-monsoon

discharge. The discharge variation can be best explained by a two-year Moving Average model, which is shown by red line.

5. The spring outlet is located in jointed and fractured quartzite. Hence this spring is categorized as a fracture/joint spring. In this case, the anomalous discharge pattern is attributed either to tectonic disturbance in the recharge area or to the remoteness of recharge area from the outlet.

6. A time lag of about eight months is observed in the peak discharge (in May) from the onset of monsoon (July/August of the following year), which can be best explained by isolation of the spring flow system from direct monsoon rainfall. The delay in infiltration and deep percolation may also be due to blockage in the flow pathway inside the fractured and jointed quartzite-schist host rock.

7. The contribution from winter rainfall was absent as increase in discharge was not observed in January.

8. As compared to the cold-water springs at Dharasu and Ratodi Sar, both of which are gravitational springs, the hot spring at Gangnani is a volcanic spring having deep seated origin. The spring hydrograph of Gangnani (***Fig. 6.14***) is of shorter duration viz. from August 2016 to January 2018. However, the discharge variation is typical of a hot spring as pre-monsoon (May) discharge is low compared to post-monsoon (January) discharge. Due to deep percolation, rain water gets heated up (due to high geothermal gradient) and emerges as a flow of hot water spring. The anomalous high discharge in January 2017 and January 2018 is attributed to measurement at the main source, instead at the two outlets in the bathing pond (*Rishi Kund*), where discharge is measured in May, August and November. During the peak winter season (December/January), the bathing pond is completely dewatered for cleaning and maintenance.

6.5 GROUNDWATER QUALITY STUDIES

6.5.1 Previous Work

Quality of groundwater in the aquifer mapping area was assessed on the basis of water samples collected from hand pumps, springs and occasionally from rivers during District Ground Water Management Studies in the AAP: 2005-06. A study of the complete chemical analysis of

83 water samples collected during the AAP: 2005-06 reveals the following variation in hydrochemical parameters.

Hydrogen Ion concentration (pH): The pH value was found to be ranging from 8.0 at several places (Matli, Netala, Didsari, Badhangaon, Badethi, Tilpar, Phari, Silkyara, Thati Dhanari, Manpur, Chaurangikhal, Sunagar, Barsu, Raithal, Gorsali, Jaunkani, Mahi Ka Danda etc.) to a maximum of 8.17 in a hand pump (HP) at Bhatwari.

Electrical Conductivity (EC): The EC was found to be varying within wide limits. Lowest EC of only 18 µS/cm was recorded in a spring at Bhatkot whereas the highest EC recorded was 1025 µS/cm in the hot spring at Gangnani, indicating the highly mineralized water. High EC of 599 µS/cm and 580 µS/cm were observed in the hand pumps at Peepal Mandi and Dharali, respectively.

Bicarbonate: Concentration of bicarbonate in groundwater shows a high variation. The lowest value was only 6.1 mg/L in a spring at Bhatkot, which was followed by 12 mg/L in another spring at Bagi. As expected, the highest bicarbonate was recorded in Gangnani hot spring, which was 525 mg/L. Higher values were also recorded in the Badethi HP (262 mg/L), Kalyani HP (250 mg/L) and Badhangaon spring (232 mg/L).

Total Hardness: The total hardness is expressed as concentration of calcium carbonate ($CaCO_3$). Total hardness (TH) of groundwater was found to be highly variable. The lowest TH recorded was 7.5 mg/L at Bhatkot spring, which was followed by 10 mg/L in two hand pumps at Gyansu and Badethi. The highest TH was 200 mg/L at Uttarkashi followed by 190 mg/L at Dharali. Surprisingly, TH of the highly mineralized Gangnani hot spring was only 80 mg/L.

Chloride: Chloride concentration in groundwater was found to be lowest (3.5 mg/L) in the cold-water springs at Bhatkot, Bagi, Mainola, Raithal, Gorsali and Jaunkani. Highest chloride of 85 mg/L was recorded in Gangnani hot spring, which was followed by 71 mg/L at Peepal Mandi hand pump and 57 mg/L in hand pumps at Maneri, Joshiyara and Dharali. The chloride concentrations show that groundwater is suitable for both drinking and agri-irrigational purpose.

Nitrate: Generally, groundwater is suitable for drinking as barring only two samples, nitrate concentration was found to be much below the Acceptable Limit of 45 mg/L (BIS, 2012). The lowest concentration of 0.19 mg/L was recorded at Lodara spring, followed by 0.28 mg/L at Bamangaon spring and 0.31 mg/L in Badali hand pump. Very high nitrate of 194 mg/L was recorded at Dharali hand pump, which was followed by 161 mg/L at Gangotri hand pump. Such abnormally high but sporadic values indicate anthropogenic contamination of water, attributed to the unhygienic practices like solid and liquid waste disposal adjacent to these hand pumps.

Sulphate: In 76 samples, out of total 83, sulphate in groundwater/surface water was below the detection limit. The lowest sulphate concentration was 4.8 mg/L at Uttarkashi whereas the highest concentration was 34 mg/L at Bogarigram (Mastari), which was followed by 20 mg/L in the hot spring at Gangnani. Higher sulphate concentration indicates high mineralization of water.

Fluoride: Fluoride concentration in 31 out of 78 groundwater samples (39.74% of total) was found to be below the detection limit. However, fluoride was present in all the 5 surface water samples collected from Bhagirathi River. In the river samples, concentration of fluoride was found to be ranging from 0.20 mg/L at Tiloth to 0.49 mg/L at Gangotri. Among the 47 samples containing fluoride, the lowest concentration was 0.10 mg/L at Chamyari spring and Bhetiara hand pump. Highest fluoride concentration was 1.0 mg/L at Malla hand pump, followed by 0.98 mg/L at Barsu spring and Gangnani hot spring. The range of fluoride in groundwater indicates its suitability for drinking purpose.

Calcium: Concentration of calcium was found to vary widely. The lowest concentration was only 2 mg/L at Bhatkot spring. Highest calcium concentration (52 mg/L) was recorded at Uttarkashi dug well and Bhalgaon spring. In Gangnani hot spring, calcium concentration was 24 mg/L.

Magnesium: Magnesium, another dominant cation in groundwater, was found to occur within wide limits. In groundwater samples, concentration of magnesium was highest (40 mg/L) in a hand pump at Kalyani. However, a spring at the same location has shown magnesium of only 2.4 mg/L. Lowest magnesium concentration of only 1.2 mg/L was found in springs at many places like Bagi, Raithal, Gorsali, Jaunkani and Salra and in a hand pump at Manpur. The Acceptable Limit of magnesium in drinking water is 30 mg/L with no relaxation (BIS, 2012). Apart from the hand pump at Kalyani, high magnesium was also recorded in hand pumps at Dharali (38 mg/L), Gangotri (36 mg/L), Hadiari (34 mg/L) and a spring at Siguni (34 mg/L). Long-term consumption of water from such sources may be detrimental to health, particularly due to the known laxative effect of magnesium.

Sodium: Concentration of sodium in groundwater samples was found to vary widely. Extremely high sodium in groundwater (221 mg/L) was recorded at Gangnani hot spring. Along with very high potassium, very high sodium in spring water is indicative of its volcanic source, wherein sodium and potassium were released in the water during rock-water interaction at a high temperature. Relatively high sodium was also observed in hand pumps at Badethi (46 mg/L), Peepal Mandi (39 mg/L), Joshiyara (38 mg/L) and Malla (36 mg/L). Lowest concentration of sodium in groundwater was 0.7 mg/L at Lodara spring followed by 0.8 mg/L at Bhatkot spring.

Potassium: As with sodium, concentration of potassium in groundwater was found to vary within wide limits. Very high potassium (22 mg/L) was recorded at Gangnani hot spring. However, highest potassium concentration of 68 mg/L was recorded at Dharali hand pump. Very low potassium was usually found in cold-water springs viz. 0.1 mg/L at Pheri, 0.2 mg/L at Bhatkot and 0.3 mg/L at Lodara.

Overall, it was found that groundwater in the study area is suitable for drinking, domestic and agri-irrigational use as concentration of all major inorganic constituents and physico-chemical parameters were well within the permissible limit of the revised BIS Guidelines on Drinking Water (BIS, 2012). Even the hydrochemistry of five surface water (river) samples indicate their suitability for drinking and domestic purpose.

6.5.2 Present Work

During the course of aquifer mapping study (AAP: 2017-18), twenty one normal samples and one acid treated sample (for heavy metal analysis) were collected during the pre-monsoon period. In post-monsoon, six normal samples and three acid treated samples were collected. The details of samples from hand pumps and Mahi Ka Danda tube well are given in ***Table 6.3.***

Table 6.3 Details of water samples collected for chemical analysis (AAP: 2017-18)

Sl. No.	**Location**	**Sample No.**
1. Samples collected in Pre-monsoon		
1.1 Normal Samples (for complete chemical analysis)		
1	Morgi	53J/6-2A-Morgi HP Normal
2	Geunla	53J/5-3B-Geunla HP Normal
3	Sunargaon	53J/6-3B-Sunargaon HP Normal
4	N.I.M. Uttarkashi	53J/6-1C-NIM HP Normal
5	Baldogi	53J/6-3B-Baldogi HP Normal
6	Jestwari	53J/6-2A-Jestwari HP Normal
7	Chinyalisaur	53J/6-2A-01- HP Normal

8	Lata Sera	53J/9-3B-Lata Sera HP Normal
9	Hina	53J/10-1A-Hina HP Normal
10	Matli	53J/6-1B-Matli HP Normal
11	Chaurangikhal	53J/6-2C-Chaurangikhal HP Normal
12	Pipli Dhanari	53J/6-2B-Pipli HP Normal
13	Mahi Ka Danda (ITBP)	53J/5-3C-Mahidanda TW Normal
14	Dikoli	53J/6-2A-Dikoli HP Normal
15	Brahmkhal	53J/6-1A-Brahmkhal HP Normal
16	Dunda	53J/6-2B-Dunda HP Normal
17	Mustiksaur (Mastari)	53J/6-1C-Mustiksaur HP Normal
18	Pheri	53J/6-2A-Pheri HP Normal
19	Tulyara	53J/6-2B-Tulyara HP Normal
20	Aleth	53J/6-1C-Aleth HP Normal
21	Joshiyara	53J/6-1C-Joshiyara HP Normal
1.2 Acid Treated Samples (for heavy metal analysis)		
22	Mahi Ka Danda (ITBP)	Mahidanda TW Heavy Metals
2. Samples collected in Post-monsoon		
2.1 Normal Samples (for complete chemical analysis)		
23	Joshiyara	53J/6-Joshiyara HP Normal
24	Banchaura	53J/2-Banchaura HP Normal
25	Baun	53J/5-Baun HP Normal
26	Dikholi	53J/10-Dikholi HP Normal
27	Jhala	53I/12-Jhala HP Normal
28	Mando	53J/6-Mando HP Normal
2.2 Acid Treated Samples (for heavy metal analysis)		
29	Joshiyara	53J/6-Joshiyara HP-Heavy Metals
30	Banchaura	53J/2-Banchaura HP-Heavy Metals
31	Baun	53J/5-Baun HP-Heavy Metals

The samples were sent for chemical analysis in the Chemical Lab of Northern Region, Lucknow. Till the time of writing of this report, the chemical analysis results are not available. After availability of the analysis results, it would be possible to reveal the present hydrochemical scenario in the aquifer mapping area. It would also be possible to ascertain change in hydrochemistry of groundwater, if any, by comparing it with the hydrochemical data generated during previous studies.

CHAPTER 7

AQUIFER MANAGEMENT PLAN

Delineation of subsurface geology in major part of the study area is not possible due to absence of bore hole/pilot hole data (up to a depth of 100 m) for classification of the first aquifer. Aquifer mapping in project mode was undertaken, as mandated under the guidelines, for one calendar year viz. from April 2017 to March 2018. Due to the accessibility problems, drilling sites can be selected adjacent to all-weather motorable roads. The fractured/fissured hard rock aquifers in the area are localized and discontinuous, thereby precluding any correlation of subsurface geology. However, based on the Survey of India toposheets, geological maps and thematic maps of National Remote Sensing Centre, an attempt was made to delineate areas suitable for groundwater recharge and development, as shown in ***Fig. 7.1***. Such areas are found to occur in toposheet no. 53J/6. Areas suitable for groundwater recharge and sustainable development are demarcated based on the following criteria:

1. Accessibility viz. location of recharge structures along motorable roads.
2. Suitable geomorphological landforms like valleys of Bhagirathi River, river terraces (mostly paired).
3. Lineament Density, which indicates the number of lineaments per sq. km.
4. Proximity to a village or a habitation.

High lineament density (indicated by blue colour in ***Fig. 7.1***) indicates higher prospect of groundwater occurrence. Intersection of lineaments is particularly important as groundwater flow paths are channelized along such zones of weakness. Highly undulating, mountainous topography is characterized by structural hills that constitute the run-off zones and are therefore, not suitable for groundwater development. On the basis of overlapping zones of valley/river terrace with zones of very high lineament density, few zones having relatively high groundwater potential are delineated and shown in ***Fig. 7.1.***

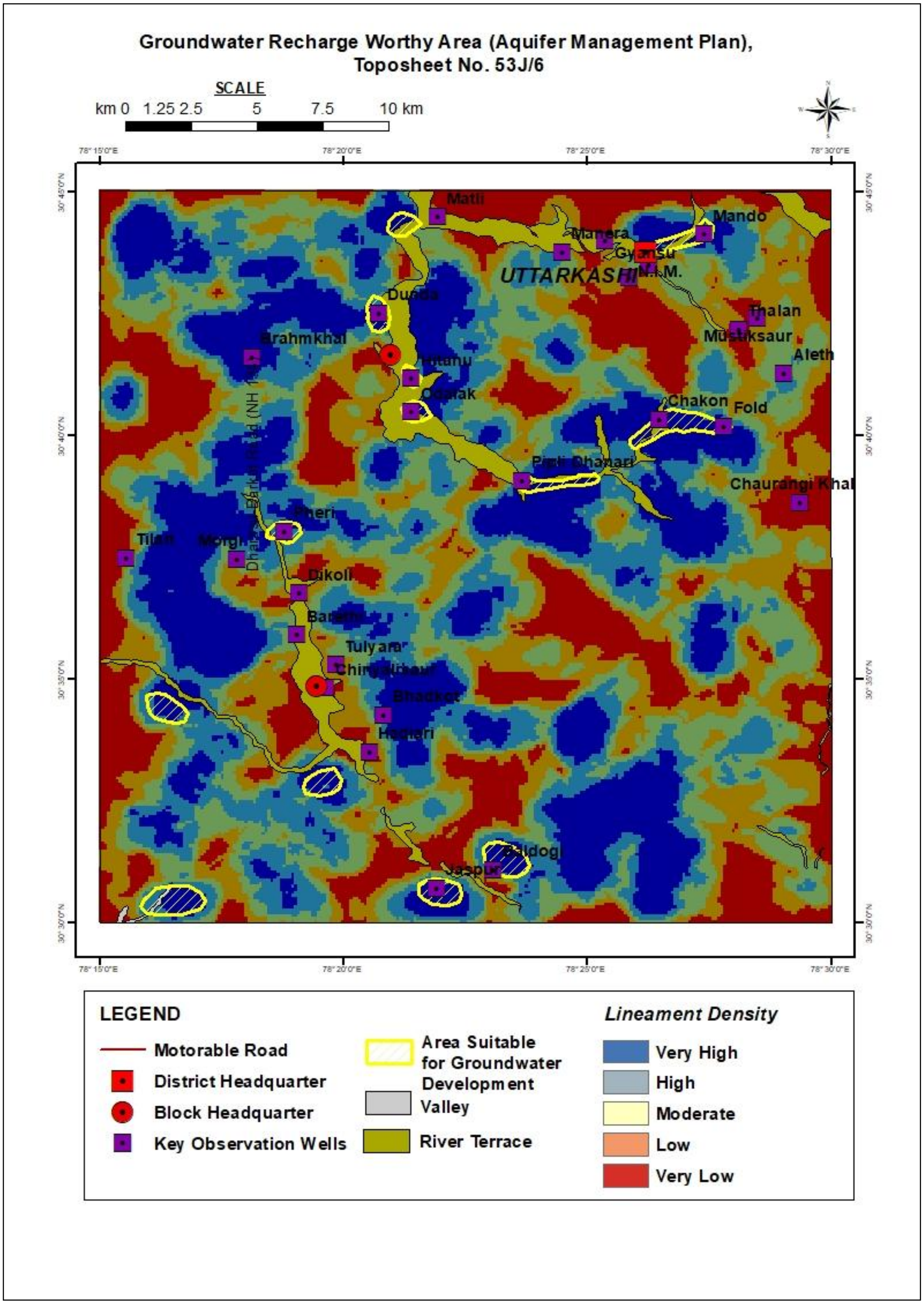


Fig. 7.1 Aquifer Management Plan showing areas suitable for groundwater Development, Toposheet No. 53J/6, Uttarkashi District

In areas suitable for groundwater development that are also close to the villages/habitations, bore wells having diameter of 6 inch or mini tube wells having diameter of 10 inch or more may be drilled to fully utilize the existing groundwater potential. Such zones are tectonically stable with low landslide hazard potential, as they are located in either plain or very gently sloping tracts that are characteristic of river valley and paired river terrace. Unpaired river terraces develop due to tectonic activities like faulting and/or destabilization of the local topography, so they should be avoided while selecting areas suitable for groundwater development and recharge.

A perusal of ***Fig. 7.1*** shows groundwater worthy areas in and around the KOWs at Jaspur, Baldogi, Pheri and to the south-west of Hadiari, all located in Chinyalisaur block. In Dunda block, such areas occur as small, elongated zones in and around Pipli Dhanari, Chakon, Fold and Dundagaon. In Bhatwari block, groundwater worthy area is restricted around Gyansu-Mando section in the north eastern part of toposheet no. 53J/6. Though the Bhagirathi Valley is relatively well developed from Matli in the west to Hina in the east, groundwater worthy areas are restricted due to relatively low lineament density. In this area, mostly massive quartzite and limestone are found along the road and river section. However, about 1 km west of Matli, a groundwater worthy zone has been delineated, which is suitable for construction of a tube well and/or implementation of artificial recharge scheme in the fractured rock aquifer.

The scope of groundwater development in toposheet no. 53J/9 (Bhatwari block) is limited as compared to toposheet no. 53J/6. Main reasons for the low groundwater potential in this area are a) narrowing of Bhagirathi Valley, b) extensive occurrence of highly dissected structural hills, which are the major run-off zones, c) relatively massive and un-fractured rocks of the Central Crystalline Group, occurring to the north of the Main Central Thrust and Vaikrita Thrust, d) overall low lineament density. However, a map showing areas suitable for limited groundwater development in toposheet no. 53J/9 has been prepared, which is shown in ***Fig. 7.2.*** A perusal of this map indicates that areas suitable for groundwater development occur to the east, north and south west of Loharinag on the Uttarkashi-Gangotri road. Due to absence of hand pump in this area, the concerned state government departments may be advised to utilize the available groundwater potential. Construction of bore wells may be taken up to increase the very low existing groundwater development. The area also falls in the popular *Char Dham Yatra*

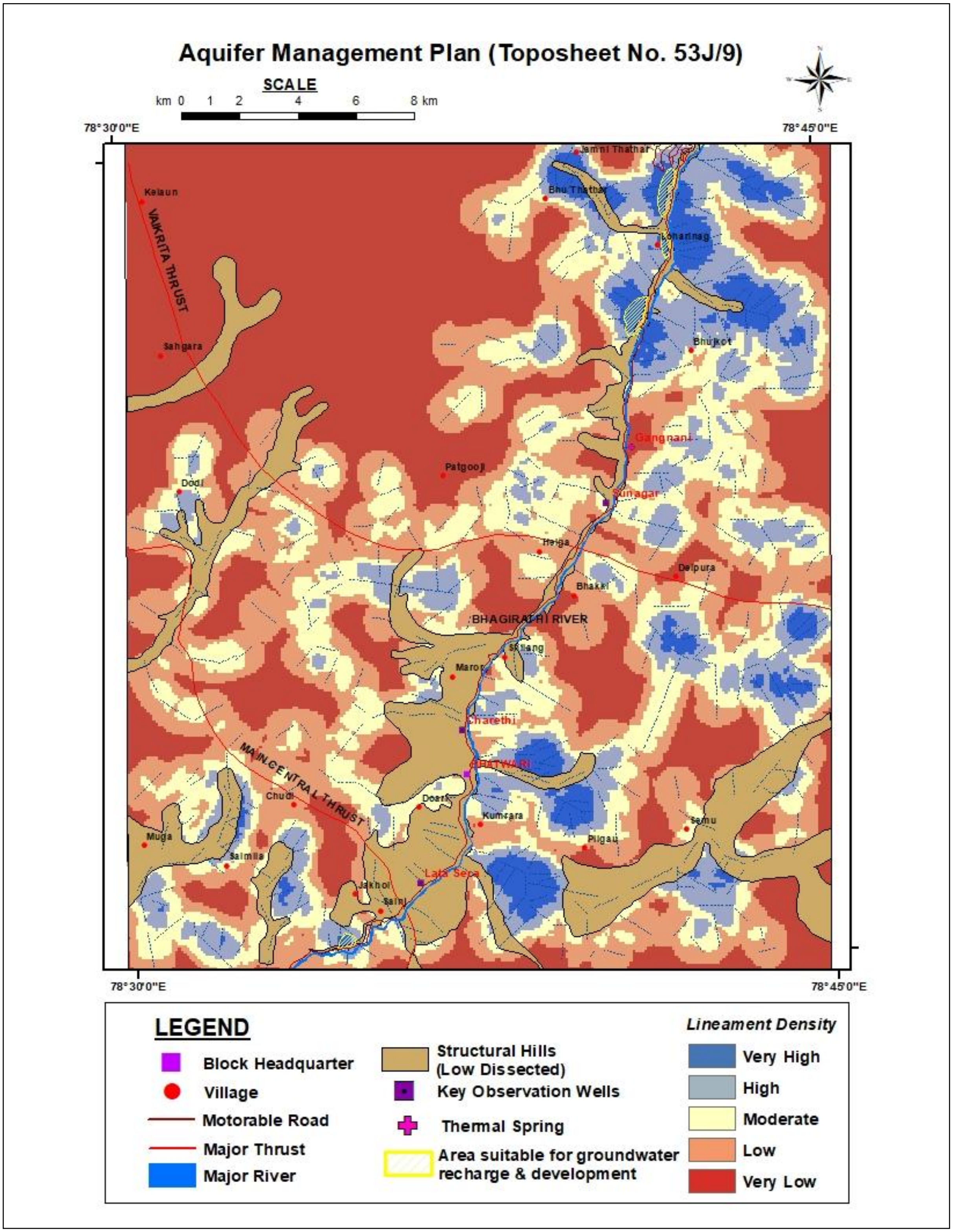


Fig. 7.2 Aquifer Management Plan showing areas having limited scope of groundwater development, Toposheet No. 53J/9, Uttarkashi District

route. Similarly, construction of bore wells may be taken up to the south west of Sainj in the same motorable road.

Another component of aquifer management is utilization of the groundwater of thermal spring at Gangnani. Due to the highly mineralized water having sulphurous smell, volcanic rock aquifers of this area need judicious use of spring water. As the hot spring water has a high therapeutic value, local eco-tourism can be developed in the area, particularly due to its location on the popular *Char Dham Yatra* route. However, intensive study needs to be taken up in this direction.

7.1 SUPPLY SIDE MANAGEMENT

Supply side management of water resources focuses on increasing the volume of water available through many ways like a) finding new resources, b) increasing storage capacity, c) diverting water to increase water supply at a particular location and d) using technology to create clean, potable water from a previously unutilized source. The techniques employed for increasing water supply are often expensive, meaning that places with fewer financial and technological resources are unable to implement them easily.

The supply side management of the aquifer management plan envisages the potential of water supply from natural sources (springs, gadheras) and man-made sources (hand pumps and mini tube wells) within the study area. The following points may be considered for supply side management in Chinyalisaur, Dunda and Bhatwari blocks of Uttarkashi district:

1. Water storage-cum-conservation structures may be constructed at places having gently sloping topography and easy approachability conditions. In toposheet no. 53J/6, areas suitable for groundwater development may be initially earmarked for construction of *chals* and *khals.* Through these, open channel (*guhl*) or closed channel (pipe) based flow irrigation system may be developed for increasing the water availability in water scarcity areas like peri-urban and urban centres e.g. Dunda, Barethi, Dharasu, Uttarkashi, Joshiyara and Matli.

2. Overall, the groundwater development is very low and there are no groundwater based irrigation system in the area. For increasing the unutilized potential, spring based water storage and distribution system (locally known as *hauz* system) may be developed on perennial springs at Dharasu (Barethi), Ratodi Sar and Netala. On the basis of long-term discharge data of Ratodi

Sar and Dharasu springs, annual water availability has been determined. The average long-term discharge of Dharasu spring was 19.14 LPM while that at Ratodi Sar was 21.52 LPM. Compared to these figures, the average discharge of Gangnani hot spring was much higher – 43.73 LPM, though the discharge calculations are made on the basis of only eight measurements from August 2016 to January 2018. Water resource potential of these three springs is as follows:

Dharasu spring: 10060 m^3/year, Ratodi Sar spring: 11311 m^3/year and Gangnani hot spring: 22984 m^3/year.

3. Although many springs are tapped by gravity schemes by the state government agencies and gram panchayats (e.g. Jestwari spring in Chinyalisaur block, Bagsari spring in Dunda block), it is observed that the concept of rain water harvesting is almost non-existent in the area. Due to the high rainfall in this part of Lesser Himalaya, there is tremendous potential of both roof top and open area rain water harvesting. Site-specific studies are required in this direction. The studies may be taken up in association with state government departments, self help groups and NGOs working in water sector.

4. Artificial recharge in Uttarkashi Formation may not be feasible due to presence of limestone, which may be dissolved in rain water and due to high slope, the velocity of storm water run-off will also be very high. As such, there is risk of slope failure and landslide due to increase in pore water pressure in limestone country rock. However, in other areas where quartzite, schist, phyllite, metabasic rocks and granitoids are exposed, managed aquifer recharge in the shallow fractured aquifers may be recommended after detailed hydrogeological and geophysical survey.

5. Based on the data of Uttarakhand Jal Sansthan, Uttarkashi average discharge of 10 inch dia. mini tube wells (near the banks of Bhagirathi River) is 1635 LPM, which is very high considering the hydrogeology of the area. The high discharge is attributed to hydraulic connectivity between the fractured rock aquifers and the perennial Bhagirathi River. Considering average running period of 5 hours in a day, the annual water availability has been worked out at 179032.50 m^3 or ~0.18 MCM. A well planned water supply and distribution system is being developed at Uttarkashi town, wherein the groundwater resources can play a pivotal role.

6. Due to the huge annual discharge (~23000 m^3/year) of water from the Gangnani hot spring, a very good scope exists for development of spring-based eco-tourism. This is more relevant as Gangnani is located in the prominent *Char Dham Yatra* route. The hot spring water may be

useful in treating various skin diseases like dermatitis, psoriasis, eczema and ichthyosis. The local administration should take proactive action in this direction.

7. To sum up the components of a holistic supply side management initiative in the aquifer mapping area, it is imperative that increase in Water Use Efficiency (WUE) practices and change in cropping pattern (depending on actual site conditions) are to be adopted on priority so that the groundwater resources potential may be utilized in an optimal manner.

7.2 DEMAND SIDE MANAGEMENT

Demand side water management can be defined as reducing the volume of water that is being used by the stakeholders for specific purposes like household use, farming, municipal or industrial needs. The main objective of demand side water management is to increase the Water Use Efficiency (WUE) throughout the year. In the present context, the demand side management of the Aquifer Management Plan is complex due to inadequate knowledge on groundwater management practices, non-existence of NGOs working in the water sector, seasonally variable groundwater demand (which peaks in the *Yatra Season* from April/May to October), lack of awareness on water resources augmentation and conservation measures – even among majority of literate people (local residents) and lack of capacity building initiatives coupled with social and behavioral issues.

Major aspects of the demand side Aquifer Management Plan in the study area are enumerated below:

1. For reducing demand and curbing wastage of precious groundwater, a spring box may be constructed wherever spring discharge is not very high (<60 LPM) so as to protect the spring sources from anthropogenic contamination, provide sedimentation and minimize the surface run off.

2. Water User Agencies (WUA) may be constituted to protect and conserve the pristine spring source e.g. by fencing around the source so as to prohibit grazing and trampling by animals and unhygienic practices by the local populace near the spring source. A corpus fund may be made at the village or community level so that the objectives of participatory groundwater management are fulfilled.

3. Due to negligible recharge to shallow, localized, fractured rock aquifers, suitable methods of water conservation need to be implemented on priority, preferably in Chinyalisaur and Dunda blocks in toposheet no. 53J/6/. Second order streams are to be considered first due to relatively higher water availability so that water resources augmentation may be done. Staggered and/or continuous contour trench, gully plug, vegetative barrier (check dam, gabion) may be constructed at suitable locations after ground hydrogeological survey.

4. In order to reduce wasteful use of groundwater in the hilly terrain, capacity building programmes need to be organized at block and/or village level so that local farmers, villagers and gram panchayat members understand the importance of water conservation and reducing wastage of the precious water resource.

5. Instead of the traditional *guhl* system of irrigation, wherein water flows in open channels, it is always better to adopt flow distribution system with minimal distribution loss. So, it is recommended that piped water supply system should be adopted for a better WUE. If the buried piped water supply system is adopted for irrigational use, the possibility of damage to the pipe lines (which results in huge distribution loss) would become minimal. This is an important aspect of the water resources management, keeping in mind the structural and tectonic disturbance prevalent in the Lesser and Central Himalaya.

6. Wherever possible, change in cropping pattern has to be adopted. For example, in parts of Chinyalisaur block, cropping pattern may be changed from paddy, which is a water intensive crop, to soyabean or maize, which has less crop water requirement. Moreover, advanced irrigation practices like sprinkler or drip irrigation should be adopted depending on the technological feasibility and economic viability. Krishi Vikas Kendra, Chinyalisaur can play a guiding role in this direction.

7. The substantial water demand of floating population during *Yatra Season* can be mitigated by creating awareness on importance of efficient water use practices among the economically affluent tourist population. Bathtubs and showers may be utilized to a minimum in the big tourist resorts and luxury hotels on Uttarkashi-Gangotri road so that demand side management can be effectively implemented through lifestyle changes.

8. An effective participatory groundwater management programme involving the local community, NGOs or Self Help Groups should be implemented on priority by the policy makers, planners and administrators.

CHAPTER 8

CONCLUSION

On the basis of findings of the aquifer mapping work in parts of District Uttarkashi (area covered: 2000 km^2), the following points are concluded:

- Along Bhagirathi River, basin fill or valley fill aquifers are formed in depressions caused by faulting or erosion or both.
- Springs located in Bhagirathi Valley occur in three different lithological types viz. (a) phyllite-schist-slate assemblage, (b) low-grade quartzite with associated schist and gneiss and (c) high-grade quartzite, granite and gneiss in the Central Himalaya.
- Discharge analysis of sixteen cold-water and one thermal spring shows that during pre-monsoon, highest discharge (25.16 LPM) was recorded at Kalyani whereas lowest discharge (0.08 LPM) was at Diwarikhol.
- About 47% of the springs revealed anomalous discharge, wherein post-monsoon discharge is reduced compared to that of pre-monsoon. This is attributed to several factors like widening of roads, disturbance of recharge area caused by landslides and blockage of main orifice of the spring sources where discharge was measured.
- High reported discharge (>1200 LPM) in two mini tube wells at Joshiyara and Gyansu is attributed to strong hydraulic connectivity between Bhagirathi River and the fractured rock aquifers feeding the tube wells.
- In general, moderately high groundwater potential exists in areas having gentler slopes and lying in close proximity to Bhagirathi River.
- Depth to water level (DTW) analysis in thirty eight bore wells fitted with India Mark-II hand pumps (Key Observation Wells) inventoried during this study indicates 61.11% of the KOWs have DTW in the range >20-30 m bgl followed successively by 26.32% (>30-50 m bgl) and 2.63% (0-5 m bgl and >50 m bgl).
- During pre-monsoon 2017, the deepest water level of 62.05 m bgl was recorded at the Key Observation Well (KOW) at Baun whereas the shallowest (3.48 m bgl) was observed in the KOW at Chakon.

- Due to unavailability of subsurface geological data, delineation of Preliminary Aquifer Boundaries and Units is not possible.
- Analysis of drilling data of hand pumps indicates that the thickness of overburden is varying from 75 to 90 m, below which lies the basement comprising hard, crystalline rocks.
- On the basis of local geological, geomorphological, hydrogeological and approachability factors, it was found that quadrant no. 2A, 1B and 1C of toposheet no. 53J/6 are most suitable for construction of exploratory wells so that aquifer geometry and aquifer parameters (hydraulic conductivity, transmissivity, storage co-efficient) can be determined though pumping test.
- Sites selected for Vertical Electrical Sounding at Dundagaon, Nalupani, Chinyalisaur, Manera and Hina will be utilized to investigate the subsurface geological and hydrogeological condition in the depth range varying from ~25 m to ~50 m.
- Well hydrographs of ground water monitoring wells at Chinyalisaur, Uttarkashi, Ganeshpur, Maneri and Charethi, prepared using available time series data, shows variable scenarios of groundwater level fluctuations. Fluctuating, steady (neither rise nor decline), slightly declining and slightly rising trends in depth to water levels were observed.
- High fluctuation in depth to water level at Chinyalisaur hand pump is attributed to periodic rise and decline in the water level (stage) of the Tehri Dam (reservoir), which is hydraulically connected with the fractured rock aquifers of Chinyalisaur area.
- Spring hydrographs at Dharasu and Ratodi Sar indicates anomalous discharge pattern wherein pre-monsoon discharge exceeds the post-monsoon discharge. This is attributed to factors like (a) tectonic disturbance/landslide in the recharge area, (b) isolation of spring flow system from precipitation, (c) blockage in the spring flow pathway inside the fractured and/or jointed rock aquifers and (d) negligible or no contribution from the winter rainfall.
- On the basis of hydrochemical data generated during previous studies, it is concluded that groundwater is suitable for drinking purpose, except for sporadically high concentrations of nitrate (Dharali and Gangotri), high magnesium (Kalyani, Dharali, Gangotri, Hadiari and Siguni) and high total hardness (Uttarkashi and Dharali).
- Integration of parameters like (a) condition of accessibility, (b) proximity to a village/habitation, (c) suitable geomorphological landforms, (d) variability in ground slope

and (e) lineament density has resulted in demarcation of zones having high groundwater potential.

- The high groundwater potential zones or *groundwater worthy areas* are suitable for moderate groundwater development in toposheet no. 53J/6 falling under the Lesser Himalaya. Thus an Aquifer Management Plan is prepared for a part of the study area, falling in toposheet no. 53J/6.
- Other parts of the study area (toposheet nos. 53J/2, J/5 and J/10) are excluded in the Aquifer Management Plan due to high tectonic activity, massive and un-weathered country rocks, problems of accessibility and low lineament density.
- On the basis of Aquifer Management Plan, *groundwater worthy areas* occur at Jaspur, Baldogi, Pheri, south west of Hadiari, in and around Pipli Dhanari, Fold, Chakon, Dundagaon, around Gyansu-Mando section and about 1 km west of Matli.
- Comprehensive supply side and demand side management plans may be formulated for increasing water use efficiency and Minimizing wastage of water resources.
- The perennial cold-water springs and thermal spring at Gangnani have substantial water resources potential of about 44000 m^3/year. There is an urgent necessity of harvesting the unutilized water resources keeping in mind the low groundwater development in the area.
- As the area receives substantial rainfall during monsoon period, there is very good scope of sustainable water resources management through adoption of roof top rain water harvesting. The practice may be initiated in government buildings like district collectorate, hospital, government colleges and schools and can be followed up by private hotel and resort owners.
- Participatory groundwater management should be taken up at village and community levels through the gram panchayat/Panchayat Raj Institutes, local NGOs and self help groups. The district administration should be more proactive in addressing the issues of water scarcity and contamination.
- Trainings on water conservation, rainwater harvesting and watershed management may be organized at village and/or block level so that the local populace, farmers and state government officials working in water sector may become aware about various techniques of sustainable groundwater management including springshed management and integrated watershed management practices.

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