Geo-Hydrological Studies for Augmentation of Spring Discharge in the Western Himalaya

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CHAPTER-1

INTRODUCTION

In the western Himalayan mountains springs are the main sources of fresh water for drinking and other household use. Springs occur where sloping ground and impermeable strata intersect with the ground water table. The water sources of such springs, in most cases are unconfined aquifers where the water flows under gravity. Spring water discharge fluctuations owe primarily due to rainfall pattern in the recharge area or more precisely stated, to variation in the amount of rainwater that is able to infiltrate the ground and recharge the ground water. Marked variation in the discharge following rainfall indicates rapid infiltration of rainwater and recharge of the groundwater in colluvial-related springs, and discharge curves show strongly periodic seasonal rhythm. Superimposed on these variations is a periodic (monthly) fluctuation resulting from occasional heavy rainfalls, generally in the rainy season. Following rain, water starts to percolate down through the soil stratum. The recharge of groundwater augments the discharge of the springs and seepages, and thus, causes more rapid outflow of the ground water. The high rate of discharge lowers the water table, reduces its gradient, and diminishes the pressure in pore spaces. This transience in recharge and discharge is the cause of the seasonal, local, and short-term fluctuations in spring water yield.

Plate 1: A spring in the western Himalayan mountains (note the water flowing from the source in the middle of the picture)

In the geo-dynamically young Himalayan ecosystem the fragile mountain slopes are tectonically active and potentially erosive. Anthropogenic activities are continuously disturbing the natural system of the Himalayan environment, impacts of which can be seen in the hydrological behaviour of streams and springs (Singh & Rawat, 1985; Valdiya & Bartarya, 1989; Valdiya et. al., 1994; Negi et. al., 1998; Negi, 2001, 2004; Negi & Joshi, 2004). Fluctuation of water discharge in different seasons and increasing amount of sediment load in streams are one of the most important problems of the Himalaya. Preliminary studies conducted on this subject indicate that human interference, unscientific developmental activities, agriculture extension and unplanned way of road construction are some of the activities which are creating the hydrological imbalances in the region (Singh and Pande, 1989; Rawat et al., 1989). Rawat and Rawat (1994) determined the rate of discharge, sediment load and rate of erosion in the Nana Kosi watershed of Kumaun Himalaya and reported that the annual discharge from the springs has been reduced by about 50%. Rawat (1993) worked out geohydrology of springs in a part of Garhwal Himalaya. In this region spring water yield both during rainy and non-rainy seasons has been found to be affected by both rainfall and the spring recharge zone characteristics (Negi & Joshi, 1996; 2002). In the eastern Himalaya, Rai et. al. (1998) found that the rate and total flow in springs were highly correlated with rainfall pattern and recession of seasonal springs was much more rapid than the perennial springs. Bartarya (1991) reported that springs originating from fluvial deposits produced water at the highest rate (mean= 405 x 10^3 L/D) and those originating from colluvium at the lowest rate (7.2 x 10^3 L/D). Rai et. al. (1998) also found a great variation in mean annual spring water yield (5-39 L/min) emanating from different recharge areas in this region. Impact of the recharge zone characteristics and land use land cover changes on water quality has also been reported in this region (Kumar et. al. 1997; Negi et al. 2001; Joshi & Kothyari, 2003).

The present study is an attempt to understand the effect of rainfall, physiography, lithology, slope and aspect, land use practices, vegetation, altitude, soil type and anthropogenic interference (e.g., road construction and settlement etc.) and other characteristics in the spring recharge zone on the water yield and water quality of the selected springs in the mid-altitudinal belt (lesser Himalaya) in western Himalaya (Uttarakhand). In this belt most of the human settlement has taken place and the need for spring water augmentation is most pressing. This investigation will suggest the recharge zone characteristics ideal for spring discharge and water augmentation in the springs. The study area is vast, but an attempt has been made to locate some representative springs that could represent the range of recharge zone characteristics in the study area. It is expected that results of this study would be useful for both researchers and extension workers in the field of hydrology in general, and planning augmentation of water for drinking and other household consumption in particular.

OBJECTIVES

- Characterization of spring on the basis of geohydrological and geomorphological features in the selected areas of western Himalaya.
- Identification of recharge zone characteristics conducive to spring discharge particularly during lean months.
- To suggest measures for conservation and augmentation of spring discharge to the user community and those involved in drinking water program in the region.

CHAPTER-2

METHODOLOGY

Geohydrological studies require observations and measurements of various parameters on short-term as well as long-term basis. The study area is vast and encompasses the western Himalayan region. To identify a range of representative springs on the basis of geology, lithology, geomorphology, altitude, slope and aspect, meteorological conditions, land use and land cover, anthropogenic influence, in this region, we consulted geological maps, published literature in the field of geohydrological investigation, geological land forms etc. of the region. Extensive visits in the region were undertaken with the geologists and based on an initial screening of 30 springs (listed in Table 1) 12 springs were selected for detailed studies under this project (Table 2). These springs were distributed over a fairly wide geographical area across the region (Fig. 1), thus represented a variety of typical geo-physical and environmental set up prevailing in the region. The location of these springs and other land use and geological features are given in Table 2. They represented all variety of topography, altitude, geology, rock types, catchment area, land use and land cover and anthropogenic influence in the spring recharge zone (as reflected by the settlements). The altitude of the spring catchment area varied from 550 -2800 m asl and slope of the catchment from 0-70^{o}. Geology of the springs encompasses almost all the geological forms (Colluvial, Fluvial deposits, Joints and Fracture) and rock types (Mica schist, Quartzite, Phyllite, Slate, Lime stone, Micaceous gneiss, Granetiferous schists etc.). The land use varies from agriculture, forests, grazing land and wasteland to land under urban and rural settlements.

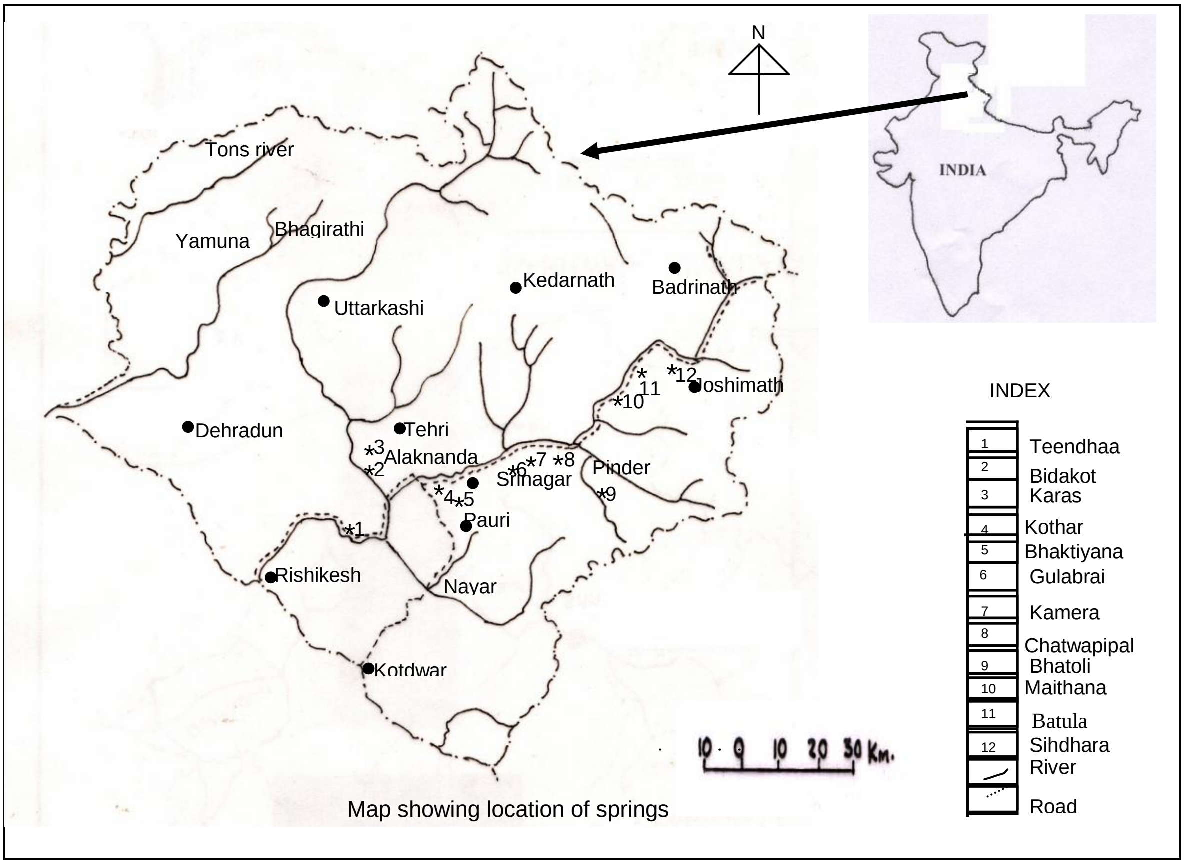

Figure 1. Location of the springs selected for detailed study in the western Himalaya

Table 1: Inventory of springs in Western Himalaya

S. No.	Name of spring	Geology	Land Use & Land cover	Altitudinal range of the catchment (≈m asl)	Type of spring
1	Gulabrai*	Quartzite/Phyllite	Pine forest / Broad leaf trees	700-1400	Fracture / joint
2	Kamera*	Quartzite/Phyllite	Agricultural land/ Pine forest/ Broad leaf forest	750-1500	Fracture / joint
3	Chatwapipal*	Quartzite /Phyllite/Mica schist	Pine forest/ Barren rocks	750-1500	Fracture / joint / colluvial
4	Maithana*	Massive Phyllite with interbedded Quartzite	Cultivated land	1000-1800	Colluvial / Fracture / joint
5	Batula*	Phyllite/Quartzite	Agricultural land / Oak forest	1400-2000	Fracture / joint
6	Bhatoli 1*	Quartzite interbedded with Phyllite	Crop field/ Fodder trees / Pine forest	1200-1800	Colluvial / Fracture / joint
7	Bhatoli 2	Quartzite / schist	Crop fields	1250-1800	Colluvial / joint
8	Bhatoli 3	Quartzite / Phyllite	Grass land / Pine forest	1300-2000	Fracture / joint
9	Kheti	Phyllite	Crop plants/ Oak shrubs	1000-1550	Fracture / joint
10	Pharson	Phyllite	Pine forests/ Barren lands	900-1600	Fracture / joint
11	Pandavkhal	Phyllite/ Quartzite	Oak forest	1250-1700	Fracture / joint
12	Rampur 1	Phyllite/ Schist	Broad leaf forest/ Oak plants	900-1500	Colluvial / Fracture / joint
13	Rampur 2	Quartzite / schist	Broad leaf forest/ Oak plants	900-1500	Colluvial / Fracture / joint
14	Ranibagh	Conglomerate / sedimentary rocks	Sal Broad leaf forest	600-1600	Colluvial
15	Garampani	Schist / phyllite	Broad leaf forest	600-1400	Fracture / joint
16	Lohali	Micaceous schist	Crop fields	1200-1600	Colluvial / Fracture / joint
17	Beedakot*	Phyllite / Quartzite	Cultivated land and pine forest	1400-1800	Fracture / joint
18	Karas*	Phyllite	Cultivated land	1600-2000	Colluvial / Fracture / joint
19	Sangdoya	Quartzite/ Phyllite	Pine forest	1600-1900	Fracture / joint
20	Chhabisa	Quartzite /Phyllite/Mica schist	Pine forest/grassland	1200-1400	Colluvial / Fracture / joint
21	Dadholi	Coarse grain quartzite	Pine forest/grazingland	1350-1800	Colluvial / Fracture / joint
22	Sipaidhara	Limestone	Oak-Deodar forest	1900-2100	Fracture / joint
23	Kosi	Mica schist	Pine forest/grazingland	1200-1700	Colluvial / Fracture / joint
24	Ghorikhal	Phyllites/phyllitic quartzite	Grazing land and bushes	1400-1800	Colluvial / Fracture / joint
25	Joshimath*	Kynite schists	Urbanized / Oak forest	2100-2800	Colluvial / Fracture / joint
26	Pauri	Phyllite / quartzite	Urbanized / Oak-Deodar forest	1660-2000	Colluvial / Fracture / joint
27	Kothar (Srinagar)*	Phyllite with quartz veins	Grazing land/cropland /settlements	550-1000	Colluvial
28	Katarmal	Mica schist, Quartzite	Agriculture / Barren land	1250-1500	Colluvial / fracture
29	Bhaktiyana*	Phyllite	Scant Pine forest / grazing land	600-850	Colluvial / fracture
30	Teendhara*	Quartzite / slate	Barren land / rock cliff	700-900	Joint/fracture

*Springs marked with asterisks were selected to conduct detailed studies.

Table 2: A summary of location and lithology of the springs selected for study

Sl. No.	Name of Spring	Location		Altitude (a.m.s.l.)	Catchment slope (^{o})	Lithology
		Latitude	Longitude			
1	Gulabrai	30^{o}16’64.26N	78^{o}58’07.72E	688 m	0-70	Quartzite
2	Chatwapipal	30^{o}16’09.82N	79^{o}10’12.90E	769 m	10-60	Phyllite
3	Kamera	30^{o}17’13.09N	79^{o}07’29.41E	732 m	0-60	Phyllite
4	Bhatoli	30^{o}11’28.50N	79^{o}14’20.19E	1105 m	20-60	Quartzite
5	Maithana	30^{o}21’34.84N	79^{o}19’02.04E	960 m	0-65	Granite gneisses and schists
6	Batula	30^{o}24’38.81N	79^{o}24’51.67E	1186 m	15-65	Dolomitic limestone and slate
7	Joshimath	30^{o}33’28.07N	79^{o}33’24.36E	1847 m	0-70	Quartz-mica gneisses
8	Kothar	30^{o}13’11.59N	78^{o}47’37.17E	594 m	0-45	Phyllite
9	Bhaktiyana	30^{o}13’08.97N	78^{o}58’01.72E	550 m	0-60	Phyllite
10	Karas	30^{o}71’35.48N	78^{o}36’13.14E	1611 m	0-50	Phyllite with metabasics and quartzite bands
11	Bidakot	30^{o}12’48.56N	78^{o}35’32.72E	1427 m	10-60	Phyllite
12	Teendhara	30^{o}05’56.17N	78^{o}34’26.60E	700 m	10-60	Quartzite

1. Geological Survey and Delineation of Spring Recharge Zone:

Extensive fieldwork in the western Himalayan region was carried out using Survey of India Top sheets during the survey work to delineate geology of the area. Path and traverse surveys were also used for more detailed survey. Altitude of the spring catchment was determined using a calibrated Altimeter. Different rock-types were identified and structural discontinuities related with them as folds, faults, fractures, joint patterns were also determined during the survey work. With the help of Brunton Compass the attitudes of different rocks were determined. In addition, extensive literature existing on this subject published by the regional workers was consulted.

2. Land Use and Land Cover Survey:

Detailed survey was conducted to delineate the different land use practices in the recharge zones of the identified springs. It was done on the basis of land under cultivation, wasteland, forestland, barren land and other land uses. For the different springs the land cover, vegetation type (broadleaf and conifer forests, scrubs, bushland etc.) were surveyed as these will affect the rainfall, surface runoff, water infiltration, evaporation and ultimately will lead to the water discharge of the spring. A query with the local inhabitants was also held to determine the land use practices in the recharge zone.

3. Slope Analysis and Aspect:

Slope and aspect of the recharge zone of each of the springs was determined with the help of a Brunton Compass during the survey. Slope type was determined to divide the respective catchment into various slope categories ranging from 0-60^{o}.

4. Soil Profile Survey:

At various places in the spring recharge zone soil profile survey was done by digging the soil up to the rock bed, and also wherever possible by measuring the soil depth along the gullies, stream banks and land surface exposed due to minor landslide, etc. using a measuring tape. The depth of soil cover was determined and classified into different horizons. The soil profile maps of the respective catchment were also prepared.

5. Soil Physical Characteristics:

Soil samples from the spring recharge zones were collected and brought to the laboratory for their physical properties (e.g., grain size, water holding capacity, soil type etc.). This would suggest the permeability and evaporation factors of soil.

6. Meteorological Data Records:

Rainfall, pan evaporation and atmospheric temperature data recorded at various places by the IMD stations, CWC stations and Hydro-Power Project authorities in the study area where these springs are located were collected for the period 2004-August 2007). This data has been used to develop relationship between spring discharge, rainfall and other factors.

7. Discharge Measurements:

Springs discharge measurement was taken at monthly / bimonthly intervals during 2004-2007 (data for 2006-2007 has been given in this report; data for 2004- 2005 have been given in earlier Annual Reports) with the help of a measuring cylinder and a stop watch. Discharge was measured thrice on each sampling date and mean value was calculated. The water samples were collected for further analysis and stored in the deep fridge for the water quality analysis.

8. Water Quality Studies:

The spring water was analyzed for various physico-chemical parameters such as, pH, conductivity, cations and anions and trace metals using standard techniques (APHA, 1989). Water samples were analyzed at the National Institute of Hydrology, Roorkee and also at the G.B. Pant Institute of Himalayan Environment & Development, Kosi-Almora.

METEOROLOGY OF THE STUDY AREA

Meteorological data of the three sites (representing the high altitude, middle and lower altitude zones within the study region) were collected from different sources during the study period (2004- August 2007). Thus the meteorological data represent the average values for 2004-2006. For the high altitude zone (Joshimath) the data were obtained from the Hydropower Project authorities. For the middle and lower altitude zones the data was obtained from IMD network stations at these sites in Karnprayag and Rudraprayag, respectively. At the high altitude site (Joshimath) the mean annual rainfall recorded was 1347 mm, out of which about 51% was occurred in the rainy season (July – September). The mean monthly maximum temperature was recorded maximum in July (33.2 ^oC) and the mean monthly minimum was recorded in January (10 ^oC) (Table 3).

At the middle altitude site (Karnprayag) the annual rainfall was recorded as 1745 mm, out of which about 66% was occurred in the rainy season (July – September). The mean monthly maximum temperature was recorded in June (39.7 ^oC) and the mean monthly minimum was recorded in December (18.4 ^oC) (Table 3).

Table 3: Monthly rainfall (in mm) of different stations 2004-2007

Station	Altitude	Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Rudraprayag	700 m (amsl)	2004	34	11.7	71.3	46	99.6	317	455.2	107.6	117	5.8	8.5	Nil
		2005	79.2	98.4	53.7	8.8	127	205	470.1	56.3	222	16	18	5
		2006	10.9	4.3	60.8	85.1	230	71.5	408	286.1	264	6.4	6	49
		2007	27	144.7	110.7	63.7	47.8	172	408	286.1	-	-	-	-
Karnprayag	750 m (amsl)	2004	33.1	13.4	-	54.4	146	217	507.3	454.3	192	88	NIl	5.2
		2005	98.4	123.7	92.8	8.6	40.2	114	467.5	238.5	498	13	17	6.2
		2006	35.6	6	73.8	59.6	205	199	484.6	577.9	122	Nil	9	34
		2007	75.7	141.4	102.2	71	114	144	214.7	310	-	-	-	-
Joshimath	2100 m (amsl)	2004	25.8	17.6	Nil	46	59.5	77.6	392.1	345.4	100	71	1	22
		2005	117	155.1	123.1	26	49.6	52.4	284.9	343.4	117	155	123	26
		2006	49.6	52.4	284.9	138	32	104	56.5	75.6	345	100	71	1
		2007	22.1	203.7	234.5	110	53.9	113	184.9	223.5	-	-	-	-

At the low altitude site the annual rainfall was recorded 1372 mm, out of which about 58% was occurred in the rainy season (July – September). The mean monthly maximum temperature was recorded in June (40 ^{o}C) and the mean monthly minimum was recorded in January (21.3 ^{o}C) (Table 4).

Table 4: Mean monthly temperature (in ^{0} C) of different stations 2004-2007

Station	Altitude	Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Rudraprayag	700 m (amsl)	2004	21	26	34	36	42	37	39	35	26	33	24	21
		2005	20	26	29	37	39	42	37	37	36	32	26	21
		2006	23	29	31	36	37	41	37	34	34	33	25	23
		2007	22	24	29	37	38	38	36	36	-	-	-	-
Karnprayag	750 m (amsl)	2004	19	27	34.6	37.3	42	37.8	38.3	35.6	35.3	30.9	21.8	18.5
		2005	19	23.9	30.2	35.9	39	41.9	38.4	36.9	36.3	30.8	24.2	17.9
		2006	20	27.8	29.5	34.5	36	39.4	39	38.8	34.5	32.3	25.2	18.7
		2007	18	26.1	31.1	39.5	38	40.4	37.2	33.9	-	-	-	-
Joshimath	2100 m (amsl)	2004	8.5	15	27	28	35	39	33	27.5	28	29	15.5	11.5
		2005	8.6	17.1	20.4	26.8	29	26.9	38	30	30	30	18.5	13.5
		2006	13	20.5	22.5	25	29	29	28.5	31	26	25	25	16.5
		2007	10	18	24	29	28	28.5	31	28	-	-	-	-

CHAPTER-3

GEOLOGY OF THE STUDY AREA

(I). GEOLOGICAL SETUP OF THE WESTERN HIMALAYAN REGION

The Himalayan orogenic belt is visualized as compressive plate boundary zone between the Eurasian plate on the north and the Indian plate to the south. The plate conversance between the formerly separated continental masses (the plates), resulted into complete demolition of the Tethys ocean basin, which was intervening between the two plates till the Mid-Miocene. The collision of the two plates gave birth to the Himalayan orogeny. The Himalayan general strike is WNW-EWE, measuring about 2400 km long and average width about 270 km. Uttarakhand Himalaya occurring in the central part of the Himalayan folded belt has exposed rock types varying in age from Proterozoic to Late tertiary period, disposed in four major tectonic belts designated as the Foothill Siwalik belt, Lesser Himalayan belt, Central Crystalline and Tethyan belt. The tectonic evolution of Himalaya began with the formation of a geanticlines ridge during Precambrian uplifting the Central Crystalline Group and dividing the basin into northern and southern realms. The deposition of the Precambrian Martoli took place in the northern basin while in the southern basin the sediments of Kumaun Super Group were deposited. Due to subsequent upliftment a 'graben' was formed in the south for the deposition of sediments of the Garhwal Group and Askot formation while the Martoli got incorporated with the central zone geanticlines.

The Lesser Himalayan belt consists of a vast stretch of unfossiliferous zone in Garhwal and Kumaon regions bounded by the Main Boundary Fault (MBF) to the south and the Main Crystalline Thrust (MCT) in the north is geologically very intricate. This belt includes rocks designated as Mandhalis, Chandpurs, Nagthat overlain by Blaini, Infra Krol, Krol, Tal and Paleogene Nummulitics in ascending order. The other belt is Almora-Dudatoli crystalline belt consisting of pelitic, psamitic and semipelitic schists and quartzites intercalated with bands of migmatites, granitic gneisses and non-foliated granites rocks occurring in asymmetric synform. The other important rock group is the northern sedimentary belt, a vast unfossilferous group referred to as Garhwal group. This belt latterly stretches from Uttarkashi in the north-west to Kali River in the south east where it extends into Nepal and they are represented by ortho-quartzite-carbonate sequence with minor argillaceous component. At time an association of similar phyllitic rock types is also observed with in the Garhwal Group below the Upper Arenaceous Facies (Chamoli Quartzite and its equivalents).

All the three formations of Jaunsar i.e., Mandali, Chandpur and Nagthat are located to the east of Chakrata in Yamuna valley. Mandhali limestone is partly equivalent to Deoban (Tejam). Chandpur slates and phyllites sometimes with bands of quartzites are exposed in Aglar valley in Tehri, around Deoprayag in Ganga and Pauri-Ghurdauri road section in Garhwal and also in the lower reaches of Machhlad and Purvi Nayar. These phyllites are also locally known as Pauri Phyllites. These phyllites are overlain by thick quartzites which are best exposed in Nagthat hill on the right bank of Yamuna River. These quartzites are very extensive throughout the Lesser Himalaya in a linear belt below the Krol Group of rocks.

Garhwal Group extends from the Kali valley in the east to the Yamuna River and beyond in the west in a uniform structural setup, bounded on the south and north by the North Almora Thrust (NAT) and MCT, respectively (Kumar & Agarwal, 1975). The Chandpur Formation is underlain by a thick sequence of purple, pink and cream coloured quartzites and greywacke known as Saknidhar Formation and is equivalent to the Rudraprayag Formation (Ahmad 1977). The Rudraprayag quartzite (Rudraprayag Formation) shows well developed stratification including numerous ripples marks and cross bedding. Purple and greenish grey slates are also present with these quartzites. Just in the northeast of Rudraprayag Lameri Formation is uncomfortably overlying the Rudraprayag formation consisting of black, grey and purple slates, phyllite and intercalated with chert and stromatolitic dolomitic limestone.

The next higher member of the Rudraprayag Formation of Garhwal Group is Haryali Quartzite (Srivastava and Ahmad, 1979), which occupies a greater part of the area between NAT and Alaknanda Fault. Around Nagrasu, Gauchar, Srikot and Thalassu coarse to gritty, often conglomeratic quartzite has been altered to schistose grit, perhaps due to contact effect of Chandrapuri Granite-gneiss exposed north of Gauchar. East and south of Karnaprayag and in certain other areas like Narkota, Dhari and west of Rudraprayag there are huge bodies of metavolcanic rocks known as Karnaprayag Metavolcanic, which represents penecontemporaneous volcanic activity in these parts, whereas Haryali Quartzite and Thalassu Schistose Grit (Rudraprayag Formation) were being deposited in adjoining parts of Alaknanda valley. The carbonate-argillite sequence of Pokhri Formation is overlain by a total arenaceous facies with metavolcanics, which has been referred by Auden (1935) as the Chamoli Quartzite. The exposure of this facies lies between the area north-east of Langasu and Nandprayag represent southern limb of the Maithana Syncline.

Towards the north of Chamoli Quartzite, Chinka Formation, Pipalkoti Formation and Gulabkoti Formation are exposed. The Pipalkoti formation forming the core of the Pipalkoti anticline shows widespread development and consists of alternating sequence of slate and dolostone. In the north this formation has been thrust upon by the Gulabkoti Formation along Gulabkoti thrust whereas in the south these have been separated from the Chinka Formaion by the Birhi Fault. The Gulabkoti Formation comprising of quartzites, dolostone and mylonites has been thrust upon by the rocks of 'Central Crystallines' along the low angle northerly dipping 'Main Central Thrust'. The mylonites, occurring in this formation, lie in the 'Intra Thrust Zone' and are bounded by the Main Central Thrust in the north and the Salur Thrust in the south. In the south, the Pipalkoti anticline is followed by the Chamoli syncline consisting of quartzites which at Birhi have undergone mylonitization in a 'Shear Zone' bounded by the 'Birhi Fault' and 'Chinka Fault'

Whole sequence of Garhwal Group has been intruded by granites e.g., Chirbatiakhal granite-gneiss, Chandrapuri granite gneiss, Pokhri granite gneiss and Chinka granite-gneiss. Similarly, there is profuse intrusion by the dolerite, altered to epidiorite, which penetrates particularly whole of the sequence Garhwal Group and

Crystalline. The Nandprayag Crystallines, exposed between Rupa and Nandprayag, forms a broad synformal structure, having an exposed width of nearly 8 km and along the Nandakini river these Crystallines are exposed. Lithologically they are granite gneisses and schists with thick lenses/ bands of white quartzite's and the basic silts. These quartzite bands resemble the litho-units of the Chamoli Quartzite formation. The northern contact with the Chamoli Quartzite is occupied by the basic rock. The southern contact of these crystalline is appeared to be thrusted/ faulted (Virdi, 1984, Srivastava and Ahmad, 1979).

Crystalline at Dudatoli forms a major synclinal structure from Khirsu to Almora via Dudatoli and Ranikhet. It is believed that these crystalline traveled a great distance along a thrust plane and are resting at Almora, Askot, Baijnath, Lansdowne etc. The roots of these crystallines lie in the Central Crystallines. Dudatoli Crystallines are part of a much bigger Almora Nappe, which has thrust on its northern and southern flanks. The northern thrust is dipping to the south quite steeply and is known as NAT. The southern thrust is dipping gently to the north and is termed as South Almora Thrust (SAT). These two thrust join together in arcuate shape, right at Khirsu-Bugani area. Therefore, SAT does not continue further west and a trace of NAT continues to the west via Koteshwar (Srinagar thrust), Silkakhal road and Gadolia up to Pratapnagar only (Pratapnagar Thrust). Saryu thrust, Naulapani Fault and Dharasu Fault are also equivalent to NAT. A series of coalescing triangular facets on the slopes beyond the river in the Srinagar area are strong evidences of thrusting, which extend from Koteshwar crossing the river just downstream of the bridge. The thrust is characterized by a wide shear zone incorporating fragment of phyllite, quartzite, slates, basics and calcareous rocks. Shearing, crushing, slickensides and vertical drag folds suggesting the thrusting in this area. These crystallines are high grade metamorphics, show phyllonites, mica schists, garnetiferous mica schists, gneisses and granites as seen away from the thrust to the core of the syncline.

The Main Central Crystalline belt consist of a complex of mylonite gneisses, phyllite, garnetiferous schist and kyanite bearing schist, calc silicate rock and quartzite with associated migmatite syntectonic granite gneisses and late to post tectonic tourmaline bearing granite including the famous Badrinath granite. This belt is subjected to poly-phase deformation and poly-metamorphism with isoclinal and reclined fold plunging towards NNE. The long belt of Central Crystalline is marked at many places by mica schist and gneisses with sills of amphibolites of the gabbroid to dioritic composition. Lower most gneisses show upward increase of the content of plagioclase feldspar. Over lying rocks are the psammitic gneisses with the preponderance of garnet, staurolite, kyanite etc. within the overall biotite gneisses or migmatitic zone. In Garhwal Himalaya enormous thickness of quartzite is developed with short strike extension. Linear intrusion of tourmaline granite is seen towards the upper most part of Garhwal Himalaya.

Major Structures in the Garhwal Himalaya: The main structural discontinuities running through the entire study area of Uttarakhand are the Main Central Thrust (MCT) and the North Almora Thrust (NAT) which in its western part is referred to as Srinagar thrust. The MCT has brought the Central Crystalline in juxtaposition with rock of the low grade complexes (Lesser Himalayan belt of rock) and in a sense marks the southern boundary of Higher Himalaya. The surface trace of this north dipping plane is sinuous and at places offset by transverse fault. The MCT at the base of Central Crystalline is a low angle feature when discernible and in a regional way does not present persistently linear traces. The NAT southerly to sub vertically dipping discontinuity separates the quartzites from the phyllites. Apart from the regional thrust following the Himalayan trend a number of faults of transverse disposition dissect and displace the rock units.

Maithana Synform corresponds with Askot-Baijnath Synform of Kumaun Himalaya and may belong to regional curvilinear synformal trend, the core of which is invariable occupied by the crystalline rocks. Pokhri anticline, Karnaprayag anticline, Nag syncline, Pingalpani syncline, Chirpatiakhal anticline, Rudraprayag anticline and associated faults are the products of intersection of forces acting during the formation of major faults and thrust like MCT, Kande Fault, Alaknanda Fault, NAT and Saknidhar Fault. The Rudraprayag anticline almost follows the bed of Alaknanda River around

Rudraprayag. The general trend is NE-SW to ENE-WSW. Between Alaknanda Fault and NAT around Rudraprayag and west of it there are several almost E-W trending folds and faults of considerable extent have been reported. Pauri Syncline, Saknidahr anticline and Garhwal Syncline, Godiyon Anticline and Nainidanda Anticlines are the other major structures of regional extent.

Alaknanda Fault: The Alaknanda Fault, which offsets the earlier structures, has been traced over a strike length of 45 km from 3 km east of Langasu in the east to 1.5 km south of Chirbatiyakhal on the west. A bewildering disposition is the non-continuation of various litho-units, occurring north of Alaknanda Fault to its south. Alaknanda Fault also appears a sub-vertical fault which is strike-cum-dip slip fault. The down throw of this fault appears to be the north of this plane, thus bringing the younger sequence of the north (Pokhri Formation) in juxtaposition with the older Rudraprayag Formation, in the south. This means the movement along this plane was in reversed direction in comparison to NAT. The magnitude of displacement was perhaps also less (Srivastava and Ahmad, 1979).

North Almora Thrust (NAT): According to Kumar and Agarwal (1975) it separates the Pauri Phyllite and the Khirsu Quartzite of the Kumaun Super group from the Garhwal Group. The fault trending WNW-ESE and dipping at 45^o-60^o southwards, has been variously referred to as Srinagar Thrust (Mehta, 1971) and Srinagar Shear (Bhargava, 1972). Agarwal and Kumar (1973) traced this fault to the Bhagirathi and Yamuna valleys where it had been referred to as the Major Tectonic Unit (Auden, 1939), Nalupani Fault (Dhoundiyal and Ali, 1967) and Dharasu Thrust (Jain 1972a). Kumar et.al. (1974) have also shown that this fault does not swear around the Dudatoli Crystalline to join with the SAT as postulated by Heim and Gansser (1939), Gansser (1964) and interpreted by Rupke (1974). NAT brings the younger Phyllite Facies of Chandpur Formation in juxtaposition with its basement rocks, the Argillo-arenaceous Facies of Rudraprayag Formation. Thus the southern plane of this zone of dislocation is a down throw side, bringing down the Chandpur thousands of meters below their actual level of disposition. In the Alaknanda valley, NAT heads north words with angle, but elsewhere it dips southwards also, thus it is a sub-vertical zone of dislocation, as a result, its had oscillates, sometimes towards north and sometimes towards south. But undoubtedly the southern side is down side of this thrust (Srivastava and Ahmad, 1979).

Main Central Thrust (MCT): Auden (1935) in Alaknanda valley found a series of mica schists and biotite gneisses thrust over the rocks of Window Series consist of quartzite, limestone and dolostone. This Thrust plane separating the Garhwal Series with the Central Crystalline was named as MCT by Heim and Gansser (1939). The quartzite of Garhwal Group end against schist and gneisses of Central Crystallines along MCT exposed near Mandal and Helong. The MCT runs from Arakot in the west to Naitwar, Bhatwari, Ghuttu, Ukhimath, Chopta, Mandal, Helang, Karamnasa, Patalganga, Dhak, Tharali and Loharkhet.

Trans Himadri Fault: Trans Himadri fault lies above Vakrita thrust which separates the Tethyan sedimentary cover from the central crystalline rocks of Vakrita group. The southern boundary of Himadri terrain in having a gentle northward dipping crustal shear zone of various thrust sheets made up of mylonitized and sheared granitic rocks (Valdiya, 1962, 1979, 1980b, 1981, 1999). Mehdi et al. (1972) recognized and separated the basement complex of the Himadri from Tethyan sedimentary cover in Gori valley at Mantoli. Valdiya (1973, 1976, 1979, 1981) recognized at Malari in the west Dhauli valley and near Budhi in the Kali valley. This thrust was earlier described as Malari thrust. Sinha (1989) described it also as Tethyan thrust. The Himdri complex is having thickness 6000-10000 m homoclinal Unit and it is observed in between Trans Himadri fault and Main Central Thrust. Trans-Himadri Fault passes from Burphy, Malari, Niti etc. in the study area.

Lineament: Barkatya and Gupta (1982) used the lands at MSS images of Garhwal – Kumaun Himalaya to delineate the zones of neotectonic activity by lineament tectonic interpretation. They observed that Alaknanda river between Rudraprayag and Srinagar runs along Srinagar lineament trending N 700E and S 700W and ranging in length about 75 km. Due to this, the drainage patterns are different being parallel on the eastern side and sub parallels on the western side, Pindar lineament traveling N650W and S650E and ranging about 165 km. This lineament runs in ESE-WNW direction which coincided with the trends of the Himalayan axis. Pindar river follows this lineament about 90 km. Many lineament of Alaknanda river catchment have been coincided with earlier mapped faults and thrusts. The thematic map shows a large network of lineaments structural features in the study area which have attended evolution of Himalaya in the geological past. Shandilya and Prasad (1982) find out various lineament zones in which they describe the general trend of different lineament zones as Kontha Chandrapuri ENE-WSW, Mandakini N-S and NNE-SSW, Gauchar –Rajkhal E-W and ESE-WNW, Dhanpur Silkakhal NW-SE and EW, Rudraprayag Khirsu NS and Khirsu-Gandhidhar WSW-ENE. All the springs selected for the detail investigation in this project fall in the Lesser Himalaya and Central Himalayan zone.

(II). GEOLOGICAL DESCRIPTION OF THE SPRINGS

The study area is located between longitudes 77^0 49’ to 80^o 6’ E and latitude 29^0 26’ to $31^0$28’ N in Garhwal Division of Uttarakhand. Majority of springs fall in Alaknanda catchment stretching from Teendhara (Devaprayag) to Joshimath. The area witnesses a great variation in lithological and tectonic set up with varying micro climatic and socio-economic attributes. Geologically lower reaches are constituted by metasedimentries of Kumaun super group of rocks while upper reaches are made up of sedimentary and matabasics of Garhwal group and crystalline formations separated by Krol-Nayar thrust, Srinagar (North Almora) thrust and Main Central Thrust (MCT). The lithologies include various types of quartzite, phyllite and epidorites in Kumaun super group, quartzite, volcanic lava flows, slates and carbonates in Garhwal group, and garnetiferous mica-schist in crystalline formation along with locally or regionally developed colluvial and alluvial deposits.

Physiographically the area represents a peculiar type of lesser Himalaya morphology with NW-SE trending major ridges along with subsequent primary and secondary ridges having varying slope and climatic aspects, draining the water into the trunk stream Alaknanda river. There is great variation in temperature and rainfall from place to place and also during different seasons. Micro climate is even more variable within short distances. Such diversity in lithologies, landform assemblage and micro climate may have diverse impact on recharge- flowage- discharge and geochemistry of ground water forming the springs in this region. Relationship between the springs located in (a) different micro climate but same lithologies, and (b) same microclimate but different lithologies may be fascinating, however structural and tectonic set up will have to be considered.

In the Himalayan mountains, the great variation in the geology plays an important role to control the spring outflow. Springs occur with faults, fractures, joints, shear zone, alluvial and colluvial deposits. Lithologically the western Himalayan zone is different and has various rock types. The review of recent stratigraphical and structural studies (e.g., Kumar, 1980) in this region suggests its division into five WNW-ESE trending linear lithotectonic units, viz., the Tethyan, Central, Garhwal, Kumaun and Siwalik, each separated by major faults. The northern most Tethyan zone, exposing almost complete sequence from Precambrian to Upper Cretaceous sediments is separated from the central zone in south by Dar-Martoli fault. The central zone made-up of monotonously north dipping Achaean metasediments of the Central Crystalline Group is bounded in the south by Main Central Thrust (MCT) separating it from the Garhwal zone. The latter zone, representing low-grade metasediments, constituting the Garhwal Group, ranging in the age from Precambrian (Riphean) to- Lower Paleozoic and outlier of Askot formation. The Kumaun zone, separated from the Garhwal zone in the north by the North Almora Thrust and limited in the south by Main Boundary Thrust (MBT).

In the Kumaun Super Group six distinct litho-units have been individually mapped as formation. Of these five sedimentary units, viz., the Marchua quartzite, Pauri phyllite, Maithana quartzite, Manila phyllite and Dudatoli- Almora crystalline, appear to be related and have been put under Dudatoli Group. The Saknidhar formation is characterized by distinct lithology and sedimentary structures and has not been given the status of a group, as it is not divisible into mapable formations. Dudatoli Group and Saknidhar formations have been collectively referred to as the Kumaun Super Group (Table 5).

Table 5: Main geological formations in the study area (Source: Kumar & Agrawal, 1974).

Stratigraphy of the Srinagar-Nandprayag area

Sillurian to precambrean Garhwal Group Gavangarh formation

Chamoli formation
Lameri formation
Rudraprayag formation

North Almora Thrust
Precambrean to Archean
Dudatoli Group (Kumaun Super Group)– Dudatoli-Almora crystalline

Manila phyllite
Maithana quartzite
Chandpur phyllite
Marchua quartzite
Saknidhar quartzite

All the springs selected in this study are located in the metasedimentary and sedimentary rocks of the western Himalaya. The rocks of Kumaon Super Group to Garhwal Group occupy the study area. General rocks type are phyllite, quartzite, mica-schist, slate and dolomitic limestone. All the rocks have their different water retaining properties based upon the discontinuities therein. Some rocks are hard enough to percolate the water therein but, some are suitable for water retention. These discontinuities make the avenue for the water movement and these rocks retain a very good amount of perched water or permanent ground water. The major structures exposed in the Alaknanda valley catchment are North Almora Thrust (NAT), Main Central Thrust (MCT), MCT – I, MCT – II, Martoli Thrust. It is well known that geology, rock type and human interference in the recharge area profoundly influence water qualities and quantities of the aquifer. This investigation is expected to understand how the complex setting of recharge zone characteristics influences the water yield of the selected springs.

CHAPTER-4

SOIL PHYSICAL PROPERTIES IN THE SPRING CATCHMENT AREA

In the mountainous region the soil varies considerably from place to place because of the changes in the parent rocks, altitude, slope, aspect and vegetation (Ghildiyal, 1981). Kaushik (1961) studied the acidic soils of western Himalaya in his attempt to from pedo–ecological zones of altitudes between 500 and 2500 masl in Garhwal region. Tectonically soil formation processes like sericitization and chloritization are stimulated by thrusting, faulting and crumpling movements under humid conditions of the valleys (Saxena, 1987). In the soil formation, parent material usually plays a significant role. Regolith is renewed into soil by weathering and other associated processes (Anantharaman, Saxena and Pandey, 1982). In this region due to steep slopes and plenty of rainfall, correlation between soil and parent rock is very difficult. On the terraced hill sides to down slope drift of mineral matter is sharply reduced and consequently the soil is stabilized and leaching becomes an important process of profile formation (Andres, 1966). On moderate to steep slopes and also on the southern aspect of concavo – convex slopes of low mountains the presence of thin shallow surface horizons of soil which are of medium to coarse texture is the result of very little tectonic effect in the region. On level summits residual soils are well developed. The sub soils are deep and heavily textured. “A” horizon with a high content of organic matter is highly leached and acidic in character. Valley soils are well developed from the colluvial material brought down from the up slopes. In such cases the soil profile tends to remain in youthful stage as mineral fragments are continuously carried down the slopes. Soils of valley bottoms and river terraces are composed of alluvium deposited by rivers in the process of aggradation. These soils are generally coarse in texture and least acidic. The characters of soils are largely controlled by the type of rocks from which disintegrated material is allowed to lie at a place and biochemical activity starts to operate (Anantharaman, Saxena and Pandey, 1984). Majority of the soils are diluvial but correlation with parent rock become significant over gentle slopes, which occurs in a particular formation of large extent. Quartzites produce a sandy shallow and dry soil with adequate amount of gravels and this type of soil is liable to erosion. Light open and sandy – silt –clayey soils of variable depth are produced by granitic and schistose rocks. Dark deep and rich silty-clayey soils are formed from gneiss which disintegrates excellently. Stiff clayey soils are produced by limestone and phyllite formations. Generally it is observed that deeper soils rich in basic constituents occur on the northern aspect of the hills where adequate moisture is present.

In the spring micro-catchments selected for the present study soil physical characteristics (soil depth, moisture, texture and water holding capacity) were studied. Soil was dug up to the bed rock at various places in the spring recharge zone depending upon the broad soil zonations. The depth of soil cover was determined and classified into horizons. Soil samples from different spring recharge zones were collected and brought to the laboratory for their physical properties. This would suggest the permeability and evaporation factors of soil. The soil profile maps of the respective catchments were also prepared (Figs. 5 - 15). As evident through these maps the soil depth was found ranging from 45 - 90 cm across the spring catchments. In the lower elevation zones the soil depth was generally more with well developed soil profiles. Soils of various stages were found across the soil horizons: very fine black soil, fine soil, medium grain soil, very coarse grain soil and coarse grain soil with angular fragments. The top soil layer containing very fine soil was always thin presumably due to soil erosion on the sloping catchments.

Soil Profile

Different types of soil profiles (Sp) (Sp1 – Sp5) have been categorized in different parts of the spring catchment for all the springs selected for study (Figs. 2-11). These are described as follows:

1. Gulabrai spring (Fig. 2) (Sl. No. 1 in Table 2):

Sp1:- In this profile moving from top to down- 10 cm deep very fine soil, 30 cm deep coarse grain soil, and 25 cm deep medium grain soil have been noticed.

Sp2:- In this profile moving from top to down 10 cm deep coarse grain soils, 70 cm deep soils with rock fragment have been observed.

Sp3:- In this profile moving from top to down 5 cm deep fine black soil, 15 cm deep coarse grain soil, 20 cm deep coarse grain soils, 10 cm deed soil with angular fragments have been found.

2. Chatwapipal (Fig. 3) (Sl. No. 2 in Table 2):

Sp1:- In this profile moving from top to bottom are 10 cm deep very fine soil, 45 cm deep very coarse grain soil have been noticed.

Sp2:- In this profile moving from top to down 5 cm deep very fine soil, 30 cm deep very coarse soil, 40 cm deep very coarse soil with angular fragments have been observed.

Sp3:- In this region soil layer from top to bottom was 5 cm deep fine soil, 15 cm deep medium grain soil, 40 cm deep very coarse soil, 20 cm deep very coarse soil with angular fragments have been measured.

3. Kamera (Fig. 4) (Sl. No. 3 in Table 2):

Sp1:- In this region soil layers from top to bottom are 10 cm deep very fine soils, 50 cm deep medium grain soils have been noticed.

Sp2:- In this profile moving from top to down 5 cm deep very fine black soil, 15 cm deep medium grain soil, 25 cm deep very coarse grain soil, 10 cm coarse grain soil with angular fragments have been observed.

Sp3:- In this profile moving from top to down 5 cm deep fine soil, 10 cm deep medium grain soil , 20 cm deep very coarse grain soil, have been measured.

Sp4:- In this region soil layer from top to bottom are 10 cm deep fine soils, 25 cm deep medium grain soils have been measured.

4. Bhatoli (Fig. 5) (Sl. No. 4 in Table 2):

Sp1:- In this profile moving from top to bottom are 10 cm deep very fine soil, 50 cm deep coarse grain soil have been noticed.

Sp2:- In this profile moving from top to down 5 cm deep fine black soil, 10 cm deep medium grain soil, 20 cm deep coarse soil, 30 cm deep medium grain radish soil have been observed.

Sp3:- In this region soil layer from up to down wards 10 cm deep medium grain soil, 40 cm deep very coarse soil have been measured.

5. Maithana (Fig. 6) (Sl. No. 5 in Table 2):

Sp1:- In this profile moving from top to bottom are 5 cm deep very fine soil, 15 cm deep medium grain soil, 35 cm deep coarse grain soils have been noticed.

Sp2:- In this profile moving from top to down 10 cm deep medium grain soil, 60 cm deep coarse grain soil have been observed.

Sp3:- In this region soil layer from up to down wards 5 cm deep very fine soil, 10 cm deep fine black soil, 20 cm coarse grain soil, 30 cm very coarse grain soil have been measured.

6. Batula (Fig. 7) (Sl. No. 6 in Table 2):

Sp1:- In this profile moving from top to bottom are 10 cm deep fine grain soil, 70 cm deep coarse grain soil with angular fragments have been noticed.

Sp2:- In this region soil layer from up to down wards 5 cm deep fine grain black soil, 15 cm deep medium grain soil, 20 cm coarse grain soil, 30 cm coarse grain soil with angular fragments have been measured.

7. Joshimath (Fig. 8) (Sl. No. 7 in Table 2):

Sp1:- In this profile moving from top to bottom are 15 cm deep very fine grain soil, 20 cm deep medium grain radish soil, 35 cm deep very coarse grain soil with angular fragments have been noticed.

Sp2:- In this region soil layer from up to down wards 10 cm deep very fine soil, 20 cm deep medium grain soil, 25 cm deep very coarse grain soil with angular fragments have been measured.

8. Kothar (Fig. 9) (Sl. No. 8 in Table 2):

Sp1:- In this profile moving from top to down 5 cm deep fine black soil, 10 cm deep fine brown soil, 30 cm deep coarse soil with angular rock fragments, 120 cm deep reddish soil with very coarse angular rock fragments have been measured.

Sp2:- In this profile moving from top to down 15 cm deep coarse reddish soil, 10 cm deep coarse whitish soil, 30 cm deep fine reddish soil, 30 cm deep whitish soil with angular rock fragment, 25 cm deep fine reddish soil, 30 cm deep whitish soil with rock fragments, 15 cm deep fine reddish soil and 60 cm deep whitish soil with rock fragments have been noticed.

Sp3:- In this region very thin soil layers have been found. From top to bottom they are 10 cm deep fine soil and 35 cm deep coarse soils with some rock fragments.

Sp4:-In this profile moving from top to down 130 cm deep coarse soil and 510 cm deep alluvial soil have been found.

Sp5:- In this region very thin soil layers have been found. From top to bottom they are: 45 cm deep coarse soil and 195 cm deep alluvial soil without soil sorting.

9. Bhaktiyana (Fig. 10) (Sl. No. 9 in Table 2):

Sp1:- In this profile moving from top to down 30 deep cm fine whitish soil and 180 cm deep coarse reddish soil with very coarse angular rock fragments have been noticed.

Sp2:- In this profile moving from top to down 30 cm deep fine reddish soil, 30 cm deep soil with angular rock fragment, 120 cm deep soil with some pebbles and 40 cm deep very coarse soil with rock fragments was recorded.

Sp3:- In this region very thick soil layers have been found. From top to bottom they are, 60 cm deep sandy soil with pebbles 90 cm deep coarse soil, 60 cm deep coarse sand layer, 30 cm deep very coarse sand layer, 60 cm deep coarse soil, 30 cm deep medium grain soil, 20 cm deep coarse sand layer, 15 cm deep reddish soil, 60 cm deep sandy soil with pebbles, 20 cm deep fine soil, 60 cm deep coarse soil with some pebbles, 30 cm deep sandy soil with some rock fragments, 60 cm deep fine soil, 60 cm deep pebbly soil with some rock fragments, 30 cm deep fine soil, 60 cm deep soil with rocks fragments, and 300 cm thick casts of different shape and size have been found. The total depth of the soil may approximately measure up to 30 m.

10. Karas (Fig. 11) (Sl. No. 10 in Table 2):

Sp1:- In this profile moving from top to down 5 cm deep very fine soil, 15 cm deep medium grain soil, 30 cm deep very coarse grain and at last 20 cm deep very coarse soil layer with angular rock fragments have been measured.

Sp2:- In this region soil layers from top to bottom are: 15 cm deep fine black soil, 30 cm deep medium grain reddish soil and 45 cm deep coarse soil with some rock fragments have been noticed.

11. Bidakot (Fig. 12) (Sl. No. 11 in Table 2):

Sp1:- In this profile moving from top to down 10 cm deep medium grain soil, 7 cm deep very fine soil, 15 cm deep coarse grain soil, 15 cm deep medium grain soil, 20 cm deep coarse grain soil and at last 60 cm deep very coarse soil layer with angular rock fragments have been noticed.

Sp2:- In this region soil layer from top to bottom was 20 cm deep medium grain soil, 5 cm deep fine grain soil, 30 cm deep coarse grain soil and 45 cm deep coarse soil with some rock fragments have been noticed.

Sp3:- In this part from top to bottom the sequence of soil layers was 15 cm deep layer each for medium grain and coarse grain soil and 90 cm deep soil layer with maximum angular fragments.

Soil Horizons:

The soil of the study area can be divided into soil horizons O, A and B. The uppermost layer (horizon O) was composed of organic matter (dead and decayed plant parts and soil fauna). This layer was usually very thin and not divisible into further horizons. The O horizon was followed by A horizon. The A Horizon is the top layer of the soil horizons or 'topsoil'. It contained rooting zone of the plants and many faunal species. A is a surface horizon, and as such is also known as the zone in which most biological activity occurs. The B Horizon is commonly referred to as ‘subsoil’, and consist of mineral layers which may contain concentrations of clay or minerals such as iron or aluminum, or organic material which get there by leaching. Accordingly, this layer is also known as "zone of accumulation". Soil depth beyond 1 m was mostly absent and not studied which is the soil formation or weathering zone.

Soil Physical Characteristics

Soils of the spring’s micro-catchments were categorized as: clay soil, clay loam and loam. These soils are regarded to be moderately productive because of the moderate depth and presence of adequate organic matter. The pH of soil ranged from 5.51 (15-30 cm depth of Kamera spring) to 7.37 (0-15 cm depth of Chatwapipal spring) (Table 6). The soil moisture (determined by oven drying the soil samples collected from the spring recharge zones) across the springs ranged from a minimum of 6% (0-15 cm depth in Teendhara spring) to 62% (15-30 cm depth in Maithana spring). The proportion of sand, silt and clay was also varied greatly from one spring to another and also across the two soil depths. In the 0-15 cm soil depth it was found ranging from 25.6% in Kothar spring to 42.6% in Kamera spring. In the 15-30 cm soil depth this value was 16.6% in Bhaktiyana and 57.2% in Kothar. In the 0-15 cm soil depth the proportion of silt was found ranging from 20.9% in Maithana spring to 43.7% in Joshimath spring. In the 15-30 cm soil depth this value was found ranging from 13.2% in Kamera spring to 42.3% in Bhatoli spring. Similarly, in the 0-15 cm soil depth the proportion of clay was found ranging from 15.8% in Joshimath spring to 43.1% in Maithana spring. In the 15-30 cm soil depth this was found ranging from 9% in Joshimath spring to 60.1% in Bhaktiyana spring (Table 6).

Water holding capacity (WHC) of soils of the spring micro-catchments was measured for two depths (0-15 cm and 15-30 cm) following standard techniques (Plate 2). The mean WHC (across the two soil depths) varied between 34 and 60% for Gulabrai and Bhaktiyana spring micro-catchments, respectively (Table 6). There was considerable variation among the water holding capacity across the two soil depths for some of the springs (e.g., Teendhara, Gulabrai, Bhatoli, Bhaktiyana, Kothar, Bidakot, Karas, Kamera, Chatwapipal, Joshimath, Batula and Maithana). Soil moisture was found directly related to soil water holding capacity. In the 0-15 cm soil depth the WHC was found ranging from 35% in Bhaktiyana spring to 66% in Gulabrai spring. In the 15-30 cm soil depth the WHC was found ranging from 33% in Bhaktiyana spring to 60% in Maithana spring.

Table 6: Properties of soil from different spring's micro-catchments

Spring Name	Depth (Cm)	pH	Moisture (%)	Mechanical composition				Water holding capacity (%)
				Sand (%)	Silt (%)	Clay %	Texture	
Gulabrai	0-15	7.17	38	35.7	22.2	40.4	Silt clay loam	66
	15-30	7.20	45	34.3	33.2	30.9	Clay loam	56
Chatwapipal	0-15	7.37	40	32.1	30.5	32.8	Clay loam	52
	15-30	6.28	46	34.7	20.9	40.9	Clay loam	47
Kamera	0-15	5.96	36	42.6	31	23.1	Clay	38
	15-30	5.51	43	36.6	13.2	40.5	Loam	40
Bhatoli	0-15	7.33	36	35.7	36	26.3	Loam	58
	15-30	7.06	45	27.1	42.3	28.3	Silt clay loam	47
Maithana	0-15	7.21	53	33.6	20.9	43.1	Clay	54
	15-30	7.28	62	24.5	29.8	43.5	Clay	60
Batula	0-15	6.97	46	39	37.9	22.5	Loam	39
	15-30	6.41	52	40.8	36.7	22.6	Loam	41
Joshimath	0-15	6.53	38	41.3	43.7	15.8	Sandy loam	57
	15-30	6.85	49	52.2	39.7	9.0	Sandy loam	53
Kothar	0-15	7.15	12	25.6	32.3	37.6	Clay loam	42
	15-30	7.13	19	57.2	20.8	20.1	Loam	35
Bhaktiyana	0-15	7.23	9	42.2	28	34.7	Clay loam	35
	15-30	6.65	17	16.6	23.9	60.1	Clay	33
Karas	0-15	7.33	28	36.2	27.5	30.3	Clay loam	47
	15-30	7.29	36	37.6	32.1	24.8	Loam	44
Bidakot	0-15	6.65	34	32	27.8	34.6	Clay loam	52
	15-30	6.67	38	33	28.3	33.4	Clay loam	45

Plate 2: Water holding capacity measurements for the soils of spring recharge zones.

Soil moisture of catchments of the springs

Soil moisture up to 1 m soil depth was determined (using an automatic soil moisture meter) in different soil profiles of each of the spring recharge zones during summer 2006 (Table 6). Soil moisture was found greater in the morning hours as compared to the evening hours (Table 7). This trend was obviously due to the evapotranspiration that might have occurred during the day time. The trend of soil moisture across the soil profiles was not uniform for all the springs. In some springs it was lower in the upper horizons (SP_1 zone) and increased with increasing depth (SP_2 – SP_5 zones). This trend was observed in Karas, Chatwapipal, Maithana, Batula and Bhaktiyana springs. In still others, the middle zones had more soil moisture compared to both the zones). This trend was observed in Bidakot, Kamera, Bhatoli and Kothar. In the morning hours the soil moisture across the springs varied from 2.4 and 31.5% for Teendhara (SP_1 zone) and Batula (SP_2 zone) springs. In the evening hours the soil moisture across different horizons of the springs varied from 1.1% (Kamera) and 20.9% (Chatwapipal). In the 0-15 cm soil depth the soil moisture was found ranging from 6% in Teendhara spring to 53% in Maithana spring. In the 15-30 cm soil depth the soil moisture was found ranging from 14% in Teendhara spring to 62% in Maithana spring.

Table 7: Soil moisture (vol. %) across different soil horizons near the springs

Name of spring			Name of spring		
Bidakot	Time of measurement		**Bhatoli**	Time of measurement	
	9.30 Am	5.30 PM		9.00 Am	4.00 Pm.
Sp1	4.7	2.3	Sp1	9.6	7.6
	3.3	3.0		9.0	5.2
Sp2	6.6	4.9	Sp2	14.8	10.7
	7.9	6.7		9.5	7.4
SP3	4.4	4.2	Sp3	5.6	4.2
	4.6	1.3		4.9	2.30
			Maithana		
Karas				9.00 Am	6.00 Pm
	11.15 Am	4.30 PM	Sp1	7.5	3.6
Sp1	8.2	6.9		9.0	6.3
	5.0	4.2	Sp2	5.3	3.8
Sp2	8.8	7.1		14.1	11.5
	11.6	9.9	Sp3	14.9	13.3
				16.2	15.6
Gulabrai			**Batula**		
	7.15 Am	6.00 Pm		8.00 Am.	4.50 Pm.
Sp1	5.1	2.9	Sp1	8.5	4.9
	4.3	3.6		9.6	7.5
Sp2	4.2	2.4	Sp2	31.5	19.4
	2.9	1.7		23.5	15.6
Sp3	4.1	3.2	**Joshimath**		
	6.2	4.2		7.00 Am	5.00 PM
			Sp1	11.8	9.4
Kamera				5.7	4.2
	9.15 Am	4.15 Pm	Sp2	7.9	4.7
Sp1	4.0	1.1		9.5	4.9
	6.3	4.4	**Kothar**		
SP2	8.4	5.1		5.00 Am	6.00 Pm
	6.1	6.8	Sp1	4.6	3.8
SP3	3.3	1.7		2.4	1.3
	2.9	1.5	Sp2	6.5	5.9
SP4	5.0	3.9		4.5	2.4
	5.2	2.4	Sp3	9.0	7.9
Chatwapipal				5.8	4.6
	7.0 Am.	5.30 Pm	Sp4	3.6	2.5
Sp1	6.6	5.8		4.6	3.5
	8.3	6.8	Sp5	5.9	4.8
Sp2	9.0	7.2		4.7	3.0
	11.2	7.8	**Bhaktiyana**		
Sp3	24.0	20.9		6.0 Am.	4.40 Pm.
	22.6	9.4	Sp1	4.9	3.6
Teendhara				5.6	4.2
Sp1	6.15 am	6.30 Pm	Sp2	12.5	10.7
	2.4	1.8		9.8	8.7
	2.8	1.9	Sp3	9.0	7.5
				6.9	5.7

CHAPTER-5

GEOHYDROLOGICAL DESCRIPTION OF THE SPRINGS

Kothar Spring (Srinagar-Garhwal)

This spring is located at an elevation of 600 m (amsl). Some striking features of the spring catchment are given in Table 8. This spring is source of potable water for the local people of Srinagar. The maximum altitude of the spring catchment is 1000 m amsl. Total area of the catchment is about 1 8.75 ha. The upper part of catchment area is occupied by scanty pine forest and some shrubs are present in the down slope (Fig. 13). Three-fourth area of the catchment is occupied by the human habitation (11.75 ha), less than one-forth is forest land (4.25 ha) and the remaining is wasteland (2.75 ha). The settlement has drastically reduced the percolation of rain water into soil due to building structures and hence the rain water flows down in the form of runoff without much infiltration. In the recharge zone of this spring slope ranges from 0-45 degree (Fig. 14). At the base of the hill due to development of the river terraces slopes are very gentle. The aspect of the hill is north.

Geologically this spring is located at the northern limb of the Dudhatoli syncline and general rock type is Pauri phyllite, which has been correlated with the Chandpur phyllite (Kumar et al. 1974) of the Kumaon Super Group. Phyllite is exposed in the spring area and it is a perennial spring. Phyllites are greenish grey, thinly bedded belonging to the Chandpur Formation. Fine compositional banding is characteristic of these phyllites. The phyllite is intruded by the quartz-veins at various places. For the simplicity the phyllite has been divided into thinly and thickly bedded phyllite. In some part of catchment weathered phyllite may be seen. This rock at times show well developed primary sedimentary structures. Parallel bedding, cross bedding, small scale graded bedding and rhythmites are the noteworthy structures. At times there are sandy bands beds, which vary in thickness from few millimeters to few centimeters. These also show parallel banding, load and flute structures and groove marks are also present. From the study of the different planar and linear structures and folds it is evident that the area has undergone at least four major episode of coaxial folding. The gross lithology and primary sedimentary structures suggest that Chandpur Formation bears an affinity with transition zone to shelf mud zone deposits of the basin. North Almora Thrust (NAT) passes through the vicinity of this township, which separates the rocks of Kumaon Super Group from the Garhwal Group of rocks. The general strike of the beds is east- west and dip is towards south with amount from 30-45 degree (Fig. 15). In the spring area various types of erosional and depositional landforms have been investigated. They promote high overland flow and consequently have low infiltration of rainwater, particularly where vegetal cover is lacking or disturbed by various activities. In the upper reaches of mini-catchment slope is very steep and soil cover is also thin. Some colluvial debris fans were also reported in the catchment area. In the low lying area, various levels of terraces (300x150 m dimension) are present. In this area after entering into the Chandpur Formation, the Alaknanda river carves a broad valley. This spring seems to be controlled by lineament which represents the trace of a fractured system on the surface. Owing to the quaternary sediment and colluvial the rain water percolates down and recharges the ground water table.

Table 8: Recharge zone characteristics of Kothar Spring (Srinagar-Garhwal)

Physiography and Structures	Spring is located at the base of a hill at an elevation of 1000 m (amsl) and rocks are fractured and jointed
Rock type	Mostly phyllite with quart veins
Land use	Waste land and settlement
Land cover	Sparse pine forest in upper reaches
Slope (degree)	Slope ranges from 0- 45 degree and more in some places
Aspect	Almost all recharge zone is facing north direction
Altitude (meters)	Spring is located at an altitude of 600m (amsl)
Soil depth (cm)	At different places soil depth varies from 175-300 cm
Spring type	Perennial spring

In 2004 and 2005 average discharge was computed 129 x 10^5 L/Yr. The maximum discharge was recorded in July (33600 L/D) and the minimum in April (7134 L/D). The decline in spring discharge in the lean month of April was about 79% of the peak discharge. The spring discharge data for 2006-07 indicate that the peak discharge was recorded in IInd week of July and August and the least in April (Fig. 16). Thereafter the discharge declined drastically. A direct correlation of spring discharge and rainfall was evident. The annual shifts in the peak discharge were mainly due to rainfall.

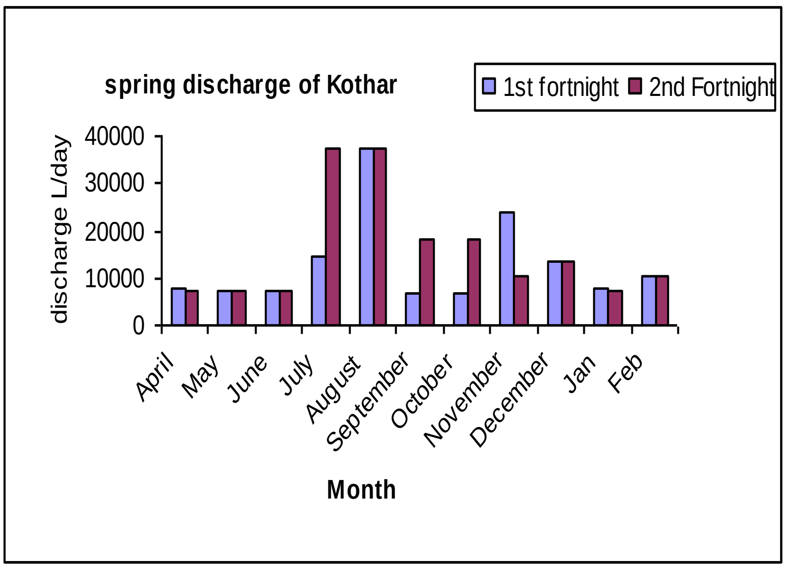

Figure 16: Water discharge pattern of Kothar spring (2006-07).

Bhaktiyana Spring (Srinagar-Garhwal)

The spring is located at 600 m amsl altitude. This spring is source of potable water for the local people of Srinagar. The maximum altitude of the spring catchment is 850 m amsl. Total area of the catchment is about 19.2 ha. The upper part of catchment area is occupied by scanty pine forest and some shrubs are present in the down slope (Fig. 17). One-half area of the catchment is occupied by the human habitation (9.5 ha), less than one-third is forest land (6.7 ha), and the remaining is wasteland and barren land. The settlement has drastically reduced the percolation of rain water into soil due to building structures and hence the rain water flows down in the form of runoff without much infiltration. In this spring recharge zone slope ranges from 0-60 degree (Fig. 18). At the base of hill due to development of the river terraces slopes are very gentle. The aspect of the hill is north-west facing. A summary of different characteristics of the recharge zone of this spring is given in Table 9.

This perennial spring is located on the river terrace and spring flows in S 40^0E–N 40^0W direction. Highly fractured phyllite with cultivated fields (River Terraces) and colluvial deposits are exposed around this spring (Fig. 19). Phyllites are greenish grey, thinly bedded belonging to the Chandpur Formation. In the phyllite fine compositional banding is reported. Six levels of river terraces developed in the area. These terraces are valley fill river terraces and comprise boulders, cobbles and pebbles of quartzites, granites, gneisses, limestone/dolomite, slate/phyllites, mica schist and basic metavolcanics and dolerite and occasionally of fossiliferous rocks. These high level terraces are of Middle to Late Pleistocene in age while Holocene terraces occur at two levels forming the T_2 and T_1 surfaces, 5-30 m above the river level. High level terraces are generally oxidized while the Holocene terraces are unoxidized. The sediments are moderate to poorly sorted, graded and show cyclic sedimentation. The sand fractions are finer-grained than the sediments of glacial domain. T_3 terrace contains fossiliferous rock fragments derived from the Tethyan zone all along the length of the valley. The six level of terraces correspond to the six phase of rejuvenation that has occurred in the region. Agriculture fields, gentle slope with unconsolidated sediment and pine forest in upper reaches make the micro-catchment area of this spring. The gentle terraced upper slope provides good recharge area for the occurrence of spring water.

In 2004 and 2005 average discharge was computed 293.8 x 10^5 L/Yr. The maximum discharge was recorded in October (172800 L/D) and the minimum in September (15732 L/D). The decline in spring discharge in the lean month of September was about 91% of the peak discharge. The biweekly discharge measurements of this spring for 2006-07 show that there was a constant flow of water in the months following the rainy season till winter. Thereafter the discharge declined during months of summer (Fig. 20). The annual shifts in the peak discharge were mainly due to rainfall.

Table 9: Recharge zone characteristics of Bhaktiyana spring (Srinagar-Garhwal)

Physiography and Structures	Spring is located at the base of a hill at an elevation of 850 m (amsl) and rock are fractured and jointed.
Rocks type	Mostly thinly bedded phyllite with quartz-veins
Land use	Waste land and mostly settlement.
Land cover	Sparse pine forest in upper reaches
Slope (degree)	Slope ranges from 0- 60^o and more in some places
Aspect	Almost all the hill is facing north-west direction
Altitude (meters)	Spring is located at an altitude of 550m amsl
Soil depth (cm)	At different places soil depth varies from 15-2300 cm
Spring type	Perennial spring

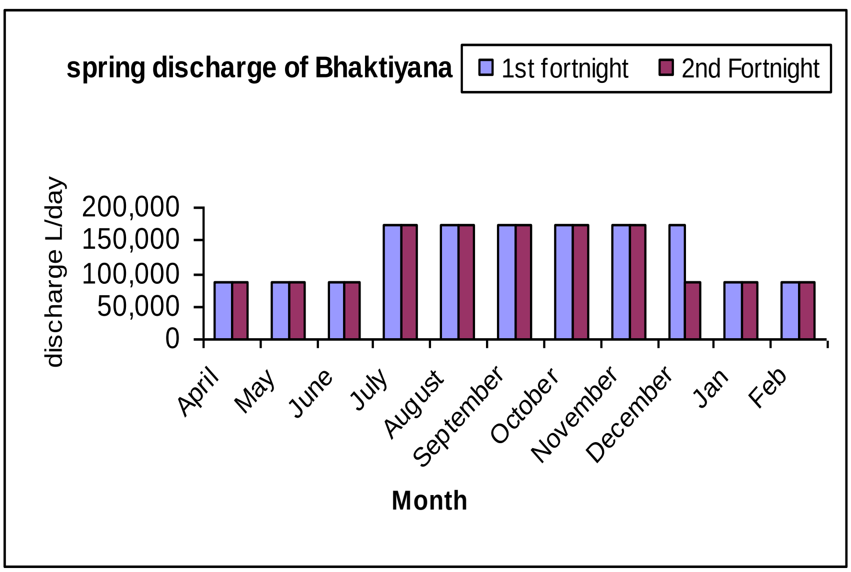

Figure 20: Water discharge pattern of Bhaktiyana spring (2006-07).

Karas Spring (Tehri-Garhwal)

The spring is located at 1500 m (amsl). It is a perennial spring, located on the old colluvial deposits and spring flow in S65^{0}E–N65^{0}W direction. This spring is source of potable water for the local people of Karas. The maximum altitude of the spring catchment is 1800 m amsl. Total area of the catchment is about 17.6 ha (Fig. 21). The upper part of catchment and one-half area is occupied by very dense Oak forest (8.1 ha). Less than one-half area of the catchment is occupied by cultivated land (7.2 ha) and the remaining is wasteland (1.2 ha) and human habitation (0.16 ha). Due to dense Oak forest the rainwater gets maximum time to percolate in the ground and enhances the ground water table. This is the basic reason that this spring gushes out maximum flow of water as compared to the others springs. The immediate upper slopes are gentle and are occupied by agricultural terraces. However the slopes further up, near to the recharge area are moderately steep, covered by dense forest cover (Fig. 22). The gentle slope (10^o-15^o) and amphitheatre form, and dense forest cover in the upper reaches provide good hydraulic gradient and recharge area, which is conducive for water recharge. The important features of the spring catchment are given in Table 10.

Geologically it is located in the Chandpur phyllite of the Kumaon Super Group (Kumar & Agrawal, 1974). The local name of the rocks is Chandrabadani member. The rocks exposed in this area are phyllite with some metabasics and quartzite bands, equivalent to Chandpur Formation (Fig. 23). The phyllite is thinly bedded, grayish white to dark grey, greenish, some time chloritic and micaceous, at places siliceous and is traversed by veins and lenticles of quartz. The phyllite is intruded by the quartz-veins at various places. In some part of catchment weathered phyllite may be seen. The formation rests on the Sakhanidhar quartzite in the south. The general strike of the beds is North East-South West and dip is towards North 120^o degree with amount from 32-45^o. Owing to the multiplicity of the joints, fractures and faults this rock serves a very good aquifer for the water retention. In the recharge zone of this spring slope ranges from 0-50^o. The aspect of the hill is west direction.

Table 10: Recharge zone characteristics of Karas spring (Tehri-Garhwal)

Physiography and Structures	Spring is located at the centre of a hill of an elevation of 1800 m (amsl) and rock are fractured and jointed
Rocks type	Mostly Phyllite with quart veins
Land use	Maximum portion is cultivated and very little settlement
Land cover	Very dense Oak forest in upper reaches
Slope (degree)	Slope ranges from 0- 50 ^{o} and more in some places
Aspect	Almost all the hill is facing west direction
Altitude (meters)	Spring is located at an altitude of 1500 m (amsl)
Soil depth (cm)	At different places soil depth varies from 5-70 cm
Spring type	Perennial spring.

In 2004 and 2005 average discharge was computed 206 x 10^5 L/Yr. The maximum discharge was recorded during July - September (172800 L/D) and the minimum in April (13935 L/D). The decline in spring discharge in the lean month of April was about 92% of the peak discharge. The biweekly spring discharge for this spring for 2006-07 shows that the water yield peaks during rainy months and decline gradually thereafter and reach a minimum in May-June (Fig. 24).

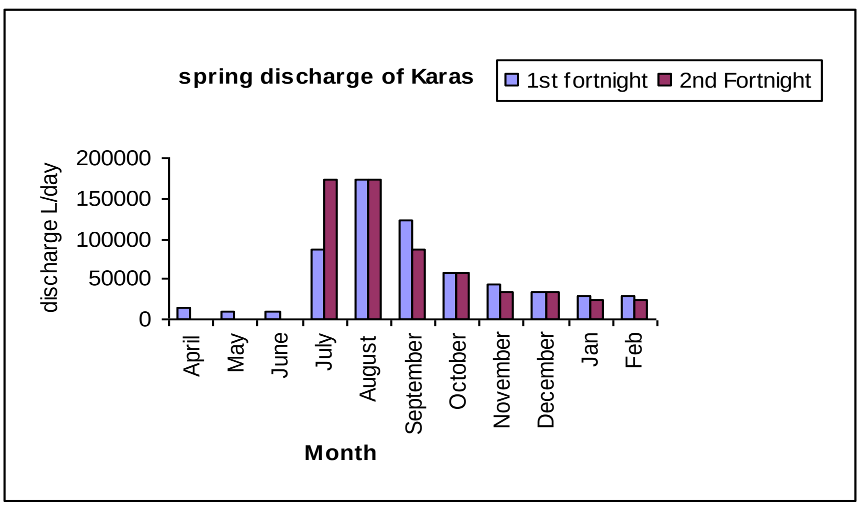

Figure 24: Water discharge pattern of Karas spring (2006-07).

Bidakot Spring (Tehri Garhwal)

This spring is located at 1250 m (amsl). This spring is source of potable water for the local people of Bidakot. The maximum altitude of the spring catchment is 1600 m amsl. Maximum area of the catchment is occupied by the cultivated land (Fig. 25). Slope of the spring ranges from 10-60^{o}. At the top of the hill slope conditions are moderate to gentle (Fig. 26). The aspect of the hill is east to southeast. The maximum part of catchment is occupied by cultivated land and some shrubs are present in the down slope. Three-forth area of the catchment is occupied by the cultivated land and rest part of the catchment is occupied by the wasteland and shrubs. In the top of the catchment a few portion is occupied by the human habitation. Due to very coarse soil conditions and moderate to steep slope rainwater either gets evaporated or flows in the form of surface runoff without much infiltration. Some of the distinguishing features of the spring are given in Table 11.

Bidakot is located on the Chandpur phyllite of the Kumaon Super Group. Phyllite is exposed in the spring area. Phyllites are greenish grey, thinly bedded belonging to the Chandpur Formation of Garhwal Group. The phyllite is intruded by the quartz-veins at various places. In some parts of the catchment interbedded slate and weathered phyllite may be seen (Fig. 27). Fine compositional banding is characteristic of these phyllites. This rock at times show well developed primary sedimentary structures. Parallel bedding, cross bedding, small scale graded bedding and rhythmites are the noteworthy structures. These also show parallel banding, load and flute structures and groove marks are also present. From the study of the different structures it is evident that this area has undergone at least four major episode of folding. Phyllite is dipping inside the hill slope i.e. in northeast direction. Generally the phyllite is fractured and sheared and three sets of joints are present. From the field study it appears that some lineament is controlling the spring because this spring is located at the seasonal nala. Colluvial material is present on the both side of the spring slope. The formation rests on the Sakhanidhar quartzite in the southwest. The general strike of the beds is North 320^{o} and dip is towards North 230^{o} with an amount ranging from 21-35^{o}.

Table 11: Recharge zone characteristics of Bidakot spring (Tehri-Garhwal)

Physiography and structures	Spring is located at the center of a hill of an elevation of 1600 m (amsl) and rock are fractured, jointed
Rocks types	Mostly phyllite, slate with quart –veins
Land use	Cultivated, wasteland and settlement in smaller fraction
Land cover	Almost forest less
Slope in (degree)	Slope ranges from 10- 60^{o}
Aspect	Almost the hill is facing east-southeast direction
Altitude (m)	Spring is located at an altitude of 1250 m (amsl)
Soil depth (cm)	In the cultivated land soil depth was approx. 30- 70 cm
Spring type	Perennial spring

In 2004 and 2005 average discharge was computed 75.2 x 10^5 L/Yr. The maximum discharge was recorded during September (57600 L/D) and the minimum in March (8388 L/D). The decline in spring discharge in the lean month of March was about 85% of the peak discharge. The spring discharge recorded at biweekly interval during 2006-07 shows that there was a decreasing trend in discharge in the months following rainy season (Figure 28). The discharge peaks during August and September and least during the months of May and June. The annual shifts in the peak discharge were mainly due to rainfall.

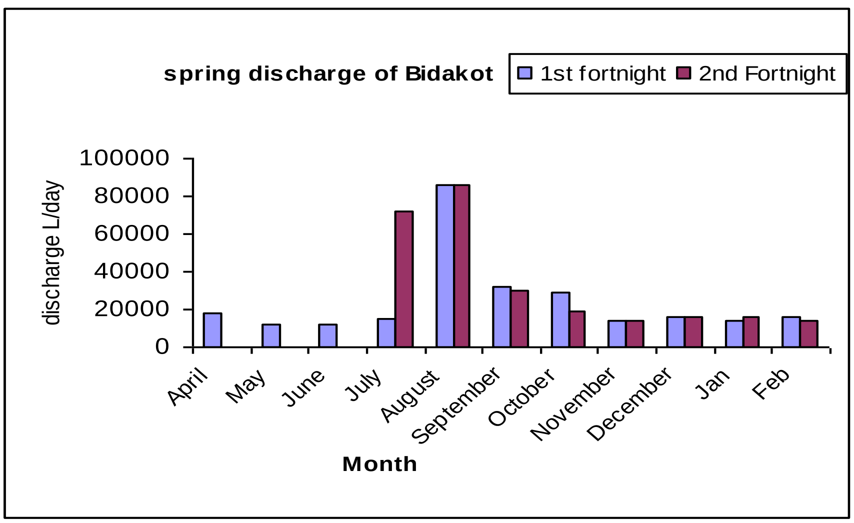

Figure 28: Water discharge of Beedakot spring (2006-07).

Teen Dhara Spring (Tehri-Garhwal)

The spring is located at 700 m (amsl). This spring is source of potable water for the local people of Teendhara and tourists who travel on the Haridwar-Badrinath highway. The maximum altitude of the spring catchment is 900 m (amsl). Almost total area of catchment is wasteland with shrubs dominating in the area (Fig. 29). The upper part of catchment area is occupied by shrubs with the rock cliff, while in the vicinity of the spring some mixed forest may be seen, which might have been grown due to moisture contents in the down slope. Shrubs have been very important to check the flow of water in the sloping surface because rainwater gets sufficient time to infiltrate and in this way it increases the ground water table. Teendhara spring's slopes ranges from 10-60^o (Fig. 30). In the maximum part of the catchment slopes are gentle to moderate. The hill is facing towards north direction. Some striking features of the spring catchment are given in Table 12.

Geologically Teendhara spring is located in the Sakhanidhar Quartzites, which are correlated with the Nagthat of the Kumaon Super Group. The rocks exposed in this area are quartzites and greywacke of Garhwal Group. The rocks are highly folded, faulted, fractured and jointed throughout the catchment (Fig. 31). The rocks are intruded by quartz-veins at various places. In some parts interbedded slate of rocks has also been found. The quartzites and greywacke are purple, pink and cream coloured. At places the quarzites and greywacke show alternate dark brown or white and cream coloured banding referred as Zebra banding. The quartzite is also showing the gritty nature. This sequence belongs to an Argillo-arenaceous Facies and referred to as Sakhnidhar Formation. In stratigraphic position this sequence is equivalent to the Rudraprayag Formation. This formation has a fault contact with the Blani Formation in the area south-west of Saknidhar. The rocks are generally dipping towards northeast. Water is coming through the joints, of the detached rock mass body. In the quartzite three sets of joints are present and along some joints shear zones were also reported. The general strike of the beds is northwest to southeast and dip is North 230^o with amount ranging from 30-45^o. The strike of the Joint sets was found N 30^o East to South 30^o. West with an amount of 45^o and NE-SW 45^o and dip is toward north 135^o. Owing to the multiplicity of joints and sheared nature of the quartzite rocks, the rainwater percolates down and recharges the ground water or perched water table of the catchment. These rocks have been very good aquifer for the water retention in the area.

Table 12: Recharge zone characteristics of Teen Dhara spring (Tehri-Garhwal)

Physiography and Structures	Spring is located at the base of a hill at an elevation of 700 m amsl and rocks are intensely fractured, jointed and folded. Maximum elevation is 900 m (amsl). The spring is in the centre of hill which has been exposed due to road cutting
Rocks type	Mostly buff coloured massive quartzite and slate with quart veins
Land use	Barren land
Land cover	Very sparse mixed forest in down slope and shrubs
Slope (degree)	Slope ranges from 10- 60^o and more in some places
Aspect	Almost all the hill is facing north direction
Altitude (meters)	Spring is located at an altitude of 700m (amsl)
Soil depth (cm)	Hardly 30 cm
Spring type	It is a perennial spring

In 2004 and 2005 average discharge was computed 73.4 x 10^5 L/Yr. The maximum discharge was recorded during September (57600 L/D) and the minimum in April (6492 L/D). The decline in spring discharge in the lean month of April was about 89% of the peak discharge. The biweekly discharge recorded for this spring recorded during 2006-07 shows that the water yield has not gone down substantially as was recorded for the earlier two springs (Fig. 32). This indicates the structural control over the spring discharge. The peak discharge was recorded in the month of September and October and the least discharge during April. This represents the delayed flow, which is greater in amount that flow in the rainiest months. The annual shifts in the peak discharge were mainly due to rainfall.

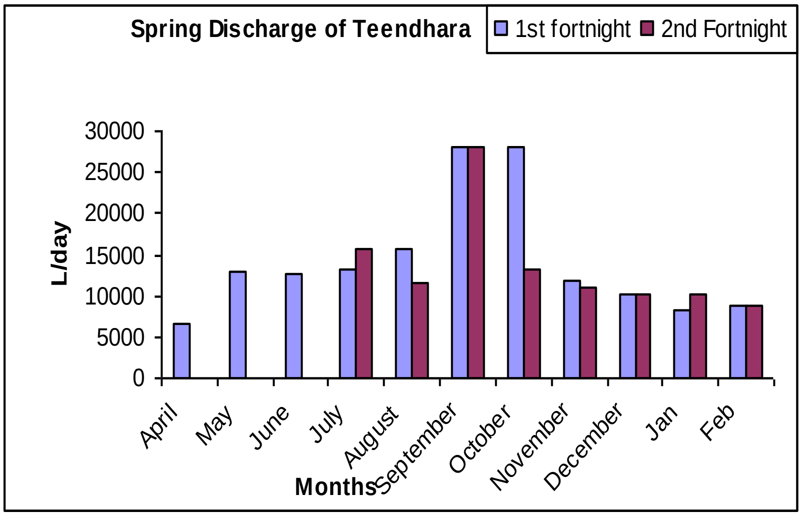

Figure 32: Water discharge of Teendhara spring (2006-07).

Gulabrai Spring (Rudraprayag-Garhwal)

This spring is located at 700 m (amsl). It is a perennial spring and spring flow in N 70^{0}E – S 70^{0}W direction. The maximum altitude of the spring micro-catchment is 1400 m amsl. The spring is a source of potable water for the people of Gulabrai. Vegetative cover in the spring catchment consisting of pine forest (a conifer) with shrubs and herbs, and coarse grain material with gentle slope makes good water holding capacity in the micro-catchment of this spring (Fig. 33). Total area of the recharge zone of the spring is about 12.3 ha. Part of the spring micro-catchment is occupied by pine forest and some shrubs are present in the down slope. About three-fourth of the micro-catchment is covered by pine forest (1.1 ha.), followed by broad leaf forest (0.7 ha), and the remaining is cultivated land (0.2 ha) and human habitation (0.11 ha). The slope of the micro-catchment ranges from 0-70^o (Fig. 34). At the base of hill due to development of the river terraces slopes are very gentle. The aspect of the hill is north. Some striking features of the spring catchment are given in Table 13.

Gulabrai is a located in the Chandpur phyllite and quartzite of the Kumaon Super Group (Kumar & Agrawal 1974). The phyllite is trotted by quartzite at various places. In some parts of the spring catchment quartzite may be seen (Fig. 35). North Almora Thrust (NAT) passes through the vicinity of this spring, which separates the rocks of Kumaon Super Group from the Garhwal Group of the rocks. Quartzite is exposed in the spring area and belong to the Rudraprayag Formation of Garhwal Group. The quartzite shows well developed stratification including numerous ripple marks and cross bedding indicating normal sequence of deposition in shallow marine environment. At some places on the basis of mineralogical character, texture, colour and the nature of intrusive, the quartzite are sub-divided into massive, gritty and schistose varieties. The quartzite is medium to fine grained and at some localities interbedded with thin bands of gray to purple slates. These quartzites are characterized by extensive occurrence of basic volcanics and intrusive, which have suffered a little metamorphosis. The basic flows are pen contemporaneous with sedimentation and are folded with host rock. The metavolcanics is dark green in colour and is very fine to amygdaloidal and vesicular in character. The vesicles being filled by secondary minerals like quartz, feldspar and epidote etc. Various types of erosional and depositional land forms have been found in this area. Numbers of colluvial deposits were reported at the higher reaches and at the lower elevation valley fill terraces are present. The slope is generally trending towards north. The foliation / bedding plane strike in general is N 70^0 E – S 70^0 W dipping 30 to 35^0 in south west direction. In the Gulabrai valley various types of erosional and depositional land forms have been found. Some hill slopes occur at spring's headwaters. They promote high over land flow and consequently have low infiltration of rain water, particularly where vegetal cover is lacking or disturbed by various activities. At the low lying area terraces are present owing to the quaternary sediment and colluvial deposits. Through these the rain water percolates down and recharges the ground water table.

Table 13: Micro-catchment characteristics of Gulabrai spring

Physiography	Spring is located at the base of a hill at an elevation of 700 m (amsl) and rocks are fractured and jointed
Rock type	Mostly quartzite/ phyllite
Land use	Broadleaf and conifer forest, settlement and cultivable wasteland
Land cover	Sparse pine forest in upper reaches and scattered broadleaf forest towards the middle of the catchment
Slope (degree)	Slope ranges from 0-70 degree and more in some places
Aspect	Almost all the hill is facing north direction
Soil depth (cm)	At different places soil depth varies from 5-70 cm
Spring type and direction	It is a perennial spring and spring flow direction is N 70^0 E–S 70^0 W.

In 2004 and 2005 average discharge was computed 187.2 x 10^5 L/Yr. The maximum discharge was recorded during August to October (172800 L/D) and the minimum in February (45473 L/D). The decline in spring discharge in the lean month of February was about 74% of the peak discharge. The biweekly discharge data for 2006-07 shows that maximum spring discharge was recorded during July and August and the minimum discharge during January. The spring discharge increased during rainy season and gradually declined thereafter (Fig. 36). The annual shifts in the peak discharge were mainly due to rainfall.

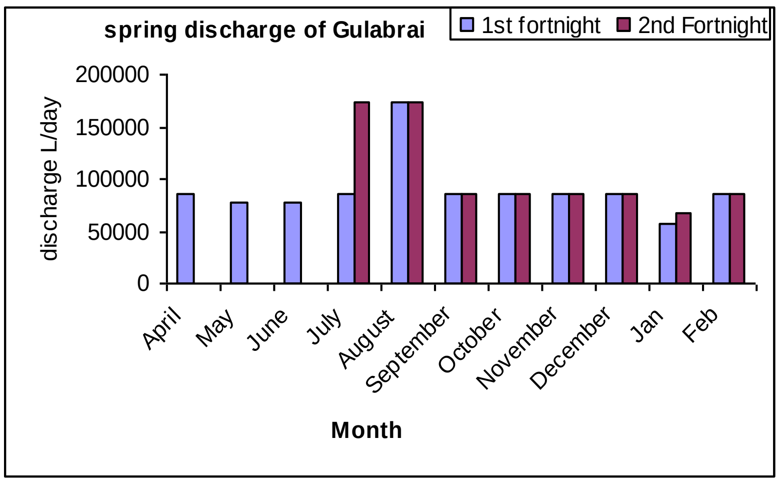

Fig. 36: Water discharge pattern of Gulabrai spring (2006-07).

Kamera Spring (Rudraprayag-Garhwal)

This spring is located at 750 m (amsl) and a source of potable water for the local people of Kamera. The maximum altitude of the spring micro-catchment is 1500 m (amsl). The maximum area of the spring micro-catchment is occupied by cultivated land (Fig. 37). The vegetative cover in the spring micro-catchment comprises of thick Pine forest in upper reaches and cultivated land around the spring. Three- fourth area of the spring micro-catchment is occupied by the cultivated land and rest part of the catchment is Pine forest in the down slope, wasteland and shrubs. In the middle of the catchment a few portion is occupied by the human habitation. Due to very medium soil, coarse soil condition and moderate slope rain water either flows in the form of surface runoff without much infiltration. In the higher reaches the slope angle is more than 70 degree while around the spring locality the slope angle is less than 20^{o} (Fig. 38). The slope is facing towards north. At the top of the hill slope conditions are moderate to gentle. The hill slopes at the spring's headwaters promote high over land flow and consequently have low infiltration of rain water to recharge the ground water. The spring is exposed along the seasonal streams (lineament controlled) but water discharge appears only at Kamera village. Some striking features of the spring catchment are given in Table 14.

Table 14: Micro-catchment characteristics of Kamera spring

Physiography	Spring is located at the base of a hill at an elevation of 750 m (amsl) and rocks are fractured and jointed
Rock type	Mostly quartzite/ phyllite
Land use	Maximum area is covered by human settlement and some part by cultivated land
Land cover	Sparse pine forest in upper reaches
Slope (degree)	Slope ranges from 0 to 60^{o} and more in some places
Aspect	Almost all the hill is facing north direction
Soil depth (cm)	At different places soil depth varies from 5-60 cm
Spring type and direction	It is a perennial spring and spring flow direction is N 80^{0} E–S 80^{0} W

Kamera is a located in the quartzite and phyllite rocks of the Kumaon supper Group. Mainly phyllite is exposed in the spring area belong to the Lameri Formation of Garhwal Group. The phyllite has the contact with the quartzite of Rudraprayag Formation. Phyllite rocks interbedded with thick quartz rocks are exposed near the spring (Fig. 39). Fractured and shear zone, quartzite and interbedded phyllite were also observed. Phyllite is fractured and sheared while in the quartzite three sets of joints are present. These rock have been very good aquifer for the water retention in the area. The foliation / bedding plane strike in general is N80^{0}E – S80^{0}W to N70^{0}E – S70^{0}W dipping at 35^0 in northeasterly direction. In the Kamera valley various types of erosional and depositional landforms have been reported. The hill slope is very steep in the upper side of the spring and its geomorphological setup indicates that maximum rain water flows away as runoff without much recharging the groundwater. The spring is located along the lineament controlled E-W trending first order stream. Two sets of joints are very prominent and these are enhancing the secondary porosity of the rock.

In 2004 and 2005 average discharge was computed 89.9 x 10^5 L/Yr. The maximum discharge was recorded during August - September (86400 L/D) and the minimum in June (14400 L/D). The decline in spring discharge in the lean month of June was about 83% of the peak discharge. Biweekly observations of the spring water yield during 2006-07 are depicted in Fig. 40. The discharge following rainy season was not diminished much till 4-5 months. The maximum spring discharge was recorded during August to October and the minimum discharge in June. The shifts in the peak discharge were mainly due to rainfall.

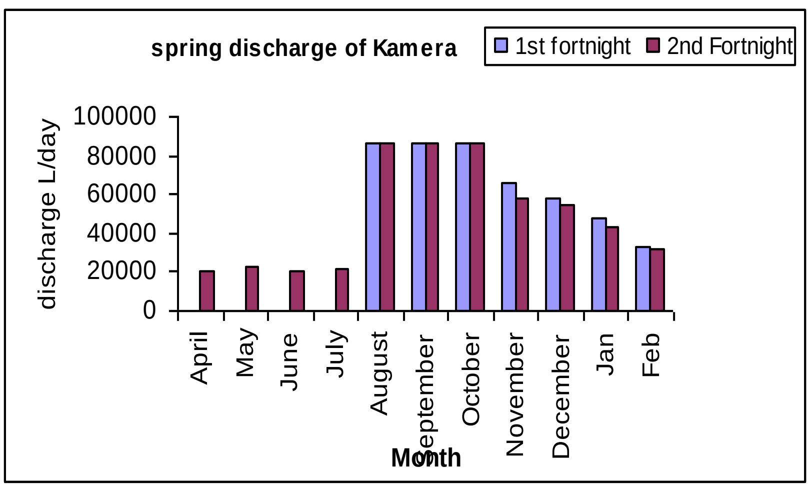

Fig. 40: Water discharge pattern of Kamera spring (2006-07).

Chatwapipal Spring (Chamoli-Garhwal)

This spring located at 750 m (amsl) is a source of potable water for the people of Chatwapipal. The maximum altitude of the spring micro-catchment is 1500 m (amsl). Most part of the spring micro-catchment is occupied by cultivated land, some parts by pine forest in the down slope, wasteland and shrubs (Fig. 41). In the top and middle of the catchment a few portion is occupied by the human habitation. In the spring micro-catchment slope ranges from 10 to 60^o (Fig. 42). At the top of the hill slope conditions are moderate to gentle. The aspect of the hill is north. A summary of different characteristics of the micro-catchment of this spring are given in Table 15.

Table 15: Micro-catchment characteristics of Chatwapipal spring

Physiography	Spring is located at the base of a hill at an elevation of 750 m (amsl). Rocks are fractured and jointed
Rock type	Mostly quartzite/ phyllite and parts of mica schist
Land use	Cultivated, wasteland and settlement in smaller fraction
Land cover	Almost cultivated land / pine forest in upper reaches
Slope (degree)	Slope range from 10 to 60^o
Aspect	Almost all the hill is facing north direction
Soil depth (cm)	At the different places soil depth varies from 5-80 cm
Spring type and direction	It is a perennial spring and spring flow direction is N 30^0 W–S 30^0 E

It is a perennial spring and spring flow in N30^{0}W– S30^{0}E direction. Geologically Chatwapipal is a located in the Chandpur phyllite and quartzite rocks of the Kumaon supper Group. The rock types are mainly phyllite and quartzite subordinated mica schist are also observed in the spring catchment areas (Fig. 43). Highly fractured phyllite and mica schist with cultivated field are exposed around the spring. Mainly phyllite is exposed in the spring area belong to the Lameri Formation of Garhwal Group. The phyllite has the contact with the quartzite of Rudraprayag Formation. The spring is located just in the south of Alaknanda Fault. The foliation / bedding plane strike in general is N 20^0 E – S 20^{0}W to N 40^0 E – S 40^0 W dipping 80 to 75^0 in south easterly direction. The rock strata are transected by the following three set of joints i.e. vertical, horizontal and oblique and are highly fractured and jointed.

In 2004 and 2005 average discharge was computed 131.7 x 10^5 L/Yr. The maximum discharge was recorded during August - September (172800 L/D) and the minimum in June (864 L/D). The decline in spring discharge in the lean month of June was about 99.5% (maximum across all the springs studied) of the peak discharge. Data of the spring discharge recorded during 2006-07 is depicted in Figure 44. The spring shows marked response to rainfall due to highly permeable nature of the deposit. The shifts in the peak discharge were mainly due to rainfall.

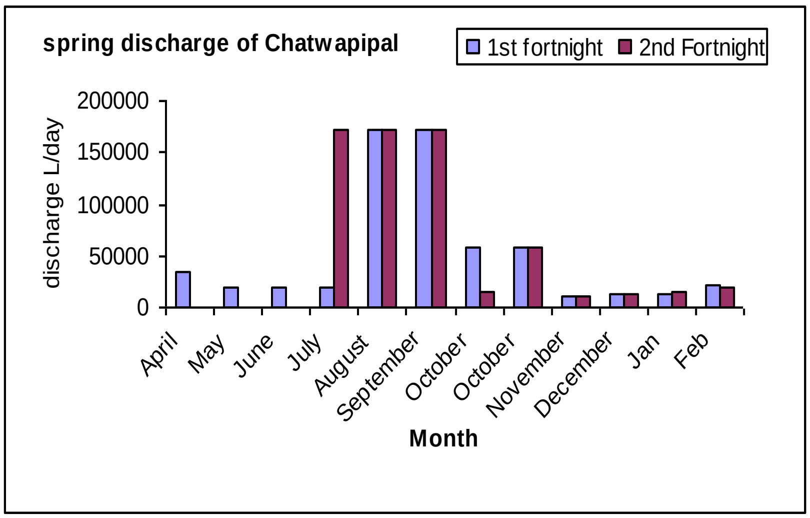

Fig. 44: Water discharge pattern of Chatwapipal spring (2006-07).

Bhatoli Spring (Chamoli-Garhwal)

This perennial spring is located at 1200 m (amsl) and flows in N40^0W–S40^0E direction. This is a source of potable water for the local people of Bhatoli. The maximum altitude of the spring micro-catchment is 1800 m amsl. The maximum area of catchment is occupied by the cultivated land and some parts by Pine forest, grass land and shrubs in the down slope (Fig. 45). In the Bhatoli spring micro-catchment slope ranges from 20 to 60 degree. At the top of the hill slope conditions are moderate to gentle (Fig. 46). The aspect of the hill is north. Bhatoli is a located in the quartzite and phyllite rocks. The rock type of spring catchment is mainly quartzite with interbedded phyllite. The spring is located at the contact of phyllite with quartzite (Fig. 47). A thick succession of fine to medium grained cream, white, pink and brown coloured muddy quartzites is exposed in and around the spring. In the upper part of spring some Quaternary colluvial material is present. This sequence is characterized by extensive occurrence of basic sills and lava flows. Amygdaloidal cavities are found in basics at many localities. The foliation / bedding plane strike in general is N70^{0}E – S70^{0}W to N50^{0}E – S50^{0}W dipping 30^0 to 35^0 in southeasterly directions. The quartzite is compact and breaks with ease along the bedding schistosity. The rock at places becomes highly ferruginous which on weathering form thin coatings of yellowish brown to brown colour along the cleavage planes. Three prominent set of joints were reported in the quartzite and at many localities joint walls are not in a direct contact and finally material in the form of gauge material or crushed rock fragment is present which, affects the strength of joints which will be that of the filling material. A summary of different characteristics of the micro-catchment of this spring is given in Table 16.

Table 16: Micro-catchment characteristics of Bhatoli spring

Physiography	Spring is located at the center of a hill at an elevation of 1200 m amsl. The rocks are fractured and jointed
Rock type	Mostly quartzite interbedded with phyllite
Land use	Cultivated, wasteland and settlement in smaller fraction
Land cover	Mostly agricultural crops / pine forest in upper reaches
Slope (degree)	Slope range from 20 to 60^o
Aspect	Almost all the hill is facing north direction
Soil depth (cm.)	At the different places soil depth varies from 5-65 cm
Spring type and direction	It is a perennial spring and spring flow direction is N 40^0 W–S 40^0 E

In 2004 and 2005 average discharge was computed 55.7 x 10^5 L/Yr. The maximum discharge was recorded during October (86400 L/D) and the minimum in January (8727 L/D). The decline in spring discharge in the lean month of January was about 90% of the peak discharge. The pattern of spring discharge for 2006-07 shows that the recession of discharge after peak in July-August was gradual (Fig. 48). Peak spring discharge was recorded during August and the least during February. The shifts in the peak discharge were mainly due to rainfall.

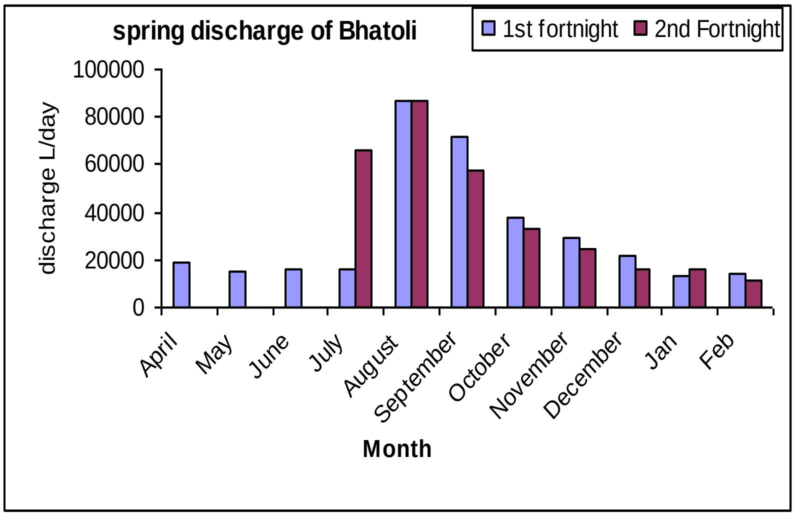

Fig. 48: Water discharge pattern of Bhatoli spring (2006-07).

Maithana Spring (Chamoli-Garhwal)

This perennial spring is located at 1000 m (amsl) and flows in N70^{0}E–S70^{0}W direction. The maximum altitude of the spring catchment is 1800 m (amsl). This spring is source of potable water for the local people of Maithana. About three-fourth area of the spring micro-catchment is occupied by cultivated land and some parts by grass land and shrub land in the down slope (Fig. 49). At the top of the catchment a few portion is occupied by human habitation. The steep slopes and coarse soil promotes the water to flow in the form of surface runoff without much filtration. Three prominent fractures in highly weathered granitic gneisses and schists are controlling the movement of ground water in this area. In the spring micro-catchment slope ranges from 5 to 65^o and facing towards south and southeast direction (Fig. 50). At the top of the hill slope conditions are moderate to gentle. The aspect of the hill is east to south east. A summary of different characteristics of the micro-catchment of this spring is given in Table 17.

Geologically Maithana is a located in the Maithana quartzite of the Kumuan supper Group (Kumar & Agrawal 1974). Lithologically they are granite gneisses and schist with thick lenses / bands of white quartzites and the basic sills (Fig. 51). These quartzites resemble the litho-units of the Chamoli quartzite Formation. The southern contact of these crystalline is appeared top thrusted. The Nandprayag crystalline exposed between Pursari and Nandprayag and forms a broad synformal structure having an exposed width of nearly 8 km. The axis of this structure passes through Maithana village. Highly fractured and folded quartzite with phyllite rocks are exposed in the spring side. Parent rocks are exposed quartzite with interbedded phyllite are also observed in the spring catchment area. The rocks of this area supposed to be equivalent to Munsiari Formation. The foliation of bedding plane strike in general is N 10^0 W – S 10^0 E dipping 40 to 45^0 in north easterly direction.

Table 17: Micro-catchment characteristics of Maithana spring

Physiography	Spring is located at the center of a hill at an elevation of 1000 m (amsl). The rocks are fractured and jointed
Rock type	Mostly quartzite and phyllite
Land use	Maximum portion is cultivated, the rest is wasteland and grass land
Land cover	Sparse pine forest in upper reaches
Slope (degree)	Slope range from 5 to 65^o
Aspect	Almost all the hill is facing east-south east direction
Soil depth (cm)	At the different places soil depth varies from 5-70 cm
Spring type and direction	It is a perennial spring and spring flow direction is N 70^0 E–S 70^0 W

In 2004 and 2005 average discharge was computed 39.6 x 10^5 L/Yr. The maximum discharge was recorded during August (43200 L/D) and the minimum in June (864 L/D). The decline in spring discharge in the lean month of June was about 98% of the peak discharge. The pattern of spring discharge recorded during 2006-07 shows that the maximum discharge of the spring was recorded during august and the minimum was recorded during April and June (Fig. 52). Although in the post-monsoon season the recession of discharge not very high but during spring and summer the discharge goes down drastically.

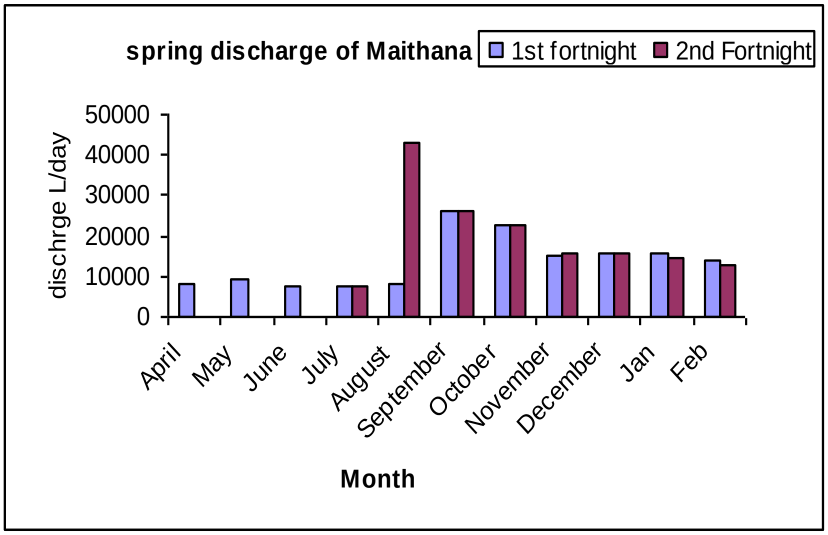

Fig. 52: Water discharge pattern of Maithana spring (2006-07).

Batula Spring (Chamoli-Garhwal)

This perennial spring is located at 1400 m (amsl). This spring is source of potable water for the local people of Batula and the tourists who travel on the Haridwar – Badrinath highway. The maximum altitude of the spring catchment is 2000 m amsl. Most of the micro-catchment of the spring is occupied by cultivated land and Oak forest (a broadleaf forest). In the top of the catchment a small portion is occupied by the human habitation (Fig. 53). Due to dense Oak forest the rain water gets maximum time to percolate in the ground and enhances the ground water table. This is the basic reason that water yield of this spring is maximum as compared to the other springs. In the micro-catchment of Batula spring, slope ranges from 15 to 60^{o} (Fig. 54). The aspect of the hill is in west direction. The gentle upper slopes making a bowl like geomorphic feature and large recharge area are indicative of availability of groundwater for recharge this spring. A summary of the striking features of this spring is given in Table 18.

Geologically this spring is located on the old colluvial deposits and flows in $S40^0W$ –$N40^0E$ direction. The rocks around the spring form an anticline whose axis is almost northeast-southwest near Pipalkoti. The area is occupied by Garhwal Group of rocks of Proterozoic age which comprises calcareous shale/ slate and dolomitic limestone. The dolomitic limestone has been further divided into thinly and thickly bedded. The rocks are very complex, folded and faulted and shear zones are present (Fig. 55). The general strike of the beds is Northeast –Southwest and dip is towards $S60^0E$ with amounts varying from 45-60^o. Owing to the multiplicity of the joints, fractures and fault this rock is a very good aquifer for the water retention. The spring is in contact of limestone and slate. Three prominent river terraces developed around the spring area. These terraces are valley fill river terraces and comprise boulders, cobbles and pebbles of quartzites, granites, dolomite, slate and basic metavolcanics. The sediments are moderate to poorly sorted, graded and show cyclic sedimentation. These high level terraces are of Middle to Late Pleistocene in age and are generally oxidized.

Table 18: Micro-catchment characteristics of Batula spring

Physiography	Spring is located at the center of a hill at an elevation of 1400 m (amsl). Rocks are fractured and jointed. The spring in the centre of hill which has been exposed due to road cutting
Rock type	Mostly lime stone and with interbedded slates
Land use	Agriculture land / oak forest in some parts
Land cover	Very dense oak forest in upper reaches
Slope (degree)	Slope range from 17 to 65^o
Aspect	Almost all the hill is facing west direction
Soil depth(cm.)	At the different places soil depth varies from 5-80 cm
Spring type and direction	It is a perennial spring and spring flow direction is S 40^0 W –N 40^0 E

In 2004 and 2005 average discharge was computed 205.3 x 10^5 L/Yr. The maximum discharge was recorded during August - October (172800 L/D) and the minimum in April (21400 L/D). The decline in spring discharge in the lean month of April was about 88% of the peak discharge. The pattern of spring discharge recorded during 2006-07 was almost constant during rainy months and suddenly dropped thereafter for the rest of the non-rainy months (Fig. 56). The peak discharge continues from July to October and the minimum discharge was recorded in April 2006.

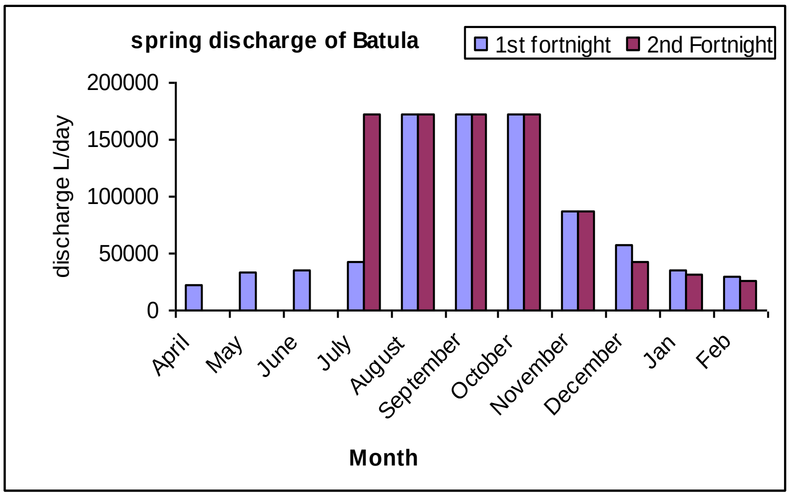

Fig. 56: Water discharge pattern of Batula spring (2006-07).

Joshimath Spring (Chamoli-Garhwal)

This spring is located at 2100 m amsl. The maximum altitude of the spring catchment is 2800 m amsl. The maximum part of catchment is occupied by the township settlement and dense Oak forest towards the ridge of the micro-catchment (Fig. 57). Due to dense Oak forest at the ridge of the spring catchment the rain water gets maximum time to percolate in the ground and enhances the ground water table. This is the reason behind the maximum water yield of this spring as compared to other springs. The other factor is that the area also receives appreciable quantity of snowfall during winter season. Slope of the catchment area of this spring ranges from 0 to 70^{o} (Fig. 58). At the top of the hill slope conditions are moderate to gentle. The aspect of the hill is in west direction. This spring is source of potable water for the local people of Joshimath. Joshimath is a located in the higher Himalaya on the Badrinath highway. Some of the striking features of this spring are given in Table 19.

Table 19: Micro-catchment characteristics of Joshimath spring

Physiography	Spring is located at the center of a hill at an elevation of 2100 m (amsl). The rocks are fractured and jointed
Rock type	Mainly micaceous gneiss with interbedded garnetiferous schist
Land use	Settlement and wasteland
Land cover	Very dense oak forest in upper reaches
Slope (degree)	Slope range from 0 to 70^o
Aspect	Almost all the hill is facing towards west direction
Soil depth (cm)	At the different places soil depth varies from 5-95 cm
Spring type and direction	It is a perennial spring and spring flow direction is N 10^0 E –S 10^0 W

This perennial spring is located on the old colluvial deposits and spring flow in N10^0E –S10^0W direction. The parent rocks are exposed along road cutting about 400 m below the spring catchment area. The rock types are mainly micaceous gneiss with interbedded garnitiferous schist bands and subordinated quartz veins are also observed (Fig. 59). The rock exposed in and around the spring area is high grade quartz-plagioclase-muscovite-garnet-kyanite and sillimanite bearing gneisses. The rock has high grade metamorphism of kyanite zone, which have been deformed repeatedly. The rock is jointed but their shearing resistance is high (RMR 60-65). The foliation plane strike in general is N60^0W- S60^0E to N80^0W- S80^0E dipping 30 to 35^0 in north easterly direction. The Joshimath gneisses are coarse grained and dip towards NE direction. Small scale folds, ptygmatic folds, pinch and swell structure, badinages are commonly noted in these gneisses. In quartz-mica gneisses three sets of joints are present: (i) trending in N65^oW-S65^oE dip towards N25^oE direction at 30^o-40^o, surfaces are planar and rough, (ii) vertical joints striking in N60^oE–S60^oN direction, surfaces are rough and undulating, and (iii) trending in N70^oE–S70^oW dipping towards S20^oE, surfaces are smooth and planar. The spacing of the Ist set of joints are 4-30 cm, IInd sets are 50-80 cm and IIIrd sets are 40-85 cm. The bedrock is overlain by alluvial soil near the valley, whereas the glacial moraines and solifluction lobes are common at higher elevation. Solifluction is a common process in the periglacial zone of frost heaving and frost creep. These lobes are generally triggered on permafrost action, as they swell and are converted into mud. The cultivated terraces of this area are tilted towards the river indicating creep movements. In this area the gemorphic processes that operate are sheet wash (lamilar flow), fluvial dissection and deposition, freezing and thawing and mass wasting. Slope angle is ranging from 05 to 70 degree and is facing towards west. The maximum part of catchment is occupied by the township settlement and oak forest towards the ridge of the mini-catchment. The gentle upper slopes making a bowl like geomorphic feature, presence of thick solifluction lobe, snow cover during the winter and large recharge area are indicative of availability of groundwater for recharge of this spring.

In 2004 and 2005 average discharge was computed 72.3 x 10^5 L/Yr. The maximum discharge was recorded during August – January (43200 L/D) and the minimum in April (37402 L/D). The decline in spring discharge in the lean month of April was only about 13% of the peak discharge. This value of spring discharge decline was minimum across all the springs studied. With respect to spring discharge this spring had a unique pattern of water yield (among all the other springs). The discharge is almost equal throughout all seasons due the strong structural control and shear zone/ fractured rocks (Fig. 60).

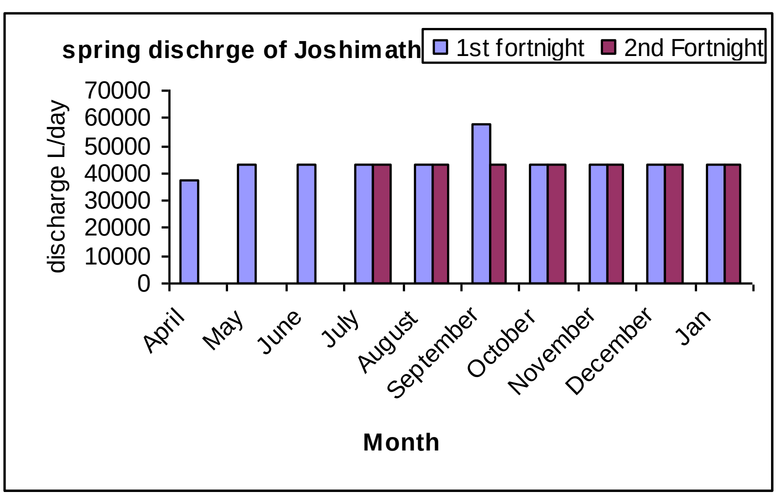

Fig. 60: Water discharge pattern of Joshimath spring (2006-07).

CHAPTER-6

WATER QUALITY OF SPRINGS

Spring water was analyzed for physico-chemical properties at National Institute of Hydrology, Roorkee (Table 20). The trace elements (Fig. 61 and 62) were analyzed using Atomic Absorption Spectrophotometer (Make: Varian; Model: AA 280 Z) and the bacteriological test (Table 21) was conducted at the laboratory of G.B. Pant Institute of Himalayan Environment & Development, Kosi-Katarmal, Almora. The pH of spring water was found ranging from 6.7 (Maithana and Katarmal springs) – 7.4 (Bhatoli and Chatwapipal springs), electrical conductivity was found minimum in Batula and maximum in Bhaktiyana springs (62 - 568 µS/cm), total dissolved solids were found minimum in Batula spring and maximum in Bhaktiyana spring (40 – 364 mg/L), alkalinity was found ranging from 36 – 170 mg/L in Maithana and Bhaktiyana springs, total hardness was found minimum in Teendhara spring (76 mg/L) and maximum in Bhaktiyana spring (276 mg/L), similarly calcium (range= 11 – 71 mg/L) was found minimum in Teendhara spring and maximum in Bhaktiyana spring, magnesium was found minimum in Chatwapipal spring (9 mg/L) and maximum in Bhaktiyana spring (24 mg/L). Nitrate was detected only in Bidakot, Joshimath, and Bhaktiyana springs and the maximum value was recorded for Joshimath spring (21 mg/L). Similarly, chloride was detected only in Bidakot, Kothar, and Joshimath springs and the maximum value was recorded in Bhaktiyana spring (18 mg/L). Sulphate was absent in the water of Karas spring and its maximum concentration was found in Bhaktiyana spring (116 mg/L).

Among the trace elements, the concentration of Fe was highest (range = 0.753 – 9.218 ug/L), followed by Cu (range = 0.119 – 0.995 ug/L) and Pb (range = 0.0016 – 0.138 ug/L) and As (0.061 – 1.166). As per Indian Bureau of Standards all the water quality parameters were found within the safe limits of drinking water except for TDS for Bhaktiyana and Kothar springs. Similarly, for the bacteriological tests, bacteria were found in all the water samples. Coliform was not found in Bidakot, Gulabrai, Kamera and Joshimath springs. *Escherichia coli* was not found in any of the water samples of these springs.

Table 20: Water quality of springs selected for study (September 2006)

Physico-chemical parameters of spring water										
Name of springs	pH	EC µS/cm	TDS mg/L	Alkalinity mg/L	T. Hardness mg/L	Calcium mg/L	Magnesium mg/L	Nitrate mg/L	Chloride mg/L	Sulphate mg/L
Teendhara	7.1	95	61	50	76	11	12	ND	ND	2.5
Bidakot	7.1	168	108	66	100	22	11	10	2	2.5
Karas	6.9	93	60	52	130	18	20	ND	ND	ND
Bhaktiyana	7.1	568	364	170	276	71	24	7	18	116
Kothar	7.2	529	338	168	262	67	23	ND	4	20
Gulabrai	7.1	134	86	70	122	19	18	ND	ND	3.5
Kamera	6.9	82	52	46	120	25	14	ND	ND	2
Chatwapipal	7.4	176	113	82	92	22	9	ND	ND	6.5
Bhatoli	7.4	290	185	158	158	42	13	ND	ND	7
Maithana	6.7	73	47	36	108	20	14	ND	ND	3.5
Batula	6.8	62	40	40	102	18	14	ND	ND	3
Joshimath	6.9	232	148	60	128	24	17	21	6	13

In summer water samples the concentration of Copper was recorded minimum in Kamera spring (0.1189 µg/L) and maximum in Teendhara spring (0.9948 µg/L). Concentration of Lead was recorded minimum in Teendhara spring (0.0016 µg/L) and maximum in Kamera spring. Concentration of Iron was recorded minimum in Batula spring (0.6267 µg/L) and maximum in Bidakot spring (9.2178 µg/L). Concentration of Arsenic was recorded minimum in Batula spring (0.0612 µg/L) and maximum in Maithana spring (1.1655 µg/L).

In the winter season the concentration of Lead in spring water was recorded minimum in Batula spring (0.0477 µg/L) and maximum in Chatwapipal spring (0.610 µg/L). Concentration of Copper was recorded minimum in Gulabrai spring (0.2224 µg/L) and maximum in Chatwapipal spring (0.9628 µg/L). Concentration of Iron was recorded minimum in Batula spring (4.1537 µg/L) and maximum in Chatwapipal spring (26.6301 µg/L). Concentration of Arsenic was recorded minimum in Joshimath spring (0.0049 µg/L) and maximum in Teendhara spring (0.2635 µg/L).

Table 21: Bacteriological tests of the spring water selected for study (September 2006)

Spring	**Bacteria**	**Coliform**	***Escherichia coli***
Gulabrai	+	-	-
Chatwapipal	+	+	-
Kamera	+	-	-
Bhatoli	+	+	-
Maithana	+	+	-
Batula	+	+	-
Joshimath	+	-	-
Kothar	+	+	-
Bhaktiyana	+	+	-
Karas	+	+	-
Bidakot	+	-	-
Tendhara	+	+	-

Relationship between rainfall and spring discharge is important to understand hydrological behavior of springs and water resources management. In this study the peak discharge of most of the springs coincided with peak rainfall, which was delayed by about one-two months in a few springs and the decline in peak discharge was not very much conspicuous even after the rainy season was over. This behavior of springs shows the structural control over the discharge and water yield of these springs. Such a phenomenon was clearly recorded for Joshimath, Kamera, Teendhara and Bhaktiyana springs. In these springs the water discharge was declined only by about 10% during the lean months as compared to the peak discharge and these could be ideal for tapping for drinking water schemes. Some springs (viz., Bhaktiyana, Batula, Karas) were characterized by high water yield (205 – 293 x 10^5L/Yr), some of them (viz., Kothar, Gulabrai, Chatwapipal) with moderate water yield (132 – 187 x 10^5 L/Yr) and the rest of the springs with low water yield (40 – 90 x 10^5 L/Yr). In terms of mean daily water discharge the springs with high annual water yield were also superior. The mean daily water yield across the springs was found ranging from 5205 – 110765 L/D.

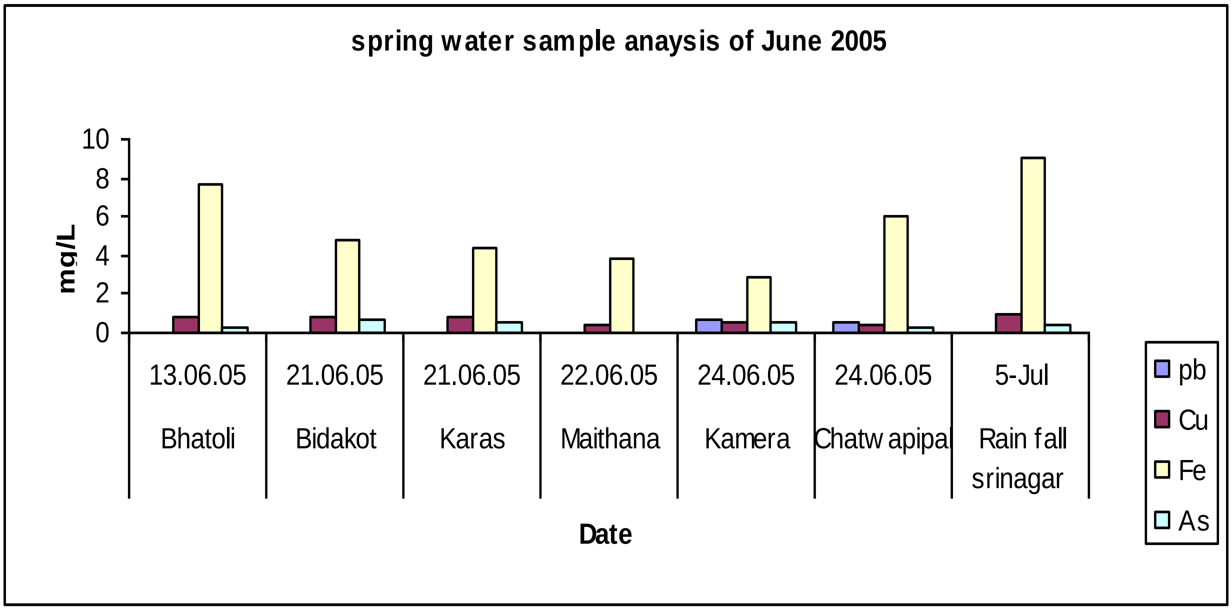

Fig. 61: Concentration of different trace elements in the spring water during summer

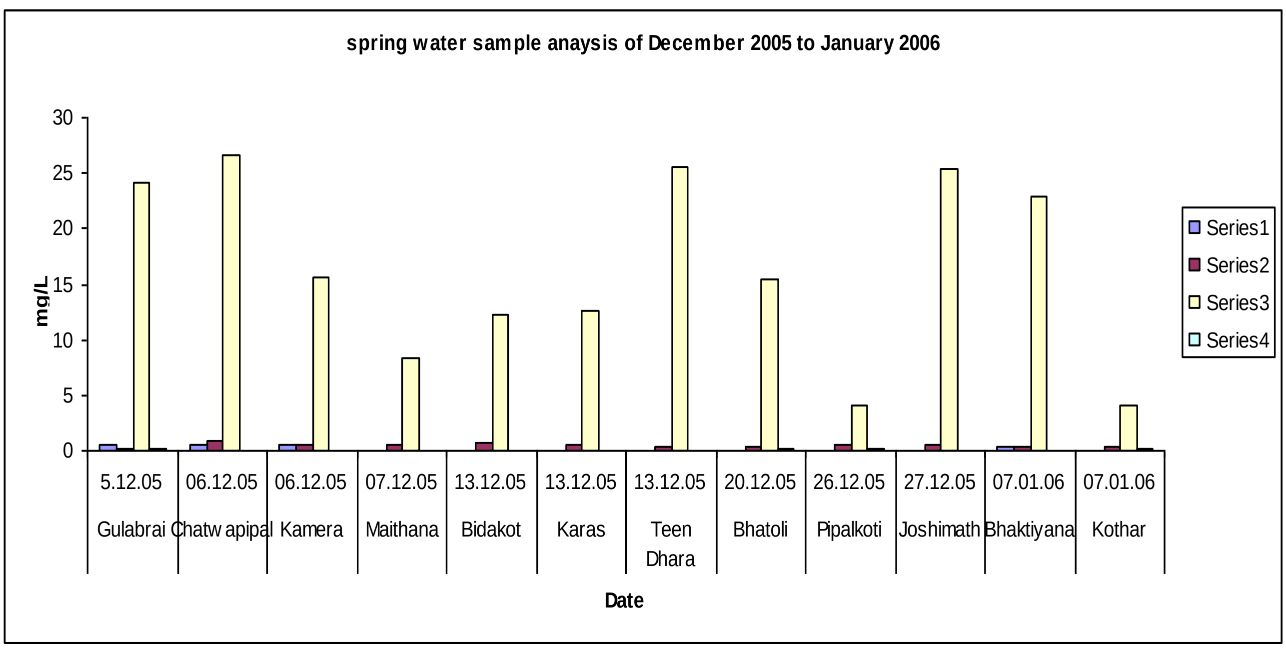

Fig. 62: Concentration of different trace elements in the spring water during winter

With regard to the water quality standards for drinking water all the springs were well within the desirable range of different physico-chemical characteristics as has been set by Bureau of Indian standards and World Health Organization. In only a few springs, such as Bhaktiyana and Kothar the water quality parameters were found towards the higher limits of the desirable limits. Water quality recorded for these springs is comparable to other studies in this region (Negi et al. 2001). These workers found pH (mean = 6.79), EC (122.4 µS/cm), Calcium (12.4 mg/L), Magnesium (11.7 mg/L), Sulphate (5.4 mg/L), Iron (168 µg/L), Chloride (8.6 mg/L) and total hardness (88.8 mg/L) in ten springs of the western Himalayan region. In an another study the mean spring discharge was recorded 3.94 L/Minute for Fracture/Joint related springs as compared to 6.47 L/Min. for Colluvial related springs (Negi and Joshi, 2004). They found the annual water yield of the six springs in the range of 15.1 – 45.1 x 10^5 L. Valdiya and Bartarya (1991) recognized 8 types of springs based on geology, nature of water bearing formations, and conditions governing their formations in central Himalaya. They found that springs originating from fluvial deposits produced water at the highest rate (mean= 405 x 10^3 L/D) and those originating from colluviums at the lowest rate (7.2 x 10^3 L/D). Different types of springs behaved differently from one another in terms of water yield, base flow, seasonal discharge pattern etc. Rai et al. (1998) found a great variation in mean annual spring water yield (14.7 – 167 L/Min.) emanating from different recharge areas in the mountains of this region.

Relationship between spring catchment area land use and spring discharge:

Following conclusions can be drawn from the data on land use (forest, settlement and cultivated land) and the spring water yield (Table 22):

1. Large catchment area was although associated with greater water yield as was found in case of Gulabrai and Kothar springs but it was not the case with Bhaktiyana and Bidakot springs.

2. The larger forest cover in the catchment area as found in case of Gulabrai, Batula, and Karas springs was associated with high water yield only when the spring catchment area was high.

3. Smaller catchment area with high proportion of cultivated land supported high spring discharge as was found in case of Chatwapipal, Kamera and Batula springs.

4. High proportion of settlement in Joshimath and Bidakot springs did not allow rainwater to infiltrate to recharge the groundwater and hence the water discharge of springs was found low.

Table 22: Land Use, Land Cover and Vegetation in the different Spring Micro-Catchment's selected for study (values in parentheses is % forest area of spring catchment

S. No.	Name of spring	Non-forest land (%)	Cultivated land (%)	Settlement (%)	Forest (%)	Total area of spring catchment (ha)	Mean spring discharge (L/day)
1	Gulabrai	0	1.9	0	97	12.3	81600
2	Chatwapipal	9.4	69.4	13.6	8	3.6	54372
3	Kamera	10.9	46.8	14.5	29	4.7	48632
4	Bhatoli	32.3	42.4	1.3	24	5.9	29300
5	Maithana	18.0	61.8	4.5	16	3.3	14237
6	Batula	5.7	44.3	2.8	48	4.9	81730
7	Joshimath	0	13.3	71.5	15	4.5	43645
8	Kothar	23.7	0	62.6	13	18.8	151200
9	Bhaktiyana	1.6	0	62.7	35	19.3	16409
10	Karas	6.8	40.9	0.9	46	17.7	45208
11	Bidakot	5.6	47.9	43.9	0.3	12.5	17182
12	Teendhara	39.2	0	0	61	1.2	14116

In this region diminished flow of springs during summer is the major challenge for the Government to cater to the demand for household water consumption. Therefore, an understanding of the relationship between spring water yield, water quality and recharge area characteristics (as investigated in this study) will be of enough applied value with regard to long-term water conservation strategies in this region where people depend mostly on springs for fresh water. A large recharge area may not be favourable for spring discharge, as it will place more demand of water on the soil moisture in terms of evapo-transpiration. A smaller recharge area may likely be easy to protect against biotic interferences, and bring desired changes in land use and land cover. Besides geology, land use and level of biotic interference emerged as one of the controlling factors for the spring discharge. It can be pointed out that oak forest (broadleaf), terraced land, moderately grazed pasture land and low biotic interference in the spring recharge area are conducive for water recharge. With regards to topography moderate slope, south-west aspect of the recharge zone and deep soil promoted the water infiltration and recharge of the ground water table. Geologically phyllite with quartzite bands, quartzite and limestone favoured the water holding capacity of rocks and resulted into high water yield. It can be stated that spring yield is influenced by a set of complex set of factors and that land use / land cover change in the spring recharge zone has a direct bearing on spring water yield and seasonal patterns. As aquifer yield is a function of many complex ecosystem processes spring water yield can only be increased when "Spring Sanctuary Development" measures are adopted (Negi and Joshi, 2002). This approach calls for physical measures (e.g., digging trenches along contours, gully plugging, construction of ponds to harvest rainwater-runoff, leveling of sloping terraces, maintaining cropfield bunds, etc.), vegetative measures (plantation of grasses and broadleaf plantations e.g., oak) and social measures (e.g., prohibit grazing, quarrying, road cutting and constructions, fire, cutting of vegetation, etc.). Thus spring recharge needs multidirectional approach and action, scaling from engineering and vegetative measures to social measures for management, rational use and aftercare of the water resources.

CHAPTER-7

SUMMARY

1. This study on geomorphological and land use / land cover and other anthropogenic influence in the spring recharge zones on spring water quality and water discharge is based on 12 representative springs of the western Himalaya.

2. These springs represented all variety of topography, altitude, geology, rock types, catchment area, land use and land cover and anthropogenic influence in the spring recharge zone). The altitude of the spring catchment area varied from 550 -2800 m asl and slope from 0-70 degrees. Geology of the springs encompasses almost all the geological forms (Colluvial, Fluvial deposits, Joints and Fracture) and rock types (Mica schist, Quartzite, Phyllite, Slate, Lime stone, Micaceous gneiss, Granetiferous schists). The land use varied from agriculture, forests, grazing land and wasteland to land under urban and rural settlements. The land cover consisted of sparse to dense forests of broadleaf (Oak) and conifer (Pine) tree species.

3. At the high altitude site the annual rainfall was recorded 1347 mm, out of which about 55% was occurred in the rainy season (July – September). At the middle altitude site the annual rainfall was recorded 1745 mm, out of which about 69% was occurred in the rainy season. At the low altitude site the annual rainfall was recorded 1372 mm, out of which about 54% was occurred in the rainy season.

4. All the springs are located in the metasedimentary and sedimentary rocks of the western Himalaya. The rocks of Kumaon Super Group to Garhwal Group occupy the study area. General rocks type are phyllite, quartzite, mica-schist, slate and dolomitic limestone. All the rocks have their different water retaining properties based upon the discontinuities therein. Some rocks are hard enough to percolate the water therein but, some are suitable for water retention.

5. In the spring recharge area the soil depth was found ranging from 45 - 90 cm. It was divided into two - five soil profiles across the springs. Soils of various stages were found across the soil horizons: very fine black soil, fine soil, medium grain soil, very coarse grain soil and coarse grain soil with angular fragments. Soils was categorized as: clay soil, clay loam and loam. The proportion of sand in the spring recharge zone was found ranging from 16.6% in Bhaktiyana and 57.2% in Kothar; silt from 13.2% in Kamera to 43.7% in Joshimath spring, and clay from 9% in Joshimath to 60.1% in Bhaktiyana.

6. The soil pH ranged from 5.51 (Kamera spring) to 7.37 (Chatwapipal spring). The soil moisture ranged from a minimum of 6% (Teendhara spring) to 62% (Maithana spring). Water holding capacity (WHC) across the two soil depths varied between 33% in Bhaktiyana and 66% in Gulabrai spring.

7. Spring water studies revealed that some springs (viz., Bhaktiyana, Batula, Karas) were characterized by high water yield (205 – 293 x 10^5L/Yr). Some of them (viz., Kothar, Gulabrai, Chatwapipal) had a moderate water yield (132 – 187 x 10^5 L/Yr) and the rest of the springs recorded a low water yield (40 – 90 x 10^5 L/Yr). The mean daily water yield across the springs was found ranging from 5205 – 110765 L/D.

8. The water discharge behavior of springs showed the structural control over the discharge of these springs. Such a phenomenon was clearly recorded for Joshimath, Kamera, Teendhara and Bhaktiyana springs. In these springs the water discharge was declined only by about 10% during the lean months as compared to the peak discharge and these could be ideal for tapping for drinking water schemes.

9. With regard to the water quality standards for drinking water all the springs were well within the desirable range of different physico-chemical characteristics as has been set by Bureau of Indian standards and World Health Organization.

10. The pH in spring water was found ranging from 6.7 – 7.4, electrical conductivity (62 - 568 µS/cm), total dissolved solids (40 – 364 mg/L), alkalinity (36 – 170 mg/L), total hardness (76 - 276 mg/L) and calcium (11 – 71 mg/L), magnesium (9 – 24 mg/L). Nitrate (range= 0- 21 mg/L) was absent in most of the springs. Similarly, chloride was detected only in four springs (range= 0-18 mg/L). Sulphate concentration was found maximum in Bhaktiyana spring (116 mg/L).

11. Among the trace elements, the concentration of Fe (range = 0.753 – 9.218 ug/L), Cu (range = 0.119 – 0.995 ug/L), Pb (range = 0.0016 – 0.138 ug/L) and As (0.061 – 1.166) were recorded. Similarly, for the bacteriological tests, bacteria were found in all the water samples. Coliform was not found in Bidakot, Gulabrai, Kamera and Joshimath springs. *Escherichia coli* was not found in any of the water samples of these springs.

12. In this study an understanding of the relationship between spring water yield, water quality and recharge area characteristics hold applied value with regard to long-term water conservation strategies in this region where people depend mostly on springs for fresh water. Besides geology, land use / land cover and level of biotic interference emerged as one of the controlling factors for the spring discharge. It can be pointed out that oak forest (broadleaf), terraced land, moderately grazed pasture land and low biotic interference in the spring recharge area are conducive for water recharge. With regards to topography moderate slope, south-west aspect of the recharge zone and deep soil promoted the water infiltration and recharge of the ground water. Geologically phyllite with quartzite bands, quartzite and limestone favoured the water holding capacity of rocks and high water yield.

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References

Action Plan for Himalaya, 1992. G.B. Pant Institute of Himalayan Environment & Development, Kosi-Katarmal, Almora.

American Public Health Association, 1989. Standard Methods of Examination of Water and Wastewater, 17th edition, APHA, Washington, DC, 1467 p.

Bartarya, S.K. 1993. Hydrochemistry and rock weathering in a sub-tropical lesser Himalaya river basin in Kumaun, India. Journal of Hydrology 146: 149-174

Barkatya, D.K. and Gupta, R.P. 1982. Lineament – Tectonic interpretations from land sat images in Garhwal – Kumaun Himalaya. Himalayan Geology 12: 1-13.

Bisht, K.S. and Sinha, A.K. 1980. Some observations on the geological and structural setup of Okhimath area in Garhwal Himalaya – A preliminary report. Himalayan Geology 10: 467-475.

Bist, K.S. and Sinha, A.K. 1980. Some observations on the geological and structural setup of Okhimath area in Garhwal – A preliminary report. Himalayan Geology 10.

Gaur, C.S., Dave, V.K.S. and Mittal, R.S. 1977. Stratigraphy, structure and tectonics of the carbonate suit of Chamoli, Garhwal Himalaya. Himalayan Geology **7:** 416-455.

Gupta, L.N. 1979. Anthophyllite – cordierite schist in the central crystalline complex of Badrinath central Himalaya. Himalayan Geology 9: Part II.

Joshi, B. K. and Kothyari, B.P. 2003. Chemistry of perennial springs of Bhetgad watershed: a case study from central Himalayas, India. Environmental Geology 572 -578.

Kumar G. and Agrawal, N.C. 1974. Geology of Alaknanda valley Chamoli and Tehri Garhwal, Kumaon Himalaya, U.P. In: Jhingran and Verma (ed.), Himalayan Geology 29-59.

Kumar G. and Agrawal, N.C. 1975. Geology of Srinagar to Nandaprayag area (Alaknanda valley), Chamoli and Tehri Garhwal, Distt., Kumaon Himalaya, U.P. In: Jhingran and Verma (ed.), Himalayan Geology 5: 29-59.

Kumar, G., Prakash, G. and Singh, K.N. 1974. Geology of the Deoprayag – Dwarahat area Garhwal Chamoli and Almora district, Kumaun Himalaya, U.P. Himalayan Geology 1: 323-347.

Maruo, Y. 1979. Geology and metamorphism of the Nanda Devi region Kumaun Higher Himalaya, India. Himalayan Geology **9**, part I, pp 3-17.

Mehrotra, G.S., Sarkar, S. and Kanungo, D.P. 1993. Lithotectonic evaluation of landslides and mass movement in Garhwal – Kumaun Himalaya. Journal of Engineering Geology, XXII, 3 and 4. Pp. 19-33.

Naithani, A.K. 1997. Studies in morphotectonics and landslides problems in area between Kedarnath and Okhimath, Garhwal Himalaya. Unpublished D. Phil. Thesis submitted to HNB Garhwal University, Srinagar (Garhwal), pp. 1-200.

Naithani, A.K., Prasad, C., Bisht, M.P.S. and Kumari Geeta. 1997. Landslide condition and geo-environmental appraisal along main central thrust zone in Mandakini valley Garhwal Himalaya, India. Himalayan Geology 18: 135-143.

Negi, G.C.S., Rikhari, H.C. and Garkoti, S.C. 1998. The hydrology of three high altitude forests in Central Himalaya, India: A reconnaissance study. Hydrological Processes 12: 343-350.

Negi, G.C.S. 2001. The need for micro-scale and meso-scale hydrological research in the Himalayan mountains. Environmental Conservation 28 (2): 95-98.

Negi, G.C.S. 2002. Hydrological research in the Indian Himalayan mountains: soil and water conservation. Current Science 83 (8): 974-980.

Negi, G.C.S. and Joshi, V. 1996. Geohydrology of springs in a mountain watershed, the need for problem solving research. Current Science 71 (10): 772-776.

Negi, G.C.S., Joshi, V. and Kumar, K. 1998. Spring sanctuary development to meet household water demand in the mountains: A call for action. pp. 25-48. In: Research for Mountain Development: Some Initiatives and Accomplishments. Gyanodaya Prakashan, Naini Tal.

Negi, G.C.S. and Joshi, V. 2002. Drinking water issues and development of spring sanctuaries in a mountain watershed in the Indian Himalaya. Mountain Research and Development 22 (1): 29-31.

Negi, G.C.S. and Joshi, V. 2004. Rainfall and spring discharge patterns in two small drainage catchments in the western Himalayan, Indian. The Environmentalist 24: 19-28.

Negi, S.S. Pandey, B.K. and Sinha, A.K. 1981. Slope studies in Rudraprayag – Tilwara – Mayali area of Garhwal Himalaya with special reference to slope stability. Himalayan Geology 12: 330-344.

Rai, S.P., Valdiya, K.S. and Rawat, J.S. 1998. Management of water resources: Spring sanctuaries. In: K.S. Valdiya (ed.), The Khulgad Project: An Experiment in Sustainable Development. Gyanodaya Prakashan, Naini Tal. India. Pp. 41-60.

Rawat, G. S. 1983. Some aspects of Quaternary geology in Alaknanda Valley, Garhwal Himalaya, (Uttaranchal). D. Phil. Thesis, HNB Garhwal University, Srinagar Garhwal.

Rawat, R.S. 1982. Petrology of the Naini group (Chail Nappe) metasedimentary rocks from inner Lesser Garhwal Himalaya, U.P., India. Himalayan Geology 12: 236-260.

Sarkar, S., Kanungo, D.P. and Mehrotra, G.S. 1955. Landslide Hazard Zonation : A case study in Garhwal Himalaya, India. Mountain Research and Development 15 (4): 301-303.

Singh, A.K. and Rawat, D.S. 1985. Depletion of Oak forests threatening springs: An exploratory study. The National Geographical J. of India. 31 (1): 44-48.

Singh, A.K. and Pande, R.K. 1989. Changes in the spring activity: Experiences of Kumaun Himalaya, India. The Environmentalist 9 (1): 75-79.

Shandilya, A.K. and Prasad, C. 1982. Geomorphic studies of lineament zones in Garhwal Himalaya. Himalayan Geology 12: 31-39.

Srivastava, R.N. and Ahmed, A. 1979. Geology and structure of Alaknanda valley, Garhwal Himalaya. Himalayan Geology, 9 Part I: 225-254.

Valdiya, K.S. 1980. Geology of Kumaun Lesser Himalaya, Gyanodaya Prakashan, Naini Tal.

Valdiya, K.S., Paul, S.K., Chandra, T., Bhakuni, S.S., and Upadhyay, R.C. 1999. Tectonic and lithology characteristics of Himadri (Great Himalaya) between Kali and Yamuna rivers, Central Himalaya. Himalayan Geology **20** (2): 1-17.

Virdi, N.S. 1986. Lithostratigraphy and structure of the central crystallines in the Alaknanda and Dhauliganga valleys of Garhwal, U.P. Current Trends in Geology IX, Himalayan Thrust and Associated Rocks. pp 155-166.

Valdiya, K. S. 1987. Environmental Geology, Indian Context, Tata Mcgarh Hill Publication Co. Ltd. New Delhi.

Valdiya, K. S. and Bartarya, S.K. 1989. Diminishing discharge of mountain springs in a part of Kumaun Himalaya. Current Science 58: 417 -426.

Valdiya, K. S., Rawat, J.S. and Rai, S.P., 1994. Response of hydrological cycle to the environmental degradation in the Khulgad watershed, Kumaun Himalaya. Technical Report, Central Himalaya Environmental Association, Nainital, 78.

SOME SPRINGS OF WESTERN HIMALAYA STUDIED UNDER THE PROJECT

Joshimath

Bidakot

Gulabrai

Bhatoli