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HYDROLOGICAL INVESTIGATIONS
AND
INSTRUMENTATION IN A SMALL WATERSHED
IN GARHWAL HIMALAYAS

आपो हि ष्टा मयोभुवः

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ABSTRACT

The report presents the preliminary results of a hydrological study in a small hilly watershed located in Tehri-Garhwal District (U.P.), representative of the mountainous subhumid agro-ecological region in the Western Himalayas. The watershed is of 1,000 ha area approx., and has not received any treatment.

Using an integrated approach of hydrologic instrumentation, field investigations, and remote sensing and GIS, the study proposed to evolve appropriate model for integrated and sustainable development in the watershed. The specific objectives proposed to be fulfilled through the present watershed study include the following major indicators, besides being aimed as a pilot project for demonstration to the interested users (e.g. students, academicians, researchers, administrators, NGOs) : (1) Erosion and Sediment Control Strategies, (2) Changes in Land Use and Vegetative Cover, (3) Rainfall-runoff Studies, (4) Soil and Water Conservation (including springs rejuvenation) Strategies, (5) Hydrologic Modelling, and (6) Devise mechanism for people's participation in sustainable development of small watersheds.

Hydrological investigations have been carried out in the Danda watershed in the Garhwal Himalayas (Hindolakhal Block, Devprayag Tehsil, Tehri-Garhwal Distt.). Some basic instruments and devices (e.g. SRRG, ORG, water stage recorder, V-notch, thermo-hygrograph) have been installed at site for monitoring the hydrometeorological and meteorological parameters. A Digital Elevation Model (DEM) of the area has been prepared using 1:50,000 Survey of India toposheet and a GIS package (ILWIS).

1.0 INTRODUCTION

1.1 General

The hilly regions of Garhwal Himalayas are facing a variety of environmental problems. The foremost is a shortage of sufficient quantity of water, especially during summers, for drinking and irrigation purposes. Inspite of the region being the source of two mighty rivers of north India, namely Ganga and Yamuna, water scarcity has been a major problem in the hills of Garhwal.

The shortage of water and other essential items of livelihood, e.g. fuelwood and fodder, has been a consequence of extensive deforestation, land use change, forest fire, etc. Interference to the natural recharge caused by deforestation is said to have resulted in the drying of Himalayan springs on which its people generally depend. The discharge of these springs varies considerably during monsoon and non-monsoon periods. Over exploitation of forested area for food, fodder, fibre and minerals, and the process of urbanisation have led to the deforestation and degradation of watershed characteristics.

The presently exploited source of water in the hills of Garhwal for drinking and irrigation purposes is the surface water (streams and rainwater). In absence of proper rainwater harvesting structures in the region, rainwater is hardly available for use, and the streamwater is available only for the population living close to the river banks (Nand and Kumar, 1989). Due to largely scattered population in the region, majority of the people do not have access to these supplies, and are generally dependent on the local sources of water supply (e.g. springs) and dug wells (only in the valleys).

A desirable watershed management strategy in this region would have to meet two main objectives (1) improvement of water supply, and (2) reduction of damage due to erosion and landslides. In order to meet these objectives, fostering of ground water recharge can be done through identification of groundwater recharge zones and creation of groundwater sanctuaries for safeguarding of quantity as well as quality of groundwater and springs.

The U.P. Jal Nigam, under its watershed management programmes, has been concentrating on water and soil conservation measures, e.g. building of check-dams, gully plugging, construction of rainwater harvesting structures, irrigation tanks and canals, in the hilly areas of Garhwal Himalayas.

1.2 Rationale

Under a UNESCO sponsored project, two local NGOs, namely South South Solidarity (SSS) and Sri Bhubneswari Mahila Ashram (SBMA) were working in the Tehri-Garhwal area for assessing water utilization and for suggesting measures for upgradation of freshwater resources and reducing labour stress of women in the study area. Probably due to lack of expertise in the study of hydrological aspects, the National Institute of Hydrology was approached for suggesting appropriate measures for augmenting springflow discharge in the study area.

A team of scientists of the Institute was deputed to study the problem at site and to suggest appropriate actions. The objective of the visit was to have a field appraisal of the watersheds, and to assess the suitability of carrying out the hydrological studies to solve the drinking water availability problem and to suggest necessary steps to the local institutions (including NGOs) for sustainable development of the watersheds.

After two successive visits to the watershed area, it was felt that the Institute will have to carry out the study with its active involvement and, accordingly, a study plan was made. Institute's scientists started field investigations with the help of scientists of the NGOs and some basic instrumentation was also deployed at suitable sites. The NGOs on their part could collect hydrological data for a period of about year (from August 1995 to August 1996). Although the NGOs were expecting an extension of the project from UNESCO for a second term, it appears the project was discontinued. The Institute then decided to continue the studies and investigations with its own efforts and with some logistic support from the local NGO, namely SBMA.

This report presents an outline of the work done upto March, 1997 under the watershed study, and also outlines the future plan of action.

2.0 SITE APPRAISAL TOUR

A team of scientists of the National Institute of Hydrology visited two watersheds, namely Danda and Chandrabhaga, located in Tehri-Garhwal district of U.P., during May 13-15, 1996. Some general observations after making the visit are summarised, first followed by a brief details of the study area.

2.1 Water Resources and Water Use in Tehri District

Garhwal region is drained almost entirely by the Ganga and its tributaries. Water is most abundant and at the same time the least managed resource in the region. Topographical and climatological features (i.e. steep gradients and fast run-off) is the major obstacle to a productive utilization of water resources. Tehri district is part of the lesser Himalayas which are a massive mountain tract separated from the Doon by the Main Boundary Fault (Nand and Kumar, 1989). As in other parts of the Himalayas, the terrain in the area is rugged and steep. Geologically, the formations are Chandpur phyllites grouped under Jaunsar Group- which is defined as greenish grey slaty and schistose phyllite interbedded with quartzites. The soils are generally shallow and not well developed, varying in texture and depth.

Since topography is the most significant factor for any developmental work, especially in a hilly region, it is imperative that topographic maps should be prepared for local use. Geology of the area is another significant factor for estimation of groundwater resources, for construction of engineering structures, for abatement of landslides, etc. Climatology is the other most important field which holds the key for planning and implementation of various developmental schemes in this hilly region.

Preparation of topographical, geological, hydrometeorological and other required maps on appropriate scales, therefore, need be taken up on priority basis to pursue any scientific studies in the region (Sehgal et. al, 1992). Also, in order to design and implement suitable methodologies to ensure sustainable supply of water at microwatershed scales in the Garhwal region, the following basic studies are essentially needed on an urgent basis :

1. Development of strategy for exploration of the localised aquifers (including springs) in the hilly regions, and for enhancing recharge of these aquifers through rainwater,

2. Development of strategy for ensuring safe quality of water from these aquifers and springs,
3. Revival of indigenous technology for rainwater harvesting, aquifer recharge, etc.
4. Design and construction of appropriate hydrological structures for conservation of soil and water, and identification of suitable sites for location of these structures,
5. Transfer of technology development and knowledge about hydrological conditions of the study area to local NGOs for implementation with peoples' participation.

Rigorous mathematical models are now available to estimate recharge to the aquifers (and springs) and suitable soil and water conservation strategies could be worked out to rejuvenate the springs using these models. Also, identification of suitable structures for groundwater development and recharge purposes is important. For example, protection of old naulas (seeps) and construction of water storage tanks adjacent to streams and gullies could be attempted. Equally desirable in hilly regions is the zonation of hills for various activities, viz. top 1/3rd for afforestation, middle 1/3rd for horticulture, pastoral uses, etc., and the bottom 1/3rd for cultivation of crops, habitation and other human activities (Valdiya and Bartarya, 1991). For effective implementation of the latter scheme, cooperation amongst local villagers is essential and here the role of 'Village Panchayats' becomes important in resolving any disputes arising thereof, and also in ensuring peoples' participation in various development schemes. With a lot of NGOs already working in this region, it should be possible to obtain their active support in carrying out such activities.

2.2 U.P. Rural Water Supply & Environmental Sanitation Project

It is quite timely that the World Bank has recently initiated a five-year project for improving rural water supply and sanitation in thirteen districts of Uttar Pradesh, including 8 hill districts (Dehradun, Tehri, Chamoli, Pauri, Pithoragarh, Uttarkashi, Nainital and Almora). The Project aims at developing and implementing a long term strategy to improve overall water resources management in the State alongwith other aspects, e.g. sustainable health and hygiene benefits, improvement in rural income. Since the objectives of the Project are demand-driven and community-based, active participation of rural communities and Support Organisations (SOs) is envisaged in pre-planning, planning and implementation phases. Going by the Project objectives, it appears that a lot in strengthening and improving the management and planning of water and related natural resources in the hill districts of U.P. can be achieved.

2.3 Location of the Watersheds

The Danda watershed lies in the Hindolakhal block of Devprayag Tehsil in Tehri-Garhwal district of Uttar Pradesh. The watershed lies in the Alaknanda catchment. The watershed consists of seven villages and has a total area of 1,000 ha approx. The highest elevation in the watershed is 1,700m amsl and the lowest elevation is 700m amsl. The watershed has a highly rugged topography with steep slopes and scanty vegetation. The climate of the watershed is generally dry. Total population in the area is about 1,000.

The Chandrabhaga watershed lies in the Anjanisain block of Devprayag Tehsil in Tehri-Garhwal district of U.P. The watershed lies in the Bhagirathi catchment. The watershed consists of thirteen villages and has a total area of 1,000 ha approx. The highest elevation in the watershed is 2,300m amsl and the lowest elevation is 1,000m amsl. The watershed has a highly rugged topography with steep slopes, and a fairly dense vegetation. Total population in the area is about 1,500.

2.4 Findings

The scientists reached Anjanisain, the Headquarters of the Shree Bhubneshvari Mahila Ashram (SBMA)- an NGO already working in the watersheds in collaboration with another Delhi-based NGO, namely South-South Solidarity (SSS), on May 13, 1996. After a brief discussion with SSS officials on the same day, a field visit was made to the Chandrabhaga watershed, accompanied by Prof. A S Chawla of WRDTC, University of Roorkee and the two geologists of SSS. In the evening, a discussion was held with the Chief Functionary of SBMA regarding the activities already done by the SBMA and those planned for the future. On May 14, 1996, a field visit was made to the Danda watershed which is located about 10 kms SE of Anjanisain.

On the basis of the visit, it was felt that a comprehensive hydrological study should be taken up by the Institute in the two watersheds (Danda and Chandrabhaga) for a period of 3-4 years. As is evident from the field visit, the Danda watershed needs greater attention and input to improve the water supply in the region. Therefore, the following activities were recommended:

- The local authorities, including the U.P. Jal Nigam, may be requested to rejuvenate and make operational the water supply through an existing network of pipe lines and stand posts. This shall ease to a great extent the demand of water supply in the region.
- Since the topography in the area is rugged, and climate and other hydro-meteorological

conditions are highly dependent on the topography, it is essential that a Digital Elevation Model (DEM) is prepared for the area, and other maps are prepared using a GIS. This would form the basis for all subsequent planning and field studies.

- The absence of forest cover in the upper region of the watershed is mainly responsible for a low discharge of water in the springs. The lack of complete utilization of the available cultivable land in the region is also a result of the shortage of water. The U.P. Forest Dept. and the local authorities (Gram Sabha, etc.) may be approached to take up the programme of afforestation in the upper regions.

- Suitable rainwater harvesting techniques may be suggested to the local inhabitants through Gram Sabha, NGOs, etc. so that harvested rainwater is utilized to a certain extent during non-monsoon periods.

- For effective control of landslips and erosion control, few checkdams, etc. may be required. The exact locations of these structures could be decided on the basis of field investigations and through the use of the DEM. Proper cultivation practices (terrace, bunding, etc) also need be ensured to control the soil erosion.

- In order to improve the quality (especially bacteriological) of drinking water, suitable measures may be suggested to the U.P. Jal Nigam and to the Gram Sabha for maintaining the cleanliness of the water storage structures (tanks) and for treatment of the stream/spring water before consumption.

- Geophysical (resistivity and electromagnetic) surveys could be conducted at few selected sites to map the origin of the springs so that these springs could be tapped at a higher elevation close to the human settlements. Moreover, potential sites for groundwater recharge could be identified with the help of these surveys. To start with, resistivity surveys could be conducted at selected sites, to be identified (in absence of available control points e.g. well logs) on the basis of lineament and fracture maps using satellite data/areal photographs, before onset of the monsoon.

- At present no hydro-meteorological observatory is available in the area. For regular monitoring of climate related parameters, it is proposed to install an AWS either at the SBMA HQs in Anjanisain or at Hindolakhal. Also, in order to study the effect of orography on the rainfall, it is proposed to install at least two ORGs and one SRRG in each watershed at different elevations. Automatic flow/discharge measurement at the stream sites would be necessary to monitor the storm events during monsoon; spring discharges could be monitored manually. Air temperature and pan evaporation measurements would also be required from at least one location in each watershed. To start with, locally available ORG, monthly water level recorder, weekly SRRG and weekly thermohygrograph could be installed at a selected site in each watershed. All these measurements would be done by the local people (after giving proper training) selected with the assistance of the NGO (SBMA).

3.0 DESCRIPTION OF THE STUDY AREA

3.1 Chandrabhaga Watershed

3.1.1 Geology

The rock type in the area is phyllite schist which is a low grade metamorphic rock. The rocks are highly weathered and fractured. The fractures and the joints are the main source of spring water. A dendritic pattern of the drainage system indicates that the area was not subjected to major folding or faulting and, hence, is not structurally controlled.

3.1.2 Land Use

The total irrigated area is 30% approx. and barren/rocky area is 20% approx., rest is covered by forest, which is mostly only in the upper region. The main crops are paddy, jhingora, and wheat. Many varieties of fruit and vegetables are also grown in the area. During non-monsoon period, irrigation is done by diverting the stream/spring water through a network of small canals (Chakraborty, 1993).

3.1.3 Water Availability

Chandrabhaga gad is the only perennial stream in the watershed, with monsoon discharge 10,000-40,000 m^3/day and during non-monsoon season the discharge reduces significantly. The dependable source of drinking water is the numerous springs with discharges of the order of 10-80 m^3/day during monsoon and 1-20 m^3/day during non-monsoon periods. The quality of water from different springs and the stream is reported to be satisfactory from physio-chemical analysis but bacteriological analysis indicated that disinfection is required before consumption for drinking purposes. Also, water supply has been provided by the U.P. Jal Nigam through pipe lines and stand posts. Due to poor maintenanace of water supply structures (tanks, etc.), this water also needs treatment before consumption.

3.2 Danda Watershed

3.2.1 Geology

The rock type in the area is phyllite schist which is a low grade metamorphic rock. The rocks are highly weathered and fractured. The fractures and the joints are the main source of spring water.

3.2.2 Land Use

The total irrigated area is 1% approx. and barren/rocky area is 40% approx., only scanty part is covered by the forest cover, and rest of the cultivable land is lying unutilized due to lack of water. Most of the upper region is barren. The main crops are jhingora, mandua, soyabean and wheat (Kishan Khoday and Jayanta Bandhopadhyay).

3.2.3 Water Availability

Silwani and Shyam Gadhera are the two small perennial streams in the watershed, with monsoon discharge of upto 6,000 m^3/day and 300 m^3/day, respectively, and during non-monsoon season the discharge reduces significantly. The dependable source of drinking water is the numerous springs with discharges of the order of 2-90 m^3/day during monsoon and upto 1-15 m^3/day during non-monsoon periods. The quality of water from different springs and the stream is reported to be satisfactory from physico-chemical analysis but bacteriological analysis indicated that disinfection is required before consumption for drinking purposes. Also, necessary infrastructure for water supply has been provided by the U.P. Jal Nigam through pipe-lines and stand posts. However, due to operational problems, the water is seldom available in the stand posts and the local inhabitants have to go to far away distances to fetch water from the springs. Many check dams were constructed on a seasonal stream by the U.P. Jal Nigam.

4.0 WORK CARRIED OUT

For the watershed development studies in Garhwal region of the Himalayas, Danda watershed in the Alaknanda catchment was selected. The location of the study area is shown in **Figure 1**. The primary criteria for choosing this watershed were (1) scarcity of water in the area, and (2) since almost no treatment was done in the watershed so far, there was every opportunity of studying the impact of various conservation measures which would be implemented as part of the study. Also, the Danda watershed is a part of a bigger watershed, which forms the catchment of a road-bridge, on the Rishikesh-Badrinath highway.

The various activities undertaken in the Danda watershed can be categorised under (1) instrumentation set up, (2) field investigations, and (3) data analysis and modelling, and are discussed in subsequent sections. It may be mentioned here that the work presented in this report, especially on the hydrological measurements, covers a part of the Danda watershed. Further investigations in the remaining part of the watershed are being planned to be taken up in the year 1997-98. In order to avoid any confusion, the name Danda watershed has been retained on various maps, etc. even when reporting the results from a part of the watershed. After the initial appraisal survey, the work reported here was done by the present authors only.

4.1 Geographical Features of Danda Area

The Danda area is east facing draining into Alaknanda river and lies geographically between latitude N 30^{0}14' and N 30^{0}15.5' and longitude E 78^{0}37' and E 78^{0}38'. The area comprises of 9 villages namely Danda, Bhainskot Centauli, Choudiyal, Gurali, Mayali, Rupoli, Limgaud and Pataun. The area covered by these villages is 246.3 hectares. The area falls in Devprayag block of Tehri district and is located on the right side of the Devprayag-Tehri road at a distance of 21 km from Devprayag. Danda is the oldest village. According to the 1991 Census the total number of households and population of these villages are 128 and 545 respectively. The topographic map and view of the Danda watershed are given in **Figure 2a** and **Plate I**, respectively. As shown in **Figure 2b**, the Danda watershed is a part of a bigger watershed which forms the catchment of a road-bridge, on the Rishikesh-Badrinath highway.

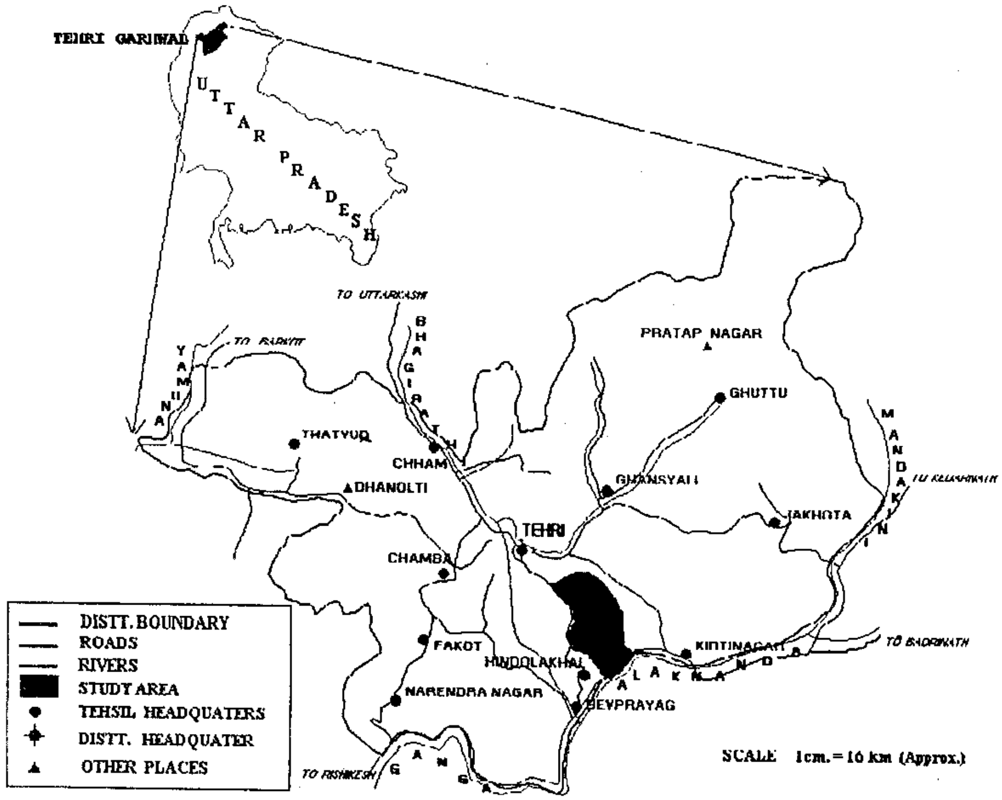


Fig. 1 Location map of the study area (Danda watershed)

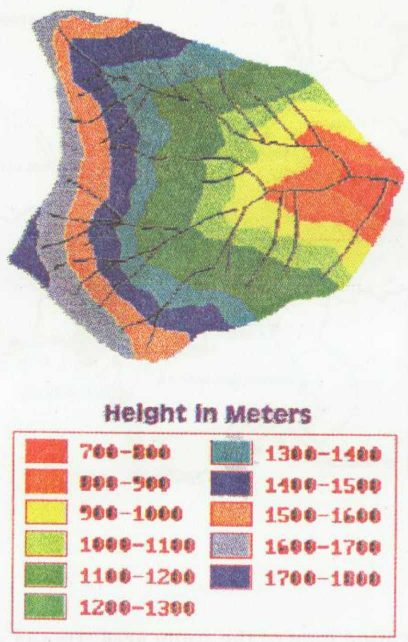


Fig 2a. Topographic map of the Danda watershed

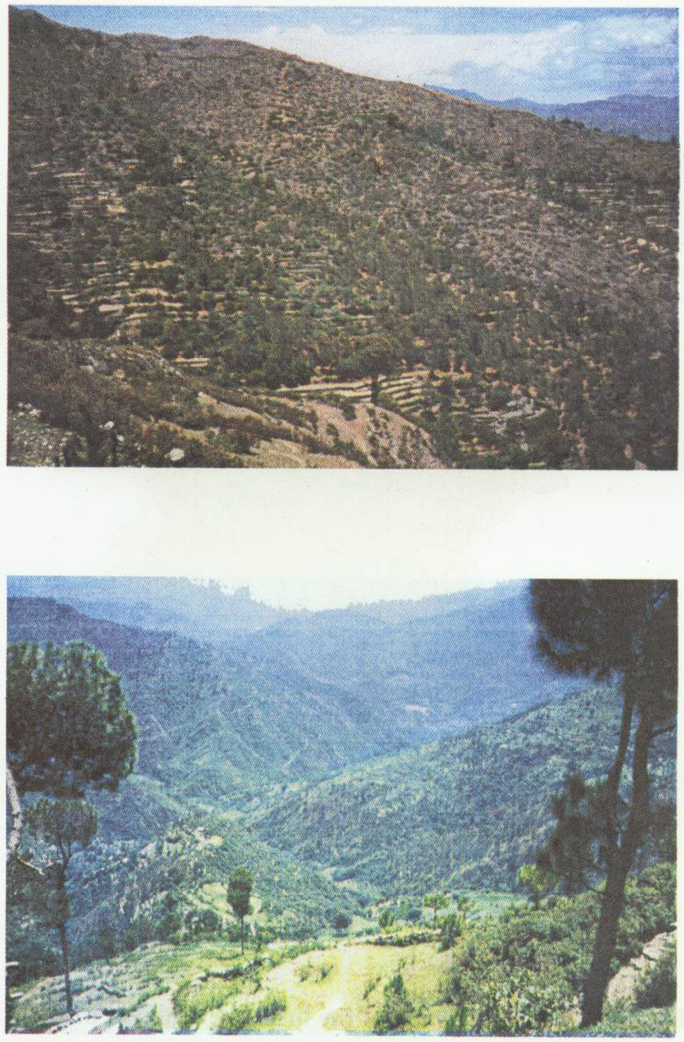


Plate I. Topographic view of the Danda watershed

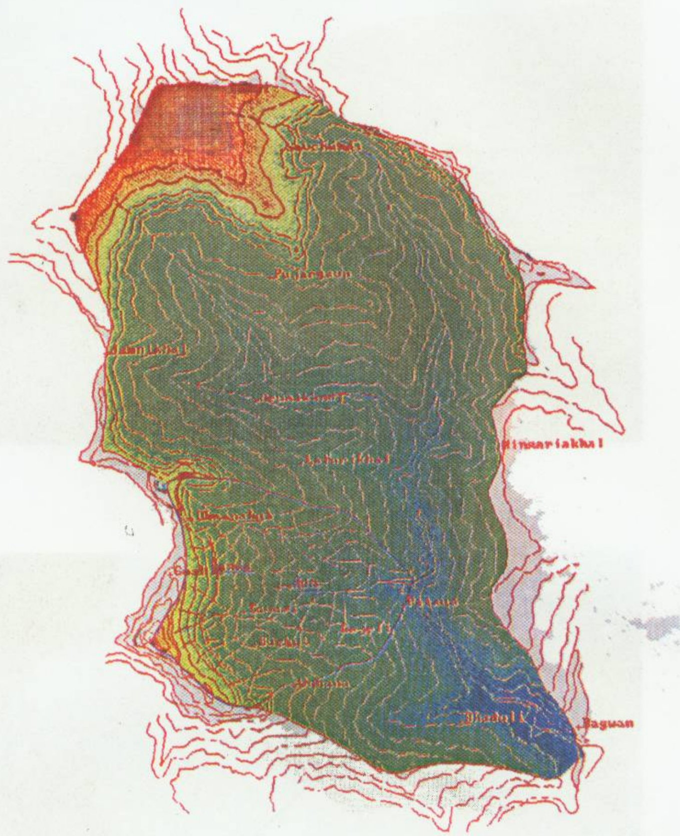


Fig 2b. Topographic map of the bridge-catchment at Bagwan

4.2 Instrumentation Setup

Following equipment were installed in the Danda watershed during July 31 to August 3, 1996 :

- One 90^0 V-notch (**Plate II**) and one monthly Water Level Recorder, at Rum Dhar,
- One weekly SRRG, each at Danda and Rum villages (**Plate III**),
- One weekly Thermohygrograph, at Danda Village.

4.3 Field Investigations

Hydrometeorological data and maps were collected from available sources; Geological (structural), Geophysical (resistivity and EM), Soil, Water quality, Topographic, and Hydrological and hydrometeorological surveys were carried out in the area.

4.4 Data Analysis and Modelling

- Contour map (**Figure 2a**) and DEM (**Figure 3**) of the Danda watershed were prepared,
- Physio-chemical analysis of soil and water samples was done,
- Interpretation of geophysical data was carried out,
- Isohyetal map of the Tehri District was prepared,
- Geological (structural) map of the Danda area was prepared.

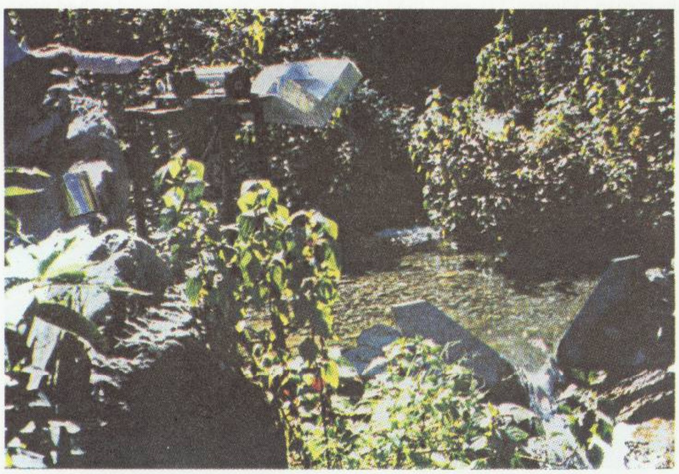
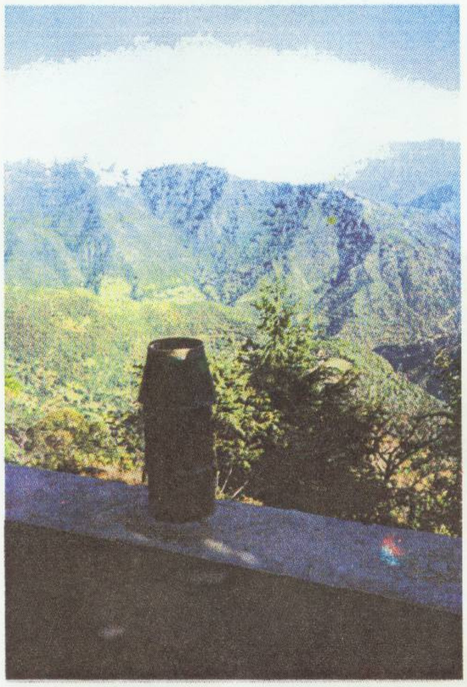


Plate II. Installation of water level (stage) recorder at Rumdhar



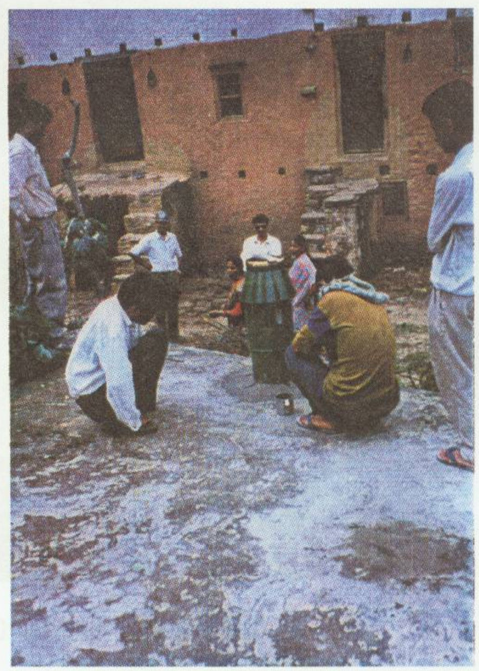


Plate III. Installation of self-recording rain gauge in Danda village

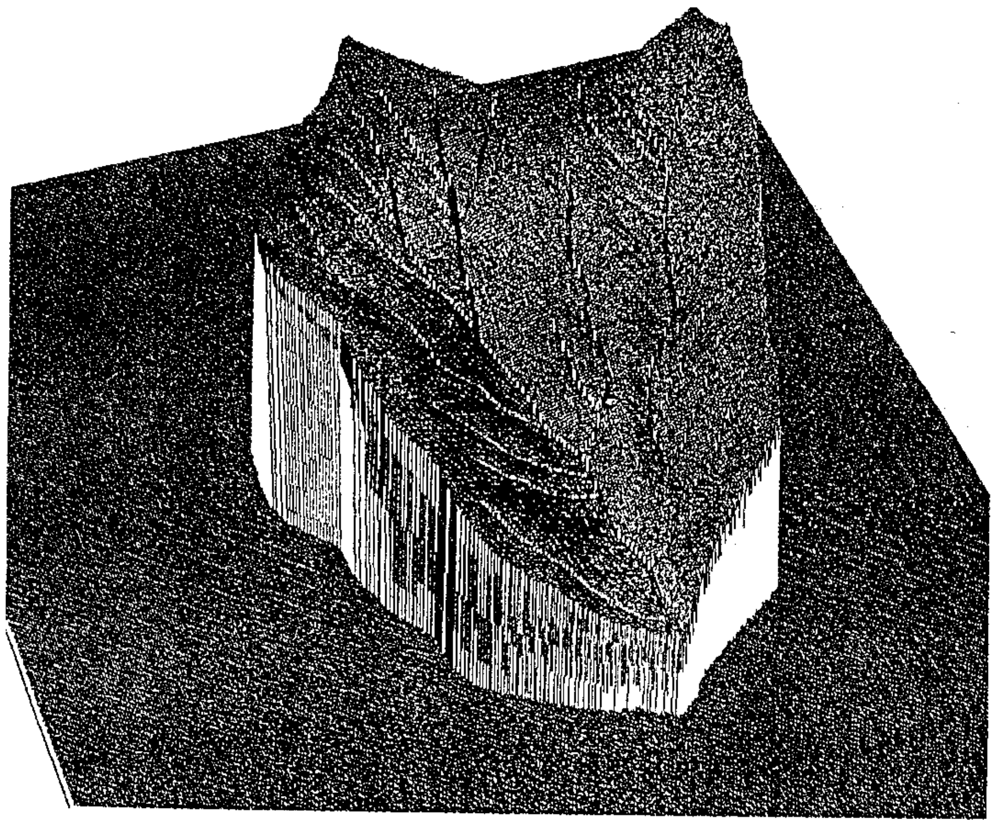


Fig. 3. Digital Elevation Map (DEM) of the Danda watershed

4.4.1 Climate

The main climatic features of Tehri district are described in the earlier portion of the report. Micro-level climate is likely to be influenced by local conditions, and it varies from one locality to the other. Climatic conditions that affect agriculture and human activities are generally described by temperature, wind flow, humidity, and precipitation. Using the available rainfall data from five rain gauge stations maintained by the U.P. Irrigation Department and three other stations, a map showing mean annual precipitation distribution over the Tehri district is shown in **Figure 4** (SSS, 1996). It is seen that the annual normal rainfall in the district varies from 96.0 cm at Tehri to 285.0 at Ghuttu. The central portion of the district between Tehri and Devprayag, and between Devprayag and Srinagar, along Alaknanda river, has the lowest rainfall.

There is no meteorological station recording any meteorological parameters in the study area. Rainfall, evaporation, daily maximum and minimum temperature, relative humidity and wind velocity data are available at Devprayag for a period varying between six to twelve years. The data of these parameters are also available at Ranichauri which is located on the other side of Bhagirathi catchment. Maximum and minimum temperature and relative humidity data are also available at Nagchaud which is about 3 km from the Danda village for a period of 10 months in 1995.

4.4.2 Rainfall

Only one ORG raingauge was installed in the watershed by SSS in August 1995. Therefore, rainfall data at Danda village are available from August 22, 1995 and is given in **Table 1**. Monthly average rainfall of the other stations is also given in Table 1. It is seen that the rainfall occurs in almost all the months of the year except in October and November and that the winter rains (1995-96) in the Danda area have been better than the average winter rainfall at other stations in the district.

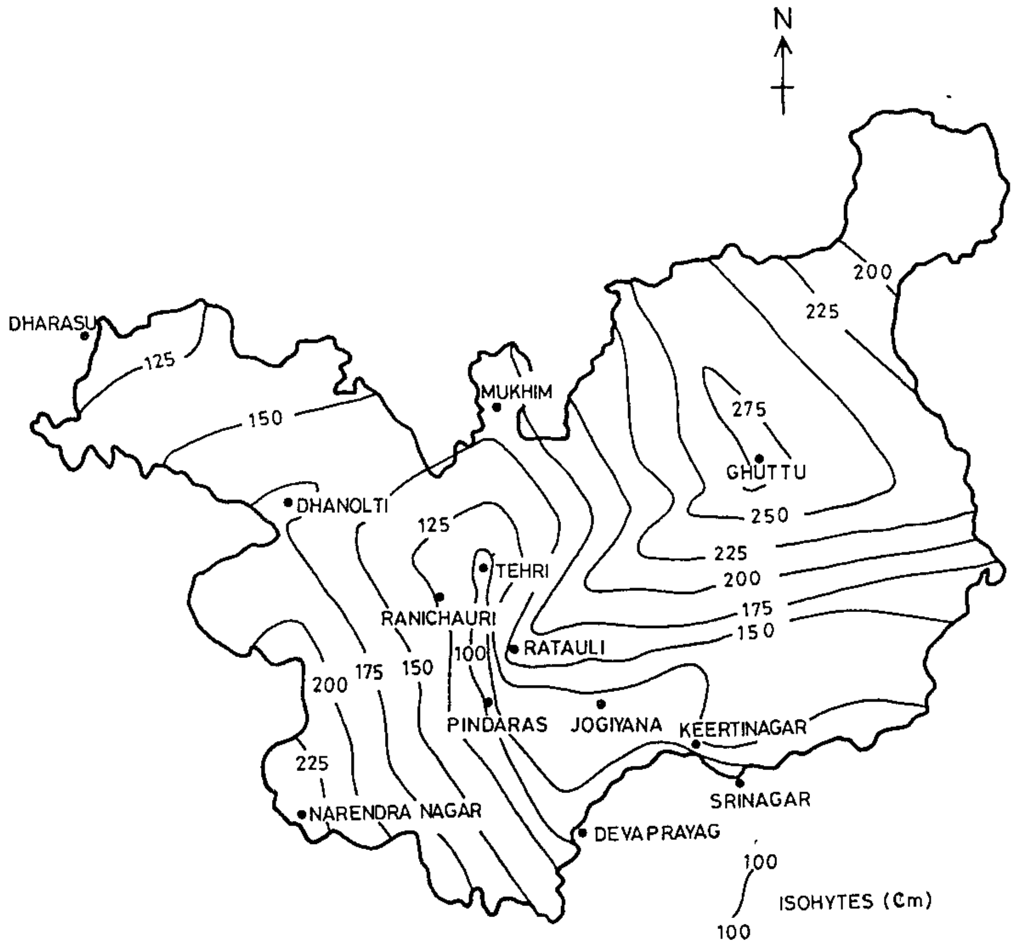


Fig. 4. Mean annual precipitation over Tehri-Garhwal District (U.P.)

Table 1.Average Monthly Rainfall (cm) at Selected Stations in and Around the Study Area

STATION	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Tehri (770m)	6.0	6.0	4.0	3.0	4.0	5.0	24	20	17	3	1	3	96
Devprayag (457m)	5	4	4	0	2	6	35	16	18	3	1	4	98
Ranichauri	6.5	10.7	8.8	4.5	6.7	11.8	28.3	26.2	15	0.5	0.6	4.4	124
Anjanisain (1700m)	6.5	15.6	6	2.1	2	16.7	11.6	27.8	16.4	0	0	0.5	105.2
Danda (1600m)	7.8	13.3	5	2.2	2.6	10.7	7.3	23.7	12.4	0	0	0.6	85.6

Source : U.P. Irrigation Dept. (Investigations & Planning Division); G.B.Pant University Hill Campus; South South Solidarity (1996)

Average annual rainfall of the district is 175.66 cm whereas the estimated annual rainfall from September 1995 to August 1996 in Danda is 85.6 cm. This value is less than the mean annual value of rainfall at other places in the district except at Tehri and Devprayag. The number of rainy days are 64 in the Danda area.

The wet spells in the Danda area were : August 22 to September 9, 1995, February 23 to 27, 1996. June 21 to 26, 1996 and July 31 to August 31, 1996. In the Danda area there are dry spells lasting more than 10 days from September 10 to 23, 1995 and July 6 to 16, 1996. Winter rain takes place in the months of January, February and March. Wet spell has been experienced in the area in the month of February 1996.

4.4.3 Temperature

The values of maximum and minimum daily temperatures were available at Devprayag, Nagchaud, Tehri and Ranichauri (**Table 2**). It is seen that the highest value of maximum temperature 38.5^0 C is recorded at Devprayag in the month of May and June and the next highest value of maximum temperature is recorded at Tehri in the month of June. The Corresponding values recorded at Nagchaud and Mukhim are 36^0 C and 26.1^0 C in the month of June. The minimum temperatures recorded at these stations range between 2.8^0 and 4.2^0 C in the month of January/ December.

4.4.4 Relative Humidity

The relative humidity data was available at Devprayag and Ranichauri. At Nagchaud relative humidity data is available from February 1995 to December 1995 (**Table 3**). It is seen that the values of relative humidity are minimum in the months of April and May which are relatively dry months. The maximum values of R.H. range between 76 and 90%, whereas the minimum value ranges between 39 and 68%.

Table 2. **Average Monthly Air Temperature (Deg C) in and Around the Study Area**

Month	Station							
	Devprayag (457m)		Ranichauri (1750m)		Tehri (770m)		Nagchaund (1520m)	
	Max	Min	Max	Min	Max	Min	Max	Min
January	21	3.8	11.5	2.8	18.9	5.0	N.R.	N.R.
February	24.1	5.09	11.9	3.0	22.4	6.6	21	6
March	29.7	8.5	15.9	6.3	27.2	11.1	24	6
April	35.8	12.3	21.4	9.9	33.0	15.8	28	5
May	38.5	16.6	25.1	13.8	36.8	19.7	32	13
June	38.5	19.4	25.7	16.2	37.1	22.5	36	17
July	34.2	21.0	23.1	16.7	33.0	23.3	33	18
August	32.9	19.5	22.4	16.6	32.7	23.5	31	17
September	31.6	18.3	21.9	14.8	32.3	21.7	28	18
October	31.0	12.4	20.3	10.2	29.5	16.2	26	12
November	25.8	7.5	16.0	6.3	25.4	9.2	18.1	10.9
December	20.4	4.3	13.2	3.5	20.9	4.2	13.0	6.8
Mean Annual	30.3	12.4	19.0	10.0	28.9	15.0	26.4	11.8

Source : U.P. Irrigation Dept. (Investigations & Planning Division); G.B.Pant University Hill Campus; U.P. Watershed Dept.

Table 3. Average Monthly Relative Humidity (%) in and Around the Study Area

Month	Station				
	Devprayag (457m)		Ranichauri (1750m)	Nagchaund (1520m)	
	Max	Min	Max	Max	Min
January	90	57	61	N.R.	N.R.
February	88	54	67	88	52
March	87	43	55	84	52
April	82	39	49	90	50
May	76	39	49	88	42
June	87.5	45	62	92	27
July	91.0	61	84	91	75
August	92.0	68.2	87.5	91	53
September	91.0	65.2	85	91	72
October	84.0	56	64	90	61
November	89	55	60	89	55
December	89	58	61	88	54
Mean Annual	87.2	53.4	65.4	89.3	53.9

Source : U.P. Irrigation Dept. (I& P Div.); GB.Pant Univ. Hill Campus; U.P. Watershed Dept.

4.4.5 Evaporation

Evaporation data was available at Devprayag and Ranichauri. The average daily evaporation at Ranichauri varies between 1.5 mm/day in the month of January and 4.6 mm/day in the month of May. Similarly the average daily evaporation at Devprayag varies between 1.39 mm/day in the month of January and 6.3 mm/day in the month of May. Annual average rate of evaporation is 3.47 mm/day at Devprayag and 2.75 mm/day at Ranichauri (**Table 4**).

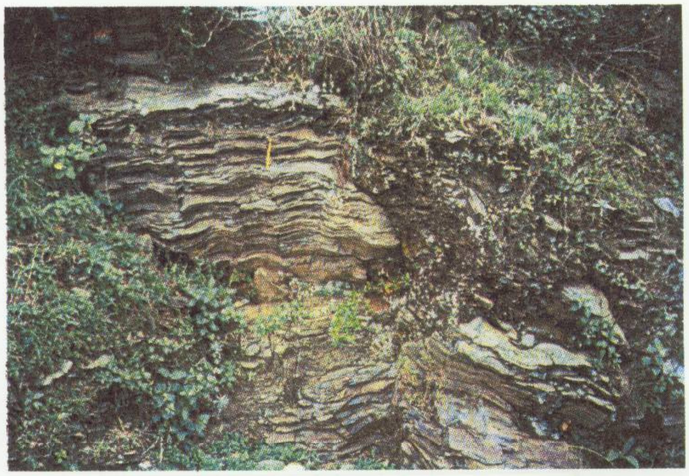
Table 4. Average Monthly Pan Evaporation (mm/day) in and Around the Study Area

Month	Station	
	Devprayag	Ranichauri
January	1.39	1.5
February	2.2	1.8
March	3.5	2.7
April	5.3	3.8
May	6.3	4.6
June	5.8	4.4
July	3.9	2.9
August	3.1	2.6
September	3.5	2.4
October	3.0	2.7
November	2.3	2.0
December	1.4	1.6
MeanAnnual	3.47	2.75

Source : U.P. Irrigation Dept. (Inv. & Planning Div.); G.B.Pant University Hill Campus

4.4.6 Geology

Lithologically, Danda area falls under the Chandpur formation of Jaunsar groups. Geology mapping was done in the Danda watershed. The rock type of the area is low grade metamorphic rock with slates. These greyish coloured low grade metamorphic rocks are highly fractured and foliated (**Plate IV**). The distance between the foliation planes are ranging from 2 mm - 10 mm. At various places, folded quartz veins are seen intermingled with the foliation planes. Altitude of these foliation planes are marked in the structural map (**Figure 5**).



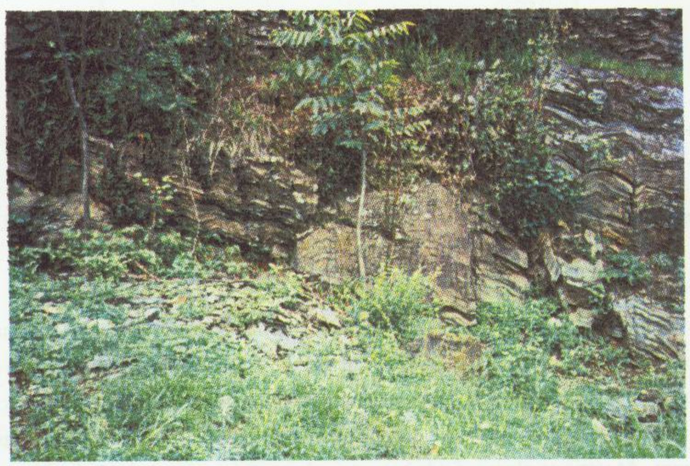


Plate IV. Geology of the Danda watershed

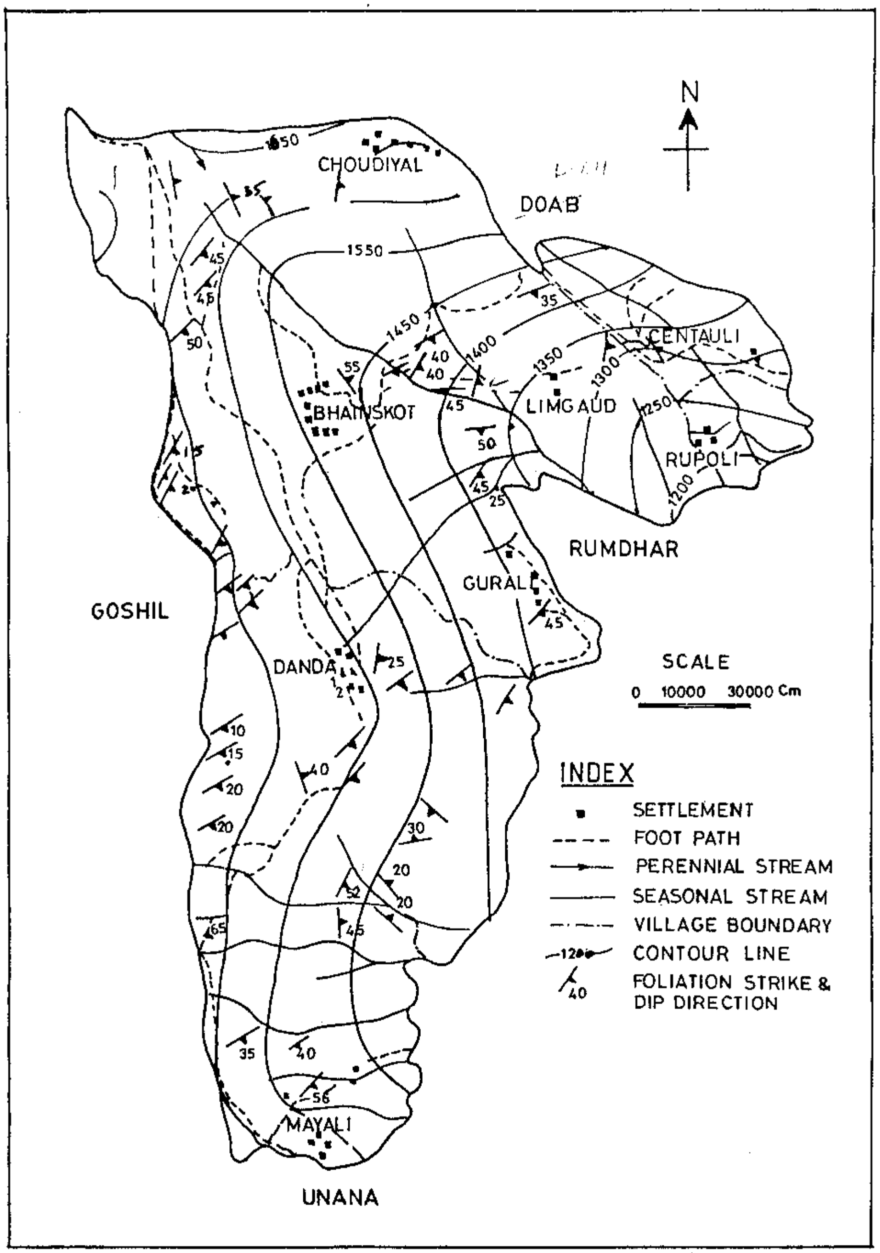


Fig.5 . Geology (dip and strike) in the Danda area

(SSS, 1996)

The altitude of the foliation planes show that:

- The strike of foliations of Choudiyal ridge is NW-SE dipping towards NE.
- The strike of foliations in Goshil region (west of the perennial stream) is NE-SW and dipping towards SE.
- The folded quartz veins and the altitude of the foliation planes show that in the study area there are at least two generations of folds and these folds are plunging folds (where the axial plane are inclined).
- The perennial stream is in the strike direction of foliation planes of Choudiyal ridge.

4.4.7 Soils and Land Use

In Garhwal area, the majority of soils are diluvial in nature. Most of the agricultural soils usually lose the top horizon either due to construction of terraces or erosion. In the terraced hillside, the downslope drift of mineral matter is sharply reduced, the soil is stabilized and leaching becomes important process of profile formation. On steep slopes, soils are generally shallow and usually have a thin surface horizon and medium to coarse texture. Residual soils are well developed on land summits of lesser Himalayas. Subsoils are deep and heavily textured. Top surface horizon with a high Content of organic matter is a characteristic feature of the area. These are highly leached and acidic in nature. Valley soils are developed from the colluvium brought down from the upslopes. Soils of the valley bottom on river terraces comprise of alluviam, brought and deposited by rivers in the process of aggradation.

Soil surveys were carried out to determine the soil types in the study area. The survey included determining soil depth, slope, texture and erosion condition. General information was collected from the villagers, fields and the block office. From the details of various soil profiles. landscape features, vegetation and present land use pattern (**Figure 6**), the land capability and irrigability classification were developed (SSS, 1996). For preparation of land capability, the system adopted by All India Soil and Land Use Survey, IARI was considered.

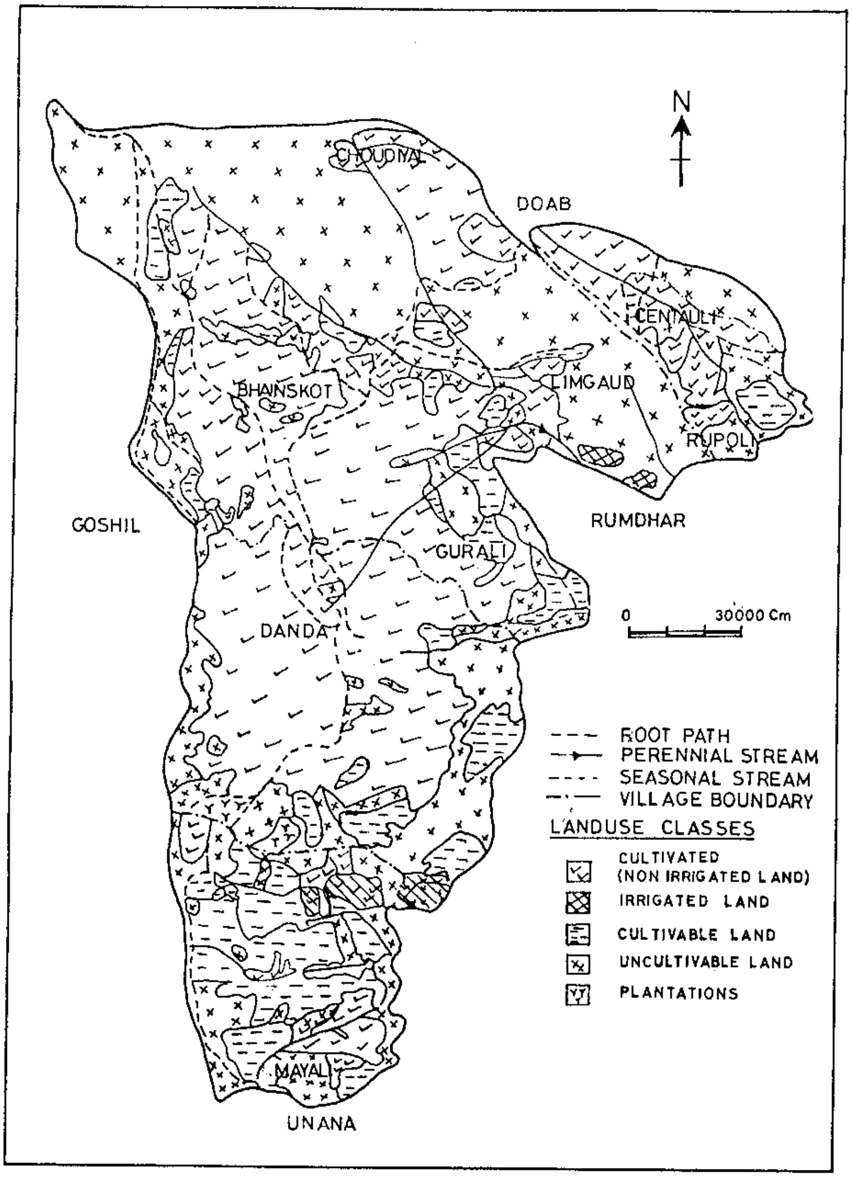


Fig. 6. Present land use in the Danda area

(SSS, 1996)

The land capability map of Danda area is shown in **Figure 7**. The soils of Danda can be divided into four soil classes. The details of each soil are given as follows:

Class III 1.1 % of the study area (9.68 hectares) is coming under this category. The land is moderately well cultivated and occurs on moderate slope 5-10^0 of shallow soil (mainly sandy soil). Slope percentage is less than 10%. The surface soil contains 10-15% gravel. The land is not much susceptible to erosion.

Class IV This category comprising 54.19 hectares (21.79 %). Fairly good land and is suited tor occasional or limited cultivation. The area is characterized by slope of 10-19^0 with moderate erosion, slope percentage is less than 33%. The soil contains 10-50% gravel.

Class VI 68.8 % of the study area (170.8 hectares) are suitable for grazing and forestry. Some of the characteristics of such land are susceptible to severe erosion by water and with steep slopes and shallow soil. Slope percentage is greater than 33%.

Class VII 8.32% of the study (20.66 ha) falls under this class. This class has land with steep slopes, rough stone or very severely eroded soil. Slope percentage is greater than 50%. The soil is loam with 20-50% gravel or stones and occurs on very steep slopes.

4.4.8 Chemical Quality of Soils

Nine soil samples were collected from various locations in Danda Gram panchayat area and analysed to determine pH, EC, sodium, potassium, calcium, magnesium, nitrate, sulphate, phosphate and chloride. The results of chemical analysis are given in **Table 5**. The soils of the watershed are normal soils with pH ranging from 6.78 to 7.79. Electrical conductivity values of the soils are low, and vary from 70 µS/cm to 230 µS/cm, indicating low salinity hazard. The chemical analysis further reveal that the soils have low NO_3 and PO_4 contents. This indicates that there is deficiency of nitrogen and phosphorous in the soils of the watershed.

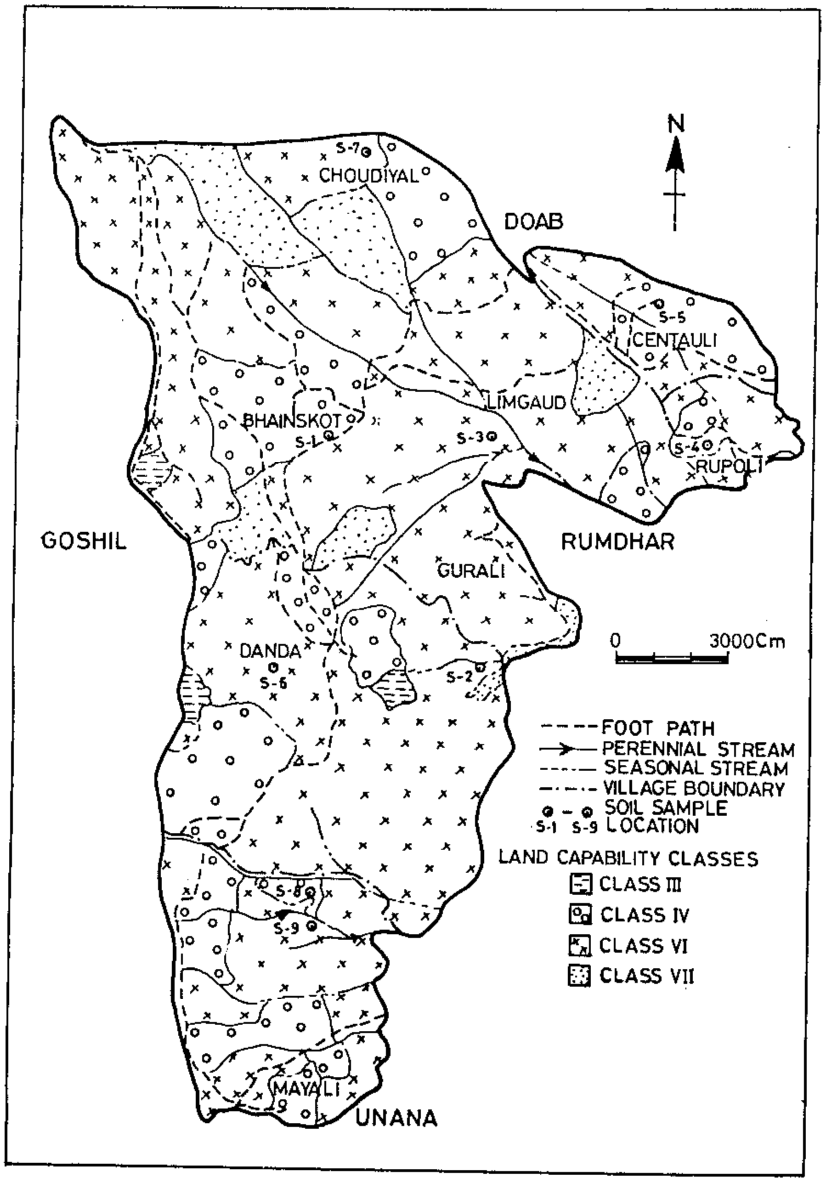


Fig. 7. Land capability map of the Danda area

(SSS, 1996)

Table 5. Results from Physio-chemical Analysis of Soil Samples from the Study Area (June, 1996)

LOCATION	ID#	ALT m	COND µS/cm	pH	TDS mg/L	CHL mg/L	ALK mg/L	HARD mg/L	Ca mg/L	Mg mg/L	NO_3 mg/L	PO_4 mg/L	SO_4 mg/L	Na mg/L	K mg/L
Karas Vill.	12	1628	140	7.56	90	8	82	80	19.2	7.8	0	0.2	0.5	0.7	0.15
Danda Sch.	11	1595	110	7.34	70	10	128	68	16	6.8	4.4	0.2	0.5	1	0.15
Mayali	14	1508	110	7.29	64	10	84	80	32	9.2	0	0	0.5	1	0.25
Mayali SS*	15	1497	140	7.23	90	6	68	82	32.8	6.7	0	0.8	1	2	0.22
Gurali	4	1362	130	7.48	83	12	126	78	16	9.2	0	0	0	1.2	0.14
Rupoli	8	1216	70	7.45	45	4	86	76	16	8.3	0	0.2	0	2	0.13
Limgaud	5	1319	170	7.38	108	6	108	102	27.2	8.3	0	1.3	0	1.5	0.25
Bhainskot	1		90	6.78	57	6	74	116	32	8.7	2.2	0.22	185	4	0.15
Centauli	10		230	7.79	147	16	138	130	32	12.1	0	8.8	0.5	2.1	0.58
Chaudiyal	13		110	7.28	70	4	64	66	16	6.3	0	0	1	0.7	0.15

* Shyam Stream

NOTE : To convert values in mg/L, multiply by 5 except for pH, ALT, & COND

5.0 HYDROLOGY OF THE AREA

5.1 Springs

Since the villagers are using spring water for their domestic purposes, much emphasis has been given for regular discharge monitoring and seasonal water quality monitoring of the springs. In Danda Gram-sabha area, there are 13 springs. Location of these springs are shown in **Figure 8**. During summer either the springs dry up or discharge gets reduced drastically. Discharge measurements have been carried out for these springs since August, 1995. Average monthly discharge of these springs are given in **Table 6**. The spring discharge data shows that the natural water availability of spring water is not enough to meet the villager's daily requirements, during the summer season (**Plate V**). During this season, the habitants of Choudiyal, Danda and Bhainskot villages have to depend upon some other far away sources of water. Water samples from the various springs in the area were collected and analysed (**Table 7**).

The resistivity surveys were conducted at a number of terrace field sites in Danda area (**Plate VI**) and it has been revealed that shallow water table exists at some locations. Boring could be done at these locations to extract water for augmenting domestic supply. Especially the location above Danda village appears to be a suitable place for boring (**Figure 9**) because from here the water can be brought to the village through gravitational flow.

5.1.1 Danda Village Springs (Danda-l and Danda-2)

There are two springs near the Danda village. Danda-l is perennial, whereas, Danda-2, is seasonal. During the summer season, there are long queues in front of this spring. Villagers collect water day and night from this spring. These springs have a large recharge area in the upper region. These upper regions are covered by agricultural fields. The forest cover is insignificant. The possibility of recharge for these springs is low unless the agricultural fields are irrigated and used for recharging. The discharge of spring Danda-l ranges between 9.94 and 143 m^3/day and discharge of spring Danda-2 ranges between zero and 143.5 m^3/day.

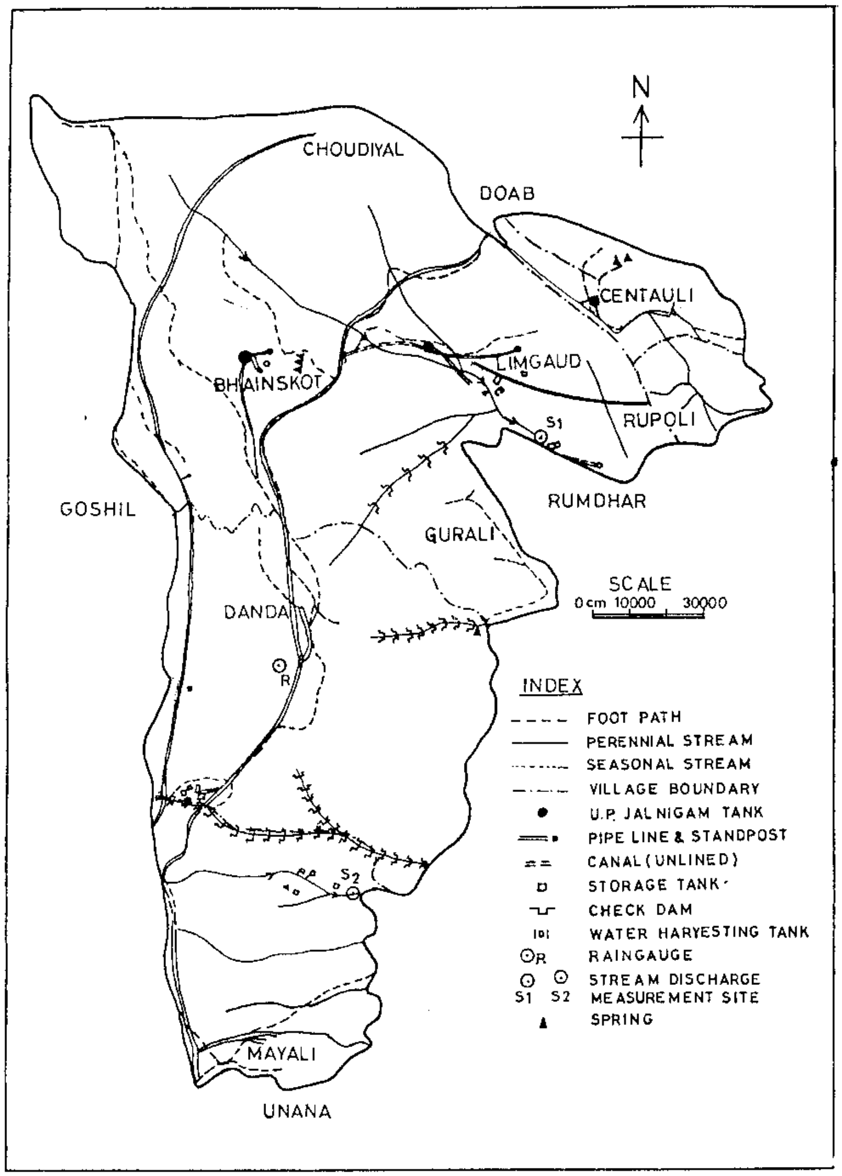


Fig.8. Location of springs in the Danda area

(SSS, 1996)

Table 6. Average Monthly Discharge of Springs in Danda Area

Name of Spring	Village	Average Monthly Discharge (m^3/day)												
		Aug 95	Sep 95	Oct 95	Nov 95	Dec 95	Jan 96	Feb 96	Mar 96	Apr 96	May 96	Jun 96	Jul 96	Aug 96
Danda 1	Danda	60.50	143.91	51.74	33.95	20.02	12.15	13.94	9.15	11.86	9.94	10.56	10.98	38.98
Danda 2	Danda	143.51	97.14	10.80	4.23	1.68	<0.10	0	0	0	0	0	0	0
Danda 3	Danda	9.20	6.20	4.50	2.60	0.50	6.37	0.55	1.12	1.12	1.03	0.66	0.87	3.35
Bhainskot 1	Bhainskot	76.70	104.01	14.03	6.43	5.10	3.83	3.51	3.56	1.91	4.38	1.00	2.18	59.37
Bhainskot 2	Bhainskot	14.70	16.75	6.44	2.92	1.99	1.54	1.30	0.87	1.24	0.77	0.80	0.94	6.06
Bhainskot 3	Bhainskot	7.67	11.24	6.02	3.20	2.43	2.16	2.20	2.88	2.20	1.04	0.90	2.16	2.83
Limgaud	Limgaud	-	-	-	-	-	19.10	12.20	22.30	12.00	6.80	2.51	2.58	48.13
Centauli 1	Centauli	-	112.2	32.90	17.50	9.40	6.70	6.30	5.70	4.30	2.70	1.96	2.63	26.80
Centauli 2	Centauli	-	3.70	3.380	3.00	2.80	2.72	2.31	2.03	2.80	1.00	0.87	1.71	2.66
Gurali	Gurali	65.70	193.67	95.05	58.24	35.99	30.88	30.40	25.30	17.70	16.71	18.78	19.93	43.26
Mayali	Mayali	-	98.70	19.60	8.35	4.60	3.50	6.50	29.10	22.50	14.90	9.98	6.78	6.93
Mayali Shyam	Mayali	-	-	-	-	-	4.30	7.67	19.20	6.80	5.20	1.54	6.75	17.21
Choudiyal	Choudiyal	-	7.60	2.70	1.70	0.78	<0.10	0	0	0	0	1.00	1.78	3.30

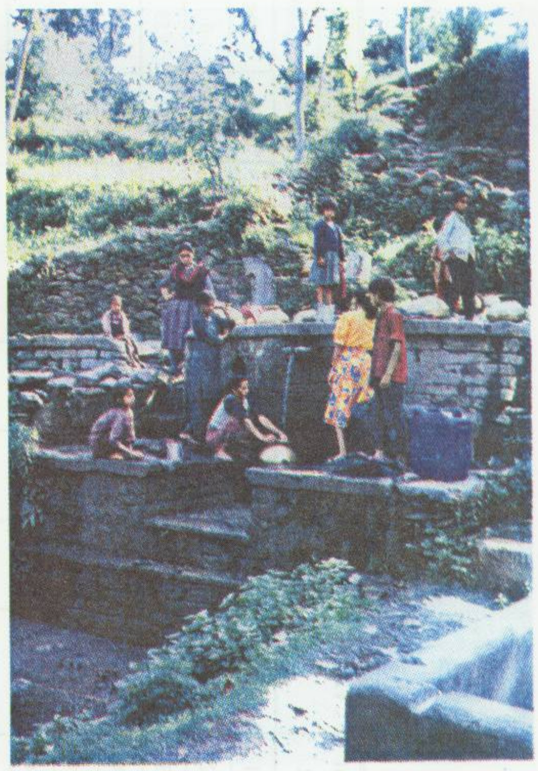


Plate V. Springs as the source of water in the Danda watershed

Table 7. Results from Physio-chemical Analysis of Water Samples from the Study Area (June, 1996)

LOCATION	ID#	ALT m	TEMP deg C	COND µS/cm	pH	TDS mg/L	CHL mg/L	ALK mg/L	HARD mg/L	Ca mg/L	Mg mg/L	NO_3 mg/L	PO_4 mg/L	SO_4 mg/L	Na mg/L	K mg/L
Karas Vill.	KS-1	1629	20.6	100	7.14	64	6	62	50	12	4.9	0	2.6	.08	3.1	.028
Karas Vill.	KS-2	1628	22.0	160	7.69	102	12	90	80	20	7.3	0	0	.15	2.8	.055
Danda Sch.	SDW2	1595		50	7.24	32	10	40	40	11	3.4	0	0	.38	2.4	.015
Mayali	SDW3	1508		80	7.22	51	4	62	30	7	2.9	0	0	.38	5.3	.025
Mayali SS*	SDW4	1497		100	7.94	64	4	68	40	9	4.4	0	0	.38	2.3	.019
Gurali	SDW5	1362	20.6	210	7.92	134	10	116	100	26	8.8	8	.44	.3	3.9	.023
Rupoli	SDW6	1216	20.9	180	7.65	115	12	100	80	20	7.5	8	0	.53	4.5	.021
Limgaud	SDW7	1319	21.2	130	7.99	83	4	96	60	14	5.8	7	0	.98	3.4	.026
Bhainskot	SDW8	1448	21.0	120	8.2	76	20	62	52	14	4.4	9	0	1.65	2.9	.057
Bhainskot	SDW9	1479	22.7	210	3.68	134	8	40	64	16.8	5.4	50	8.3	.9	2.3	.037
Danda Vill.	SDW10	1521	19.8	110	7.97	70	8	72	54	12.8	5.4	8	0	.53	2.1	.016
Centauli	SDW11	1319	23.2	110	7.91	70	24	74	60	16	4.9	5	0	1.28	3.3	.017
Centauli	SDW12	1367	22.7	80	7.11	51	14	58	44	10.4	4.4	5	0	.6	3	.16
Rumdhar@			20.7	140												

* Shyam Stream

@ Post monsoon (Sept 18, 1996)

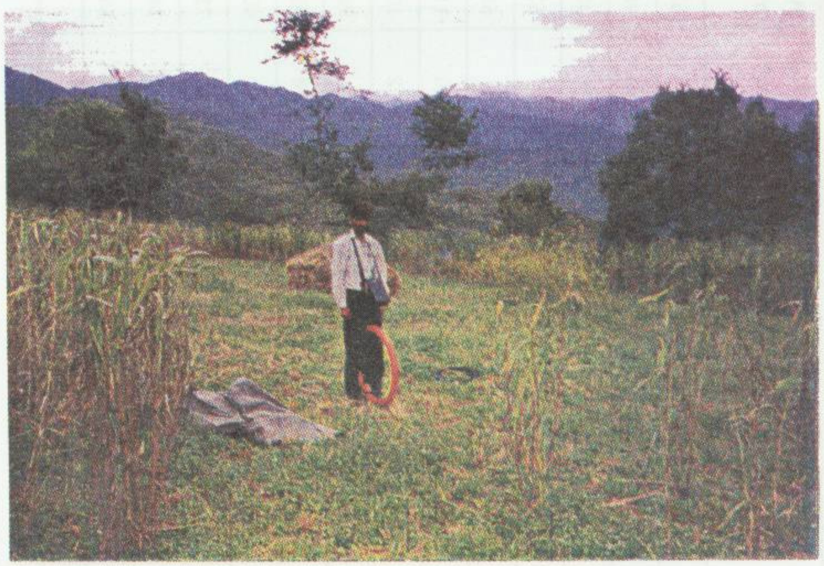


Plate VI. Resistivity and electromagnetic surveys in the Danda village

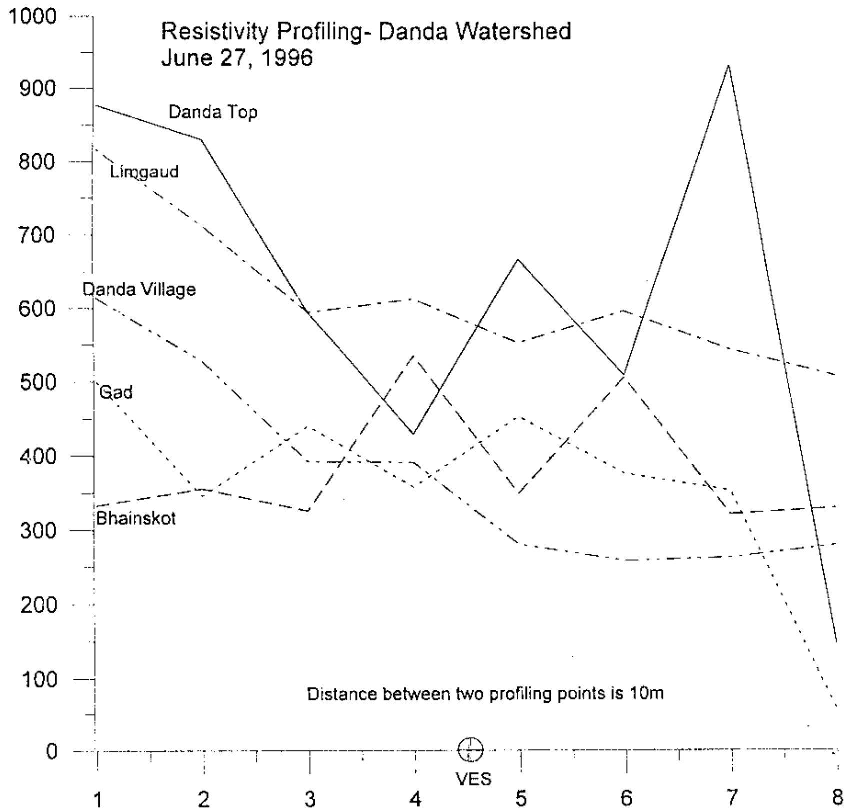


Fig.9. Resistivity profiling surveys at the Danda village

5.1.2 Danda School Spring (Danda-3)

This spring (Danda-3) is close to the Danda school and is mainly used by the school students. The upper regions of this spring which are possible recharge areas are covered under plantations. This area contains a substantial amount of water, which leads to a gradual discharge. The discharge of the spring during 1995-96 ranges between 0.5 and 9.2 m^3/day.

5.1.3 Bhainskot Springs (Bhainskot-l, Bhainskot-2 and Bhainskot-3)

There are three springs near Bhainskot village. The villagers use these springs for their domestic purposes. Discharge from all these springs gets reduced drastically during the summer period. These three springs are not able to meet the villagers' need. During the summer season, the villagers have to wait for hours to get water. The possible water recharge areas are relatively terraced cultivated lands. Water holding structures (like pits, ditches, trenches, etc) can be made to hold water on the upper region for recharging the springs. The discharge of these springs range between 0.77 and 104.01 m^3/day.

5.1.4 Limgaud Spring

Limgaud spring is located close to the village. The spring originates within the Silwani stream. During the monsoon season the water from the upper reaches of the stream meets the spring. This potentially affects the quality of the water during the monsoon season. The upper part of spring is terraced agricultural lands. The discharge of the spring ranges between 2.58 and 48.13 m^3/day.

5.1.5 Centauli Springs (Centauli-l and Centauli-2)

There are two springs (Centauli-l and Centauli-2) in the Centauli village. The villagers take water from these springs. The Centauli-l spring is a well-type of spring and the water from the spring gets collected in a small depression below the spring. The Centauli upper villagers collect water from this well-type depression. The other spring (Centauli - 2) is a flowing spring near the Centauli settlement on the lower slope. This spring is also being used by the Suradi villagers from a nearby area. There is no forest cover above the spring. The Watershed Department had planted some plants in the upper region. This may influence the spring discharge during the coming years. The Centauli springs are perennial. The discharge is ranging between 1.96 to 112.2 and 0.87 to 3.7 m^3/day, respectively, for Centauli-l and Centauli-2.

5.1.6 Gurali Spring

Gurali Spring is located around 500 metres from the Gurali village. This spring has a high rate of discharge, which can meet the villagers requirements during all the seasons. This spring has a large upper area with terraced cultivated lands with few trees. The discharge varies between 16.71 and 193.67 m^3/day.

5.1.7 Mayali springs (Mayali and Mayali Shyam)

Mayali spring is located around 300 metres from the main village. Villagers are mainly depending upon this spring for their domestic water. The Watershed Department and the Gram Sabha had planted a large portion in the upper area. This may have an influence on the spring discharge during the coming years. The discharge is ranging from 3.5 to 98.7 m^3/day.

Shyam Mayali spring is located near to the Shyam stream. Discharge records are available from January 1996 onwards only. The variation of discharge is from 1.54 to 17.21 m^3/day.

5.2 Streams

Two perennial streams, namely Silwani and Shyam, are located in the watershed. The Silwani stream is around 200 metres west of the village Rupoli, and the other stream is located about 500m north of the village Mayali. The average monthly discharges of the two streams in the area are given in **Table 8.**

Table 8. Average Monthly Discharge of Streams in the Danda Area

MONTH & YEAR	AVERAGE MONTHLY DISCHARGE (m^3/day)	
	Silwani Stream	Shyam Stream
September, 1995	4128.8	261.9
October, 1995	1515.4	136.8
November, 1995	1036.1	86.7
December, 1995	932.0	49.4
January, 1996	509.1	38.5
February, 1996	412.1	34.5
March, 1996	243.6	32.1
April, 1996	158.3	26.2
May, 1996	120.8	21.3
June, 1996	108.2	24.5
July, 1996	180.2	49.1
August, 1996	865.6	160.1
TOTAL	10210.2	921.1

5.3 Water Holding Structures in Danda area

There are a number of water holding structures present in both the Danda and Chandrabhaga area. The water holding structures include storage tanks, water harvesting structures, check dams and canals. Some of the storage tanks are constructed by the UP Jal Nigam and some by the Gram Sabhas. SBMA has also constructed a few storage tanks. Some people have their personal storage tanks also. The storage tanks are constructed for irrigation and domestic purposes. The water harvesting structures are constructed by the UP Watershed Department (Jalagam). They are constructed for the purpose of conservation of water. The canals (guls) are used for irrigation.

6.0 FUTURE PLAN OF ACTION

6.1 INSTRUMENTATION AND INVESTIGATIONS

1) Compute area, perimeter, stream density, channel length and other geomorphological parameters
2) Procure available data on watershed characteristics
3) Install AWS and additional instruments for measurement of hydromet parameters and collect data at regular intervals
4) Conduct geological and geophysical surveys for estimating groundwater potential, groundwater movement and identification of suitable sites for groundwater recharge
5) Conduct soil surveys for infiltration rate, hydraulic conductivity and physio-chemical properties
6) Perform discharge and water quality surveys at the entry and exit points of the watershed

6.2 PREPARATION OF DEVELOPMENT PLANS

1) Appropriate vegetation measures
2) Prepare present land use and land capability maps
3) Identify suitable sites for applying soil & water conservation measures
4) Identify suitable sites for location of structures needed for minor irrigations (e.g. HYDRAM), for micro-hydel development and for groundwater development
5) Use of satellite data (FCC/digital) to identify geological features, land use and vegetation cover to aid in the selection of sources of water and for conservation measures.
6) Evaluate irrigation, drinking water and other water requirements

6.3 ANALYSIS AND MODELLING

1) Perform hypsometric analysis,
2) Analyse rainfall data to identify the frequency of dry and wet spells and to decide about the conservation measures,
3) Evaluate influence of conservation measures on groundwater recharge, by monitoring water level in wells within and outside the watershed boundaries,

4) Identification of recharge area and suitable structures for rainfall recharge for augmentation of spring flow,
5) Compute monthly water balance and also for monsoon and non-monsoon periods, estimation of dependable water availability,
6) Evaluate water quality and its spatial as well as temporal variation,
7) Perform rainfall analysis (rainfall intensity, maximum daily rainfall),
8) Compute soil erodibility index, and prepare soil erodibility map.

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