Geohydrology of springs in a mountain watershed: The need for problem solving research

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Spring discharge is controlled by rainfall, land use, vegetation, grazing incidence and geomorphology of the recharge zone in a mountain watershed in Garhwal Himalaya. The decline in discharge was found low (36.4%) in a fracture/joint/colluvial related spring with SE aspect, a mix of agriculture and moderately grazed grazingland with abundance of bushes, as compared to 100% decline (dry) in a colluvial related spring with WNW aspect, agriculture and moderately grazed old-growth chir pine forest land use and a negligible amount of bushes. Springs were also characterized by (i) a peak discharge in rainy season followed by a gradual decline and negligible response to winter rains; and (ii) those who had a sharp decline from peak discharge and substantial response to winter rains. Hydrological characteristics of the springs call for research on 'spring sanctuaries' and adopt better management and technological inputs in order to cater to normal drinking water demand of the catchment people.

WATER as a natural resource and fundamental basis of existence of life is abundant in the Himalaya, but its uneven distribution both in space and time comes in the way of development needs of the region[1]. Despite the fact that the mountains provide life-giving water to millions of the downstream people through perennial river system, its people face acute shortage of water during summer. People are sometimes compelled to reduce water consumption, consume unhygienic water, purchase water, and face social conflicts[2]. Another face of the problem is soil erosion, deterioration of agricultural productivity, instability of hillslopes and landslides, and floods and associated catastrophic losses in the adjoining plains caused by the intense rainfall during rainy season[3,4]. Springs are drying up or becoming seasonal, and the difference in the volume of water flowing down the rivers during dry and rainy seasons is commonly more than 1000 times, resulting in too-little-and-too-much-water syndrome – a common feature of the desert country[5]. Studies[5,6] indicate that deforestation, land use change, intense grazing, reduced water retention capacity of the catchments, declining rainfall in some localities, etc. have led to diminishing discharge of the springs.

At present, in all hill areas, excluding river valleys, the main sources of sustenance are the sub-surface and surface water flows which need adequate recharging to meet the demand. The recharging depends upon vegetational cover, in addition to the geological and geomorphological controls in the recharge zones. Geohydrological studies suggest that the lineaments produced by joints, fractures, and faults play a very significant role on the hydrogeological regime of a catchment[5,7]. We still have a limited knowledge about the nature of the springs in response to rainfall, recharge zones, role of vegetation, land use in spring recharge, etc. Equally important are the technological inputs and management issues[2,4]. This combination of interrelated factors calls for work on 'spring sanctuaries'. The present work provides spring discharge pattern in a mountain watershed, explores interaction of spring behaviour with rainfall, land use, and other morphological characteristics of the springs, emphasizes water resource management and points out the need for research and follow up action.

Located between 30°5'N and 78°46'E and 1650 m asl altitude, Dugar Gad catchment covers about 306 ha area (Figure 1). Annual rainfall (average of 1994 and 1995) amounts to 1694 mm, of which 74% occur during rainy

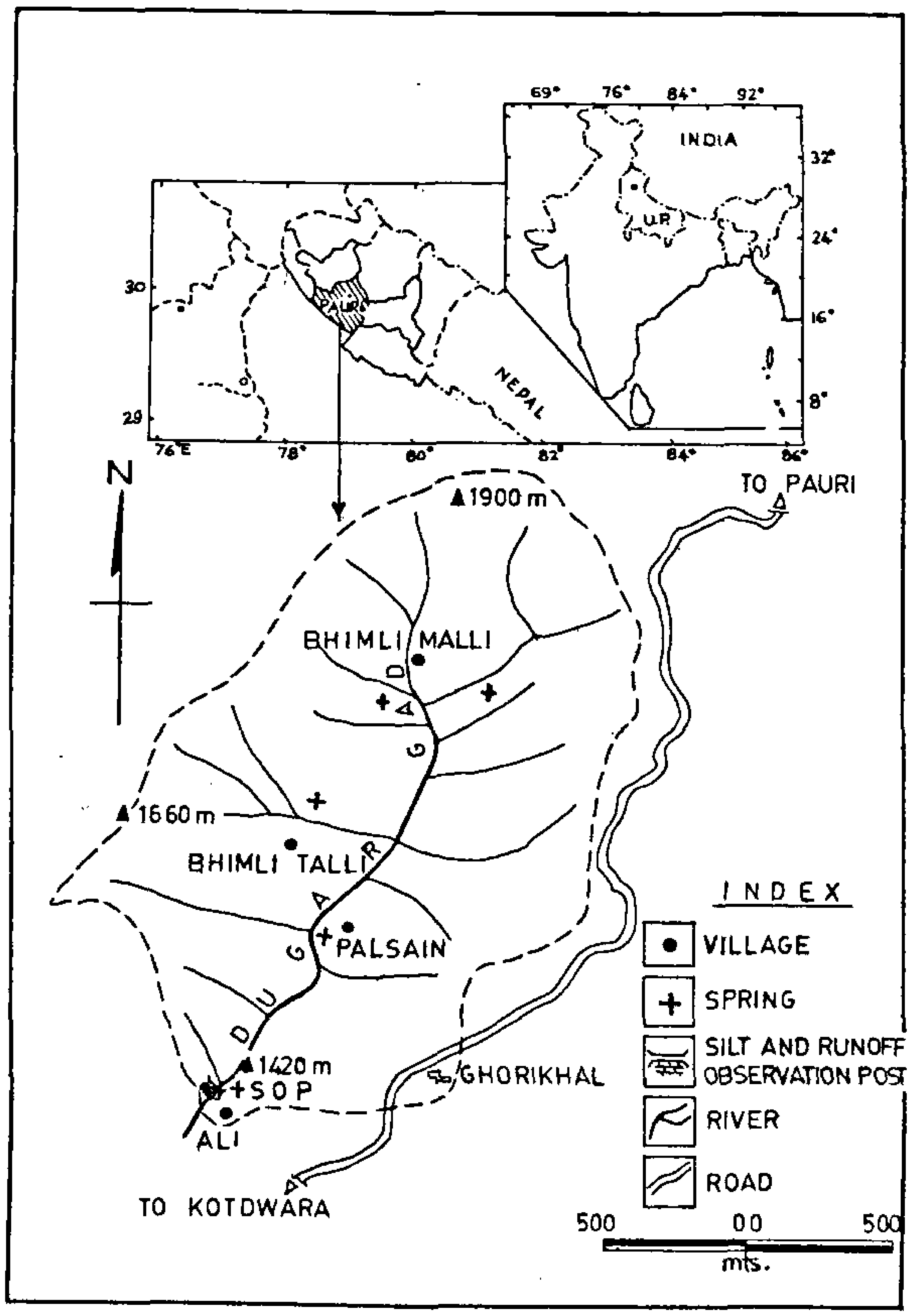

Figure 1. Location of Dugar Gad catchment.

Table 1. Some characteristics of Dugar Gad catchment selected in Garhwal Himalaya. Values in parentheses indicate the seasonal water sources. Data based on ref. 8

Parameters	Dugar Gad
Altitude (m asl)	1400–1900
Land use	
Total area (ha)	306.0
Cultivated area (%)	37.6
Forested area (%)	9.3
Wasteland (%)	53.3
Population	
Human	958
Livestock (au per ha)	6.29
Vegetation	
Fooder/firewood trees	1089
Fruit trees	539
Wild trees (chir pine)	5807
Total number of water sources	
Public tap (functional ?)	21
Spring	16 (10)
Naula	18 (11)
Well	1
Hydrometeorology	
Rainfall (m^3 ha^{-1} yr^{-1})	16940
Run off (m^3 ha^{-1} yr^{-1})	7000.4
Sediment loss (t ha^{-1} yr^{-1})	8.62
Average run off efficiency (%)	41.3

season. The mean monthly minimum temperature was 6°C (in January) and the mean monthly maximum was 31°C (in June). Population attributes, land use, water sources and a few other hydrometeorological features of the catchment are given in Table 1. Data of runoff and sediment loss are based on a separate study being undertaken by us in this catchment. Lack of irrigation, low yield, small and scattered holdings (10707 tiny terraces) are some of the reasons which have put about 60% of the cultivated land abandoned in this catchment. Despite a huge number of springs and 'naulas' (very shallow 1–2 m deep, appropriately lined wells to recover water from seepages) discharge in them diminishes during summer which compell people to reduce their household water consumption. Therefore, drinking water provisions and land and water conservation constitute the main challenges in this catchment.

Four springs, one each in the four villages of the catchment were selected for this study in April 1995. In addition, a near-extinct spring (Bhimli Talli-2) was selected for discharge revival employing vegetative and engineering methods. These springs differ from each other with respect to their nature, i.e. perennial (P) and seasonal (S), recharge zone area, upslope aspect, slope, land use, type of rocks and upslope vegetation (Table 2). Geologically these springs were of three types: colluvial related (Palsain; Figure 2 *a*), fracture/joint/

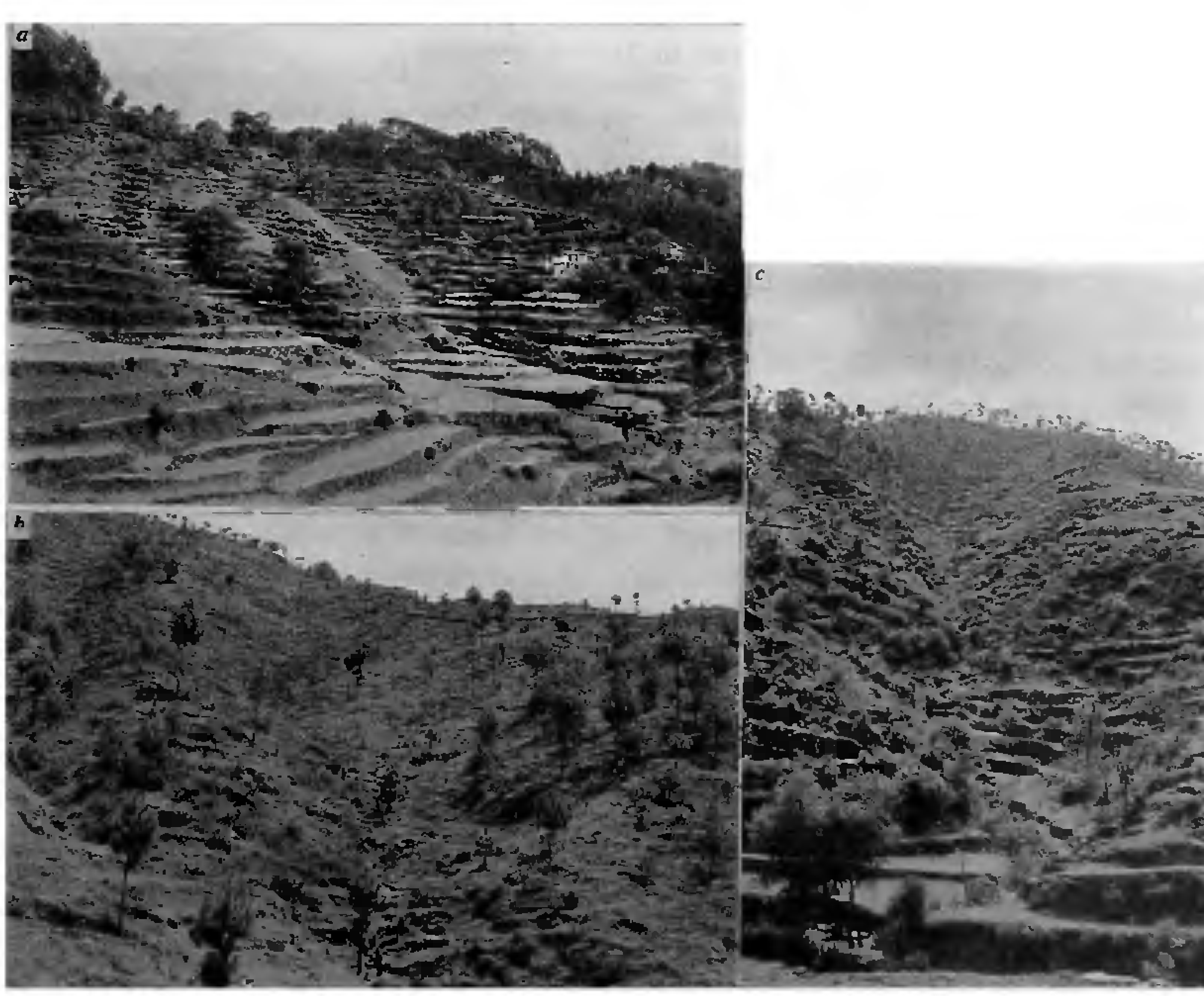

Figure 2. *a*, Palsain – a colluvial related seasonal spring. The major land use in recharge zone is terraced agriculture and old-growth chir pine forests (in the upper zones). + sign locates the spring. *b*, Bhimli Talli-1, a fracture/joint/colluvial related perennial spring. The major land use is bush land and grazing land with young chir pine trees scattered in the upper zone. *c*, Bhimli Talli-2, a fracture/joint related near-extinct spring taken up for discharge revival experiments. The major land use of recharge zone is severely grazed land without trees.

Table 2. Location, morphological characteristics, land use and vegetation associated with the springs in the Dugar Gad catchment

Name of the springs (village)	Upslope area (ha)	Type of the spring	Rock types	Average slope of catchment, aspect	Major land use	Vegetation of the spring catchment
Ali (S) (1440)	20.9	Fracture/ joint/ colluvial related	Phyllite, phyllitic quartzite	36°, SW	Forest under moderate grazing influence	Old growth chir pine (*Pinus roxburghii*) stand, bushes of *Berberis asiatica*, *Crataegus crenulata*
Bhimli Malli (P) (1550)	12.1	Fracture/ joint/ colluvial related	Phyllitic quartzite	12°, SE	Agriculture and grazingland under low grazing influence	Scattered young trees of *Celtis australis*, bushes of *B. asiatica*, *C. crenulata* and *Rubus ellipticus*
Bhimli Talli-1 (P) (1500)	40.7	Fracture/ joint/ colluvial related	Phyllitic quartzite	10°, SE	Abandoned land, shrubland and grazingland under low grazing influence	Young chir pine trees, a few trees of *C. australis*, bushes of *B. asiatica*, *C. crenulata* and *R. ellipticus*
Bhimli Talli-2 (P) (1575)	18.5	Fracture/ joint related	Phyllitic quartzite	40°, SE	Open grazingland under high grazing influence	No trees, bushes of *B. asiatica*, *C. crenulata* and *Rhus parviflora*
Palsain (P) (1450)	10.4	Colluvial related	Phyllite, phyllitic quartzite	15°, WNW	Agriculture and forest under moderate grazing influence	Old growth chir pine forest, scattered trees of *C. australis*

S, Seasonal; P, Perennial; Values in parentheses indicate altitude (m asl).

Table 3. Cumulative deviation (expressed as per cent from peak discharge) in five springs of Dugar Gad catchment in Garhwal Himalaya

Months (1995–96)	Ali (1355)	Bhimli Malli (1486)	Bhimli Talli-1 (1486)	Bhimli Talli-2 (1486)	Palsain (1355)
April	95.2	36.4	60.7	99.3	91.9
May	100**	37.1	67.3	99.5	96.1
June	100**	42.8	76.1	99.7	100**
July	74.6	16.4	53.5	99.3	83.8
August	11311*	18142*	6.4	171813*	18679*
September	0.6	21.4	12060*	62.2	13.5
October	46.7	36.2	22.9	86.7	56.0
November	66.0	34.4	38.6	96.4	77.0
December	81.4	24.1	42.3	98.1	85.9
January	32.1	27.1	47.4	98.2	79.4
February	24.6	46.4	52.3	96.5	75.1
March	51.5	38.2	55.6	97.9	58.9
Total discharge (l)	1789791	4721883	2448510	7100598	2014501

*Peak discharge (litre per day); **Spring dried up; Values in parentheses indicate total annual rainfall (mm).

colluvial related (Bhimli Talli-1; Figure 2*b*) and fracture/joint related (Bhimli Talli-2; Figure 2*c*). Spring discharge was observed once in a week and daily rainfall was recorded at two locations (1460 and 1560 m asl). Discharge pattern was found highly variable across the springs (Figure 3). Bhimli Talli-2 spring recorded both minimum (15.5 l per hour on 13 June) and maximum (5571 l per h on 19 September) discharge across all the springs, registering a drop of 99.7% from the peak. In this spring of high slope (40°), discharge declined sharply. A low to moderate decline in discharge was recorded in Bhimli Malli (55.6%) and Bhimli Talli-1 (82.9%) springs, respectively. These springs were least affected by rainfall during post-rainy season

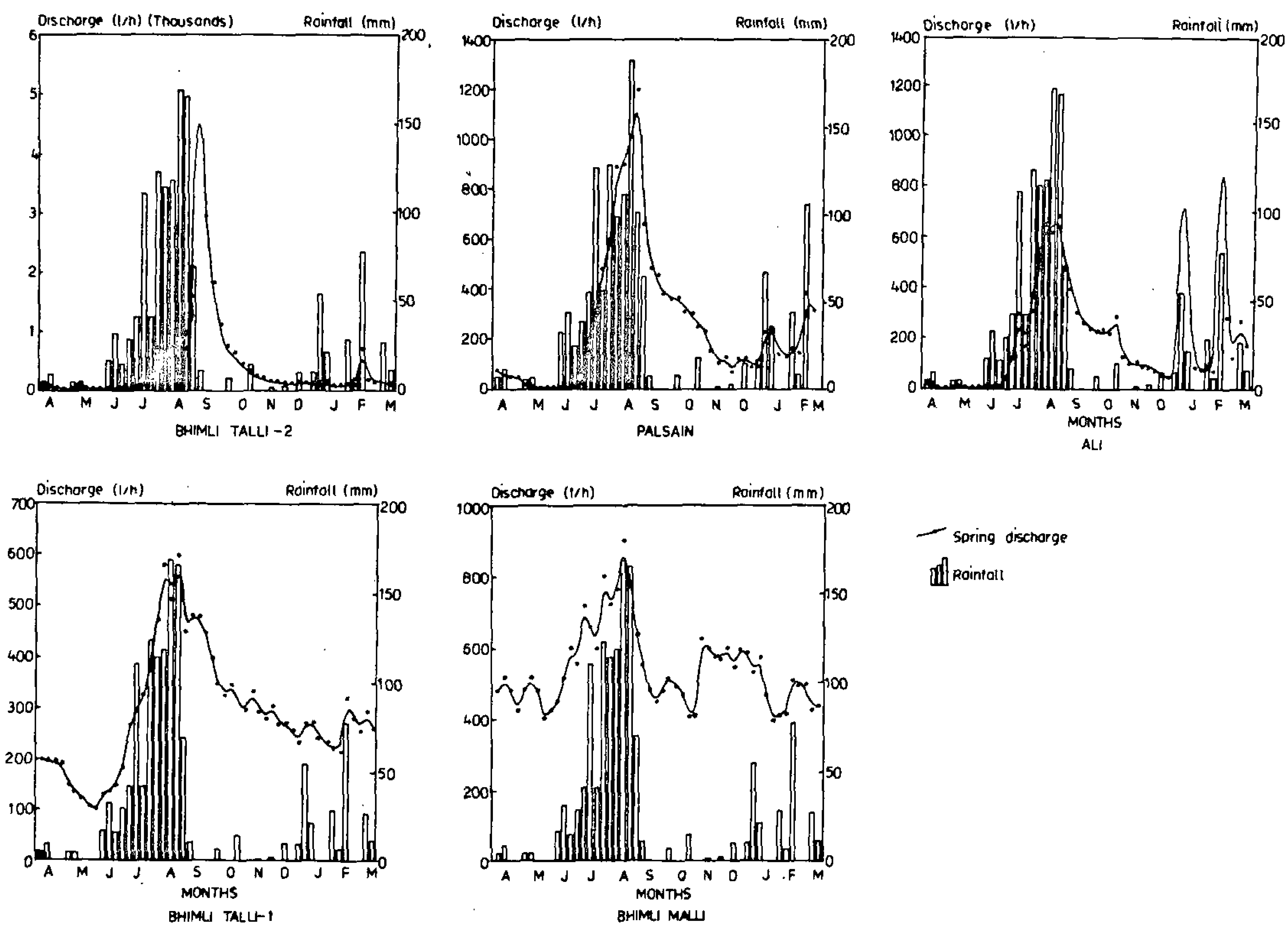

Figure 3. Spring discharge pattern in relation to rainfall in Dugar Gad catchment, Garhwal Himalaya.

(Figure 3). The upslope of these springs is rather gentle, saucer shaped and south-east facing, which allowed less exposure to sun. Recharge zone area and annual water discharge of the springs are unrelated, implying that land use and geological features were equally important. Both of them have a sizeable proportion of abandoned land with thick growth of bushes, low number of mature trees and a low incidence of grazing. Such a situation can be considered ideal for spring recharge zones. Two seasonal springs become dry for 50 days between 23 May and 11 July (Palsain) and for 63 days between 2 May and 4 July (Ali). These springs have old-growth chir pine forests in upper slopes which is under moderate grazing influence. These springs behave in close correspondence to rainfall. It can be emphasized that evapotranspiratory and interception losses, greater slope (Ali), more area under agriculture (Palsain) and year-round grazing; all work together to reduce the moisture retention capacity of the spring recharge areas and render the springs dry during summer.

Among all the springs, Bhimli Talli-2 spring was unique, with respect to land use, high degree of slope, presence of numerous rock outcrops, thin soil layer, absence of trees and most of the area under year round grazing land. Such landscapes are characterized by a lateral downslope movement of water within the soil layer via a 'quick-flow' process producing typical storm hydrographs[7]. Looking at the hydrological behaviour of these springs, it can be emphasized that each spring has its own character which is influenced by a combination of factors operated in the recharge zone.

Total discharge of the four springs, excluding Bhimli Talli-2 (taken up for discharge revival experiment) in the summer months has the potential to provide 15.6 l water per capita per day to the catchment people, only if the overflowing water is stored in suitable intake structures, distribution system is rationalized and social constraints are undermined. As a matter of fact, Bhimli Malli and Bhimli Talli-1 springs have enough discharge, which often goes waste. On the other hand Ali and Palsain springs are seasonal. People of Ali village located near road head are occasionally provided with water transported from a distant locality by district administration tankers. People of Palsain, a village occupied by the weaker section, have no other option but to dig a well at the point of origin of the dried spring and collect the dirty water. It can be stated that water shortage is a site-specific problem and needs to be solved combining hydrological and management considerations.

Understanding the site-specific nature of the springs, their response to rainfall, land use, biotic pressure and sociological constraints and limitations of our knowledge with regard to revival of springs, the following areas of problem-solving research in this region may be suggested – (i) Water harvesting, conservation of spring sanctuaries, studying recharge and discharge pattern of springs, collection and analysis of hydrometeorological data (e.g. rainfall, runoff, evapotranspiration, water budget, etc.); (ii) traditional water conservation/ management systems; (iii) identification of plants which can help in augmenting ground water recharge; and (iv) strengthening water management system and role of technological inputs to check water misuse and losses.

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Recent crustal adjustments in Dehra Dun valley, western Uttar Pradesh, India

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The compression that was responsible for India–Asia collision and consequent formation of the Himalayan orogen, though subdued, has not yet ceased. A large number of earthquakes occurring between the Main Central Thrust (MCT) and Himalayan Frontal Fault (HFF) bear testimony to the continuing compressional stress regime. The present study provides evidence of recent crustal adjustments in Dehra Dun valley to the south of Main Boundary Thrust (MBT) in the form of tilted and deformed terraces, colluvial wedges, land subsidence and older rock sequences overriding the Holocene sediments. These neotectonic movements warrant detailed investigations using modern techniques in this seismotectonically sensitive area.

INDIA–Asia convergence that started about late Cretaceous, finally resulted in plate collision in early Cenozoic (45 ± 5 Ma). The deformation front successively propagated towards south. The rate of northward movement of the Indian plate relative to Siberia is estimated to be about 44–61 mm per year[1]. Of this, about 10–15 mm per year is absorbed in the frontal Himalayan region while the remainder is distributed across the Higher Himalaya, Tibet, Tein Shan and further north[2]. Some workers[3,4] visualize MBT as the current boundary of plate convergence. Neotectonic deformation in the foreland basin of Himalaya has been studied in the Nepal sector[5], Kumaun[6,7] and Garhwal[8].

The unusually wide sub Himalayan belt between the rivers Ganga and Yamuna is known as Dun re-entrant area. This area comprises of bedded Upper Siwalik sediments and Holocene Dun gravels and houses the densely populated township of Dehra Dun in the central part (Figure 1). This Dehra Dun valley has been the focus of attention since the 1905 Kangra earthquake that had one of its high intensity zones (secondary epicentre) around this city[9]. Currently this area is rising at the rate of 1 mm per year[10]. To map the active faults between the MBT and the HFF, a detailed geological mapping was carried out by the present authors in 1994–1995 (Figure 2).

The foreland basin in the outlined area comprises a basal sandstone succession with interbedded subordinate clays overlain by pebbly sandstone and boulder conglomerate. The boulder conglomerates exposed in the vicinity of the MBT show definite late Upper Siwalik affinity (V. Raiverman and A. C. Nanda, pers. commun.). In the field no tectonic or stratigraphic break was observed between these conglomerates and the underlying sandstone–shale succession. The entire sequence has thus been equated to Upper Siwalik subgroup exposed across Yamuna[11]. These sedimentary rocks are deformed into a major NW–SE trending syncline, flanked on either side by two parallel trending anticlines. The syncline is largely occupied by Holocene Dun gravels. In the northern range, four fault planes paralleling the MBT have been identified between Yamuna and Rispana rivers. The fault plane that lies immediately to the south of the MBT follows the axial zone of the northern anticline.

In the southern belt (part of southern anticline), a major zone of back-thrusting is identified between