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Role of Geology and Landuse on Hydrology of Mountainous Area : A Case Study in Kumaun Lesser Himalaya

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ROLE OF GEOLOGY AND LANDUSE ON HYDROLOGY OF MOUNTAINOUS AREA : A CASE STUDY IN KUMAUN LESSER HIMALAYA

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ABSTRACT

In the present study an attempt has been made to understand the response of the hydrological parameters under varied geoecological conditions of the Khulgad basin, a tributary of Kosi River in the Central Kumaun Himalaya. Khulgad drains a Precambrian metamorphic gneissic terrain characterised by thrusts, faults and very prominent joints and shear zones. Discharge of selected microwatershed reveals that Bhakar ravine, which is close a tear fault, has water discharge (2,81,000 m^3/km^2/year) 4.2 times higher than that of the stream emanating from an oak forest, 1.4 times higher than that in a pine forest, 1.7 times more than that of the stream from an agricultural area, and 1.3 times greater than that of the ravine in the barren land. Strong control of geological structure on spring discharge is evident. Hydrographs of oak forest and pine forest demonstrates that there is two peaks of surface flow caused by SW and NE monsoons. However, under disturbed conditions, even pre-monsoon rains generate peak flows, implying reduction of water-retaining capacity of the ground so that there are high surface discharges in the form of floods. The regression analysis of rainfall - runoff relations demonstrates that there is no marked effect in the channel runoff upto 7 mm of rainfall in the natural system, while merely 3 mm of rainfall effects the base flow in the disturbed land channel. These observations corroborates the deduction that water generating capacity of the channels in the Himalaya is primarily controlled by geological structure and landuse pattern influences the water retaining capacity of the area.

INTRODUCTION

As a consequence of deforestation and attendant erosion in the central sector of the Himalaya the groundwater regime is beset with a number of environmental problems of serious proportion. Varied anthropogenic activities have resulted in the drying up of springs and consequent dwindling of water discharges in rivers and in the occurrence of floods during heavy rains. The extent of decrease in spring discharges in the catchment of the Gaula River in south-central Kumaun ranged from 25% to 75% within period 5 to 50 years (Valdiya and Bartarya, 1989, 1991). About 50% of changes in flow-capacity are man-induced (Rawat, 1988).

In the mountainous area, nature of rocks and secondary permeability developed by fractures, joints, faults and the extent and nature of landuse in the watershed serves as a recharge area for the groundwater. So, the zones of crushed rock developed due to faulting, provide very good aquifers of tremendous potential (Rai, 1993). Keeping in mind the facts of geology and landuse, the present hydrogeological study was undertaken in five different microwatershed in the basin of the Khulgad (Figure 1), a tributary of the Kosi River which joins the Ramganga in the central plains of U.P.

ABOUT STUDY AREA

PHYSIOGRAPHIC SETTING : The study area in the Lesser Himalayan physiographic belt is located about 15 km northwest of the Almora township (Figure 1). It is delimited by Latitudes 29°34'30" and 29°32'15" N and Longitudes 79°32'15" and 79°37' E, ranging in altitude from 1150 m to 2190 m. The Khulgad Basin has a rugged topography, but does exhibits mature stage of geomorphic development. Basin has a cool temperate climate. The average annual rainfall is 93.5 cm, nearly 70% to 90% of the total rainfall occurring in the short period between June and September. The annual temperate varies between 17.3°C and 18.4°C, the maximum being 31.7°C in June and the minimum 1.1°C in January.

The landuse pattern in the Khulgad Basin is quite varied. About 60.7% of the Basin is ecologically disturbed as a consequence of poorly managed agriculture (25.6%), horticulture (3.6%) and grazing (31.5%). The remaining 39.3% portion of area is covered by forests of coniferous and broad-leaf trees(Figure 2).

GEOLOGICAL SETTING : The Khulgad catchment is situated on the northeast-dipping southern limb of the synclinal Almora Nappe --- a thick folded sheet of Precambrian metamorphic rocks and associated granites (Heim and Gansser, 1939; Valdiya, 1980,1988).

Repeated deformation resulting in superimposed folding, multiple faulting and thrusting has created a complex geographic -geological framework. On the basis of lithology, grade of metamorphism and orientation of structural elements, five local lithological units within the Almora Group have been identified in the Khulgad Basin (Figure 3). These are as follows :

Kathpuria Schist (Top)
Deolikhan Quartzite
Dhamas Quartzite
Syahidevi Gneiss
Sitlakhet Schist (Bottom)

A large part (i.e. 39%) of the Basin is constituted of garnetiferous sericite-chlorite (with or without graphite) schists and muscovite schist alternating with micaceous quartzite of the Sitlakhet Member. The Dhamas Quartzite, locally interbedded with micaceous schists, covers 18.4% of the study area. The Deolikhan Member is made up of very friable quartzite making 18.4% of the catchment area, and the Kathpuria schists occur in the 16.3% of the area in the northwest. The Syahidevi gneisses have been thrust southwards upon the schists and quartzites of the Syahidevi ridge, resulting in extensive and pervasive crushing of quartzites practically to a powdery state (Rai, 1993).

The zone of crushed rocks related to the Sitlakhet Thrust makes a very good aquifer of tremendous potential. Many zones of crushed rocks related to strike faults on the Sitlakhet spur are characterized by extreme crushing of rocks. The NNE-SSW trending shear zones and two sets of parallel faults trending NNE-SSW and NW-SE and numerous minor faults are significant features of the structural framework of the Kosi Valley and have great bearing in the hydrological cycle.

DATA COLLECTION

The present geohydrological study embraces analysis of the patterns of monthly, seasonal and annual channel flows and the runoff yields in context of control of geology and landuse. The five microwatersheds of different geoecological conditions in the Khulgad Basin were selected on the basis of varied landuse (Figure 1, Table 1). Hydrological stations installed at the mouth of each selected microwatershed stations comprise a 90° 'V' notch weir fixed behind a stilling pond and backed by sediment trap and a water-level stage recorder with standard chart stationed above the pond. Within each microwatershed a meteorological observatory is installed. This comprises Stevenson screen, a WMO standard SRRG and a class A evaporation pan. On the basis of average daily discharge rates (l/sec), average monthly discharge rates of streams, average total annual water yield (m^3) and average rates of specific water yield ($m^3/km^2/year$) were determined for different streams.

VARIATION IN HYDROLOGICAL PARAMETERS

The Khulgad Basin has complex geographical setting and varied ecosystems. Therefore, there are significant variations in hydrological parameters from one microwatershed to another. The observations were made over a period of 36 months.

RUNOFF : Runoff pattern of streams emanating under different geoecological conditions are discussed below.

Three years (1991-1993) data show that the Naula oak-forest annually lets out 40,880 m^3 water at the rate of 1.1×10^{-3} cumecs. The monthly flow pattern (Figure 4) shows that the maximum discharge (26 to 31%) takes place in the month of September. This represents the delayed flow, which is greater in amount than the flow in the rainiest month. Due to greater absorbing capacity of soils of the oak forest, only 9 to 20% of the total annual rainfall is able to runoff in the rainy months of August, January and February. In other months, the amount of discharge is less than 5% of the total annual flow.

The runoff data indicate that the Salla pine forest annually discharges 46,990 m^3 of water at the average annual rate of 1.4 x 10^{-3} cumecs. The discharge in August is 27 to 34% of the total annual flow, while the months of January, February, August, and September register 10 to 20% and the remaining months less than 5%.

The anthropogenically disturbed agricultural field discharged water at the average annual rate of 2.8 x 10^{-3} cumecs, the total average annual volume being 1,38,128 m^3. The discharge in the month of August is 14% of the total annual flow, while January, February, July and September register 9 to 11%, and in other months the discharge is 3 to 8%. The rainy season discharge is 50% of the total annual flow (Figure 4). The barren land of the Kaneli catchment discharged 1,55,470 m^3 water (1991-93) at the average annual rate of 4.1 x 10^{-3} cumecs. About 30 to 33% occurred in the month of July(Figure 4).

The tectonically disturbed Bhakar sub-basin discharged 29,960 m^3 water at the average annual rate of 0.9 x 10^{-3} cumecs. A significant proportion (18% to 19%) of this total annual flow is discharged in the month of August alone while the months January, February, July and September register 7% to 19% of the outflow. In other months, the discharge varies between 2% and 7% of the total annual flow (Figure 4).

WATER YIELD CAPACITY : On an average, 1 km^2 land of the oak forest yields 66,900 m^3 of discharge per year, with the maximum (35,880 m^3/km^2) in September. Owing to the multiplicity of joints in the gneissic terrain, a considerable proportion of the precipitation recharges the groundwater. Hence the channel flow in other months is less, and quite negligible in the dry months.

On the average pine catchment generates water about 2,00,700 m^3 annually. The maximum (1,58,437 m^3/km^2) being in September and minimum (414.0 m^3/km^2) in December. It will be obvious that the water yield or rate of discharge from the pine forest is higher than that from the oak-forest at Naula, implying that the soil of the pine forest is less efficient in retaining rainwater compared to that in the oak forest.

The average specific water yield capacity of Khunt agricultural field stream is 1,65,300 m^3/km^2 /year, the maximum 27,140 m^3/km^2 being in August and the minimum 2,589 m^3/km^2 in December. The rate of water generation is lower than that of the pine-forest catchment.

On the average, every square kilometer area of the barren land discharges through channels 2,16,100 m^3/year, the maximum 6,28,840 m^3/km^2 being in September, and the minimum 350 m^3/km^2 in December. The minimum discharge occurring in December is less than that in the forested and the agricultural area. This implies that there is a quicker effect of rainfall on the channel discharge in the barren land. The capacity of water generation for the channel of the disturbed land is 2,81,000 m^3/km^2/year, the maximum 1,96,966 m^3/km^2 being in September and the minimum 4,044 m^3/km^2 in December.

RAINFALL-RUNOFF RELATIONSHIP : The rainfall runoff relationship for different microwatershed was obtained by integrating regression analysis reveals that in oak and pine forest catchment there is no marked effect upto 7 mm rainfall in generating water discharge in the channels (Figure 5). In the ecologically disturbed microwatershed of agricultural land and tectonically disturbed land catchments effect of rainfall in channel discharge start above 3 mm rainfall. The rate of recession (Figure 6) is very slow in the oak forest and very fast in the barren land. Significantly, in the undisturbed forest system nearly 24 hours after of rainstorms, the channel base flow is 15.9 times higher than what it was before the rainfall event. Compared to this situation in the disturbed ecosystems of the barren land, the base flow is 1.2 times higher, implying that much water had quickly runoff from the barren lands.

SPATIAL VARIATION IN WATER YIELD

During summer, the larger part of the Khulgad Basin generates or releases water for its channels at the rate of 5,000 to 10,000 m^3/km^2/month, the structurally disturbed 4.7% area at the rate more than 10,000 m^3/km^2/month and the remaining 9.3% area at the rates less than 5000 m^3/km^2/month. In the rainy season 62.5% area generates water at the rate of 10,000 to 20,000 m^3/km^2/month, while 7.8% area of the granitic terrain releases water at the rate of 5,000 to 10,000 m^3/km^2/month, and the remaining 29.7% area generates at the rate more than 20,000 m^3/km^2/month. In winter, above 55% area in middle reaches generates water to the channel at the rate of 4,000 to 8,000 m^3/km^2/month, the structurally deformed 6.5% zone produces at the rate more than 8,000 m^3/km^2/month, and the remaining 36.5% area releases at the rate less than 4,000 m^3/km^2/month (Figure 7). On the average the Khulgad Basin releases water for its channels at the rate of 54,005 m^3/km^2/month or 1742 m^3/km^2/day.

DISCUSSION AND CONCLUSION

There is a dramatic change in the hydrographs from one of the least disturbed oak forest to that of the considerably disturbed barren land. Under ecologically wholesome oak forest system, the hydrograph peak in September is due to delayed subsurface flow through its soil. Under the pine forest system, the peak is reached one month earlier. However, in the disturbed system of the barren land and agricultural fields even an early monsoon causes the formation of the peak in May or June. Obviously, this is due to the lack of water-retaining capacity of the disturbed lands. In the structurally deformed zones no pre-monsoon peak was noticed, rather there was a gradual increase in the water discharge due to delayed flow so that in August there was peak flow in the streams (Figure 4).

The rainfall-runoff relationship in different micro-watersheds (Figure 5) indicate that there is no marked effect on the magnitude of channel flows if the rainfall is less than 7 mm in the least disturbed oak forests and less than 3 mm in the disturbed agricultural fields. Rainfall in excess of 8 mm in both the disturbed and undisturbed catchments causes increase in the channel discharge. Likewise, the rate of recession (Figure 6) is very slow in the oak forest and very fast in the barren land, implying that much water had quickly runoff from the barren lands.

On the average the stream of the structurally disturbed land has water yield of 2,81,000 m^3/km^2/year, which is 4.2 times higher than that of the oak forest, 1.7 times higher than that of the agricultural land, 1.4 times higher than that of the pine forest, and 1.3 times higher than that of the barren land. In the watershed of fragile Himalaya, it is not so much the landuse pattern and the nature of vegetal cover which govern stream flow but the prominent tectonic structures such as faults, shear zones and the amount of rainfall which determine the stream discharge.

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Table 1: Characteristics of selected microwatersheds of the Khulgad watershed

Characteristics	Stations				
	Naula	Salla	Khunt	Kaneli	Bhakar
Altitude (m)	1700	1650	1210	1220	1700
Relative Relief (m)	490	310	290	320	90
Area (km^2)	0.53	0.22	0.75	0.60	0.10
Land use					
Forest	100%	80%	-	-	-
Agriculture	-	20%	80%	15%	90%
Barren	-	-	20%	85%	10%
Rock type					
Granite-Gneiss	100%	90%	-	-	30%
Mica-Schists	-	10%	100%	100%	70%
Meta-grewacks	-	-	-	-	-
Structure	Massive	Thrust	Shear	Shear	Thrust
Channel Slope					
Up slope	50°	16°	28°	30°	30°
Down slope	30°	21°	10°	20°	25°

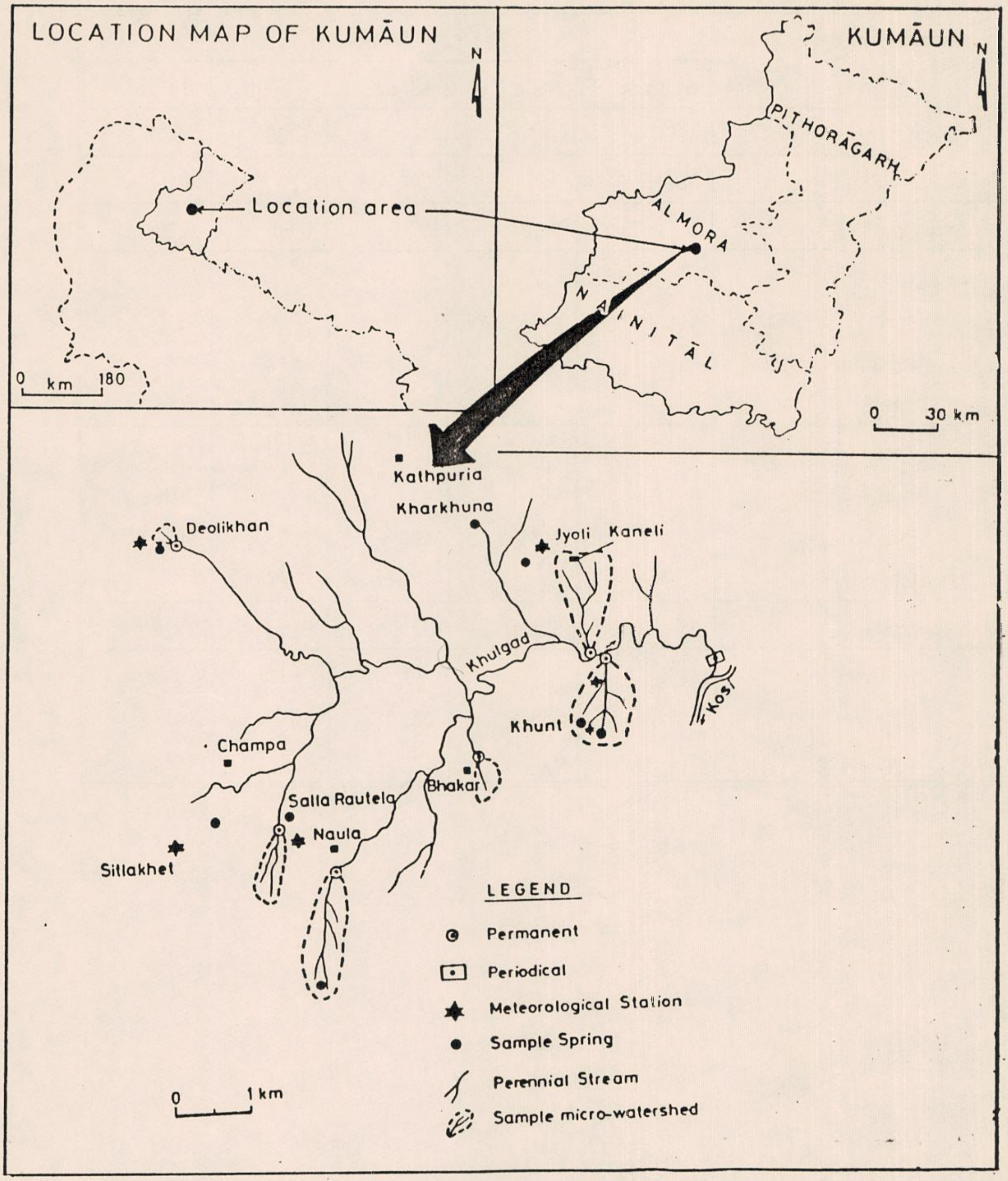

Figure 1. Location of the study area in the Khulgad Basin with the hydometeorological stations in the Kumaun Lesser Himalaya.

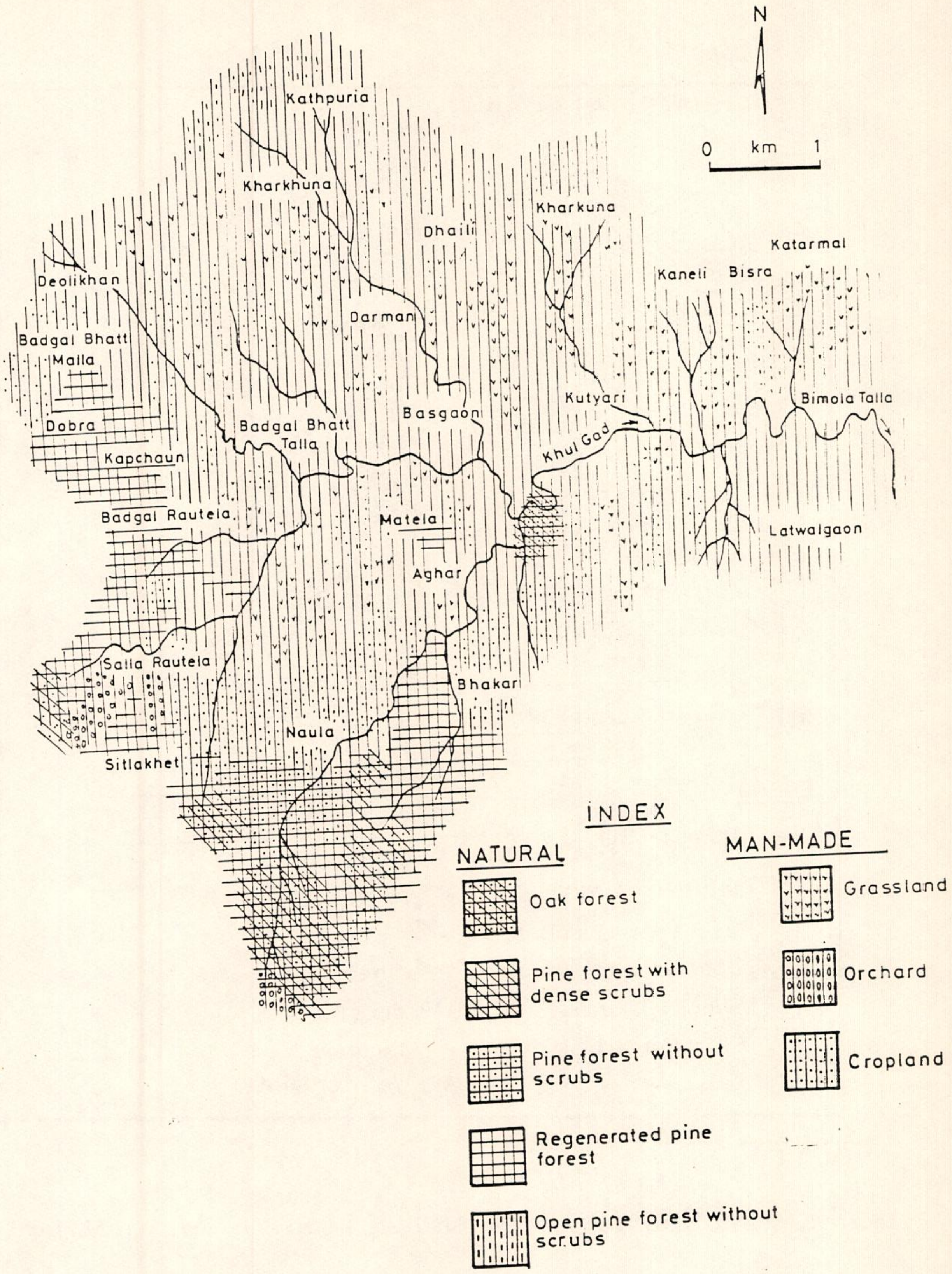

Figure 2. Landuse map of the Khulgad Basin.

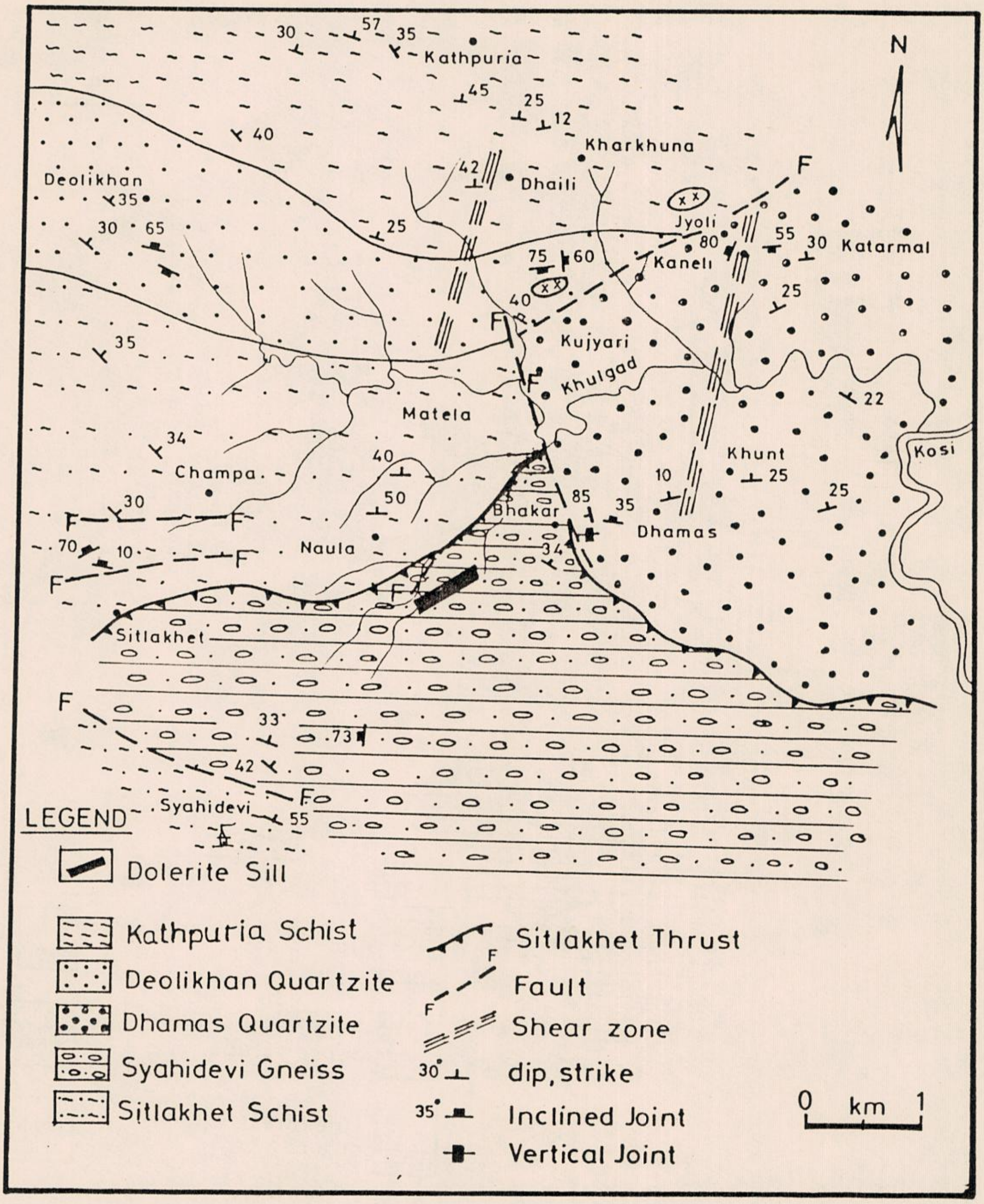

Figure 3. Geological map of the Khulgad Basin showing lithological and structural details.

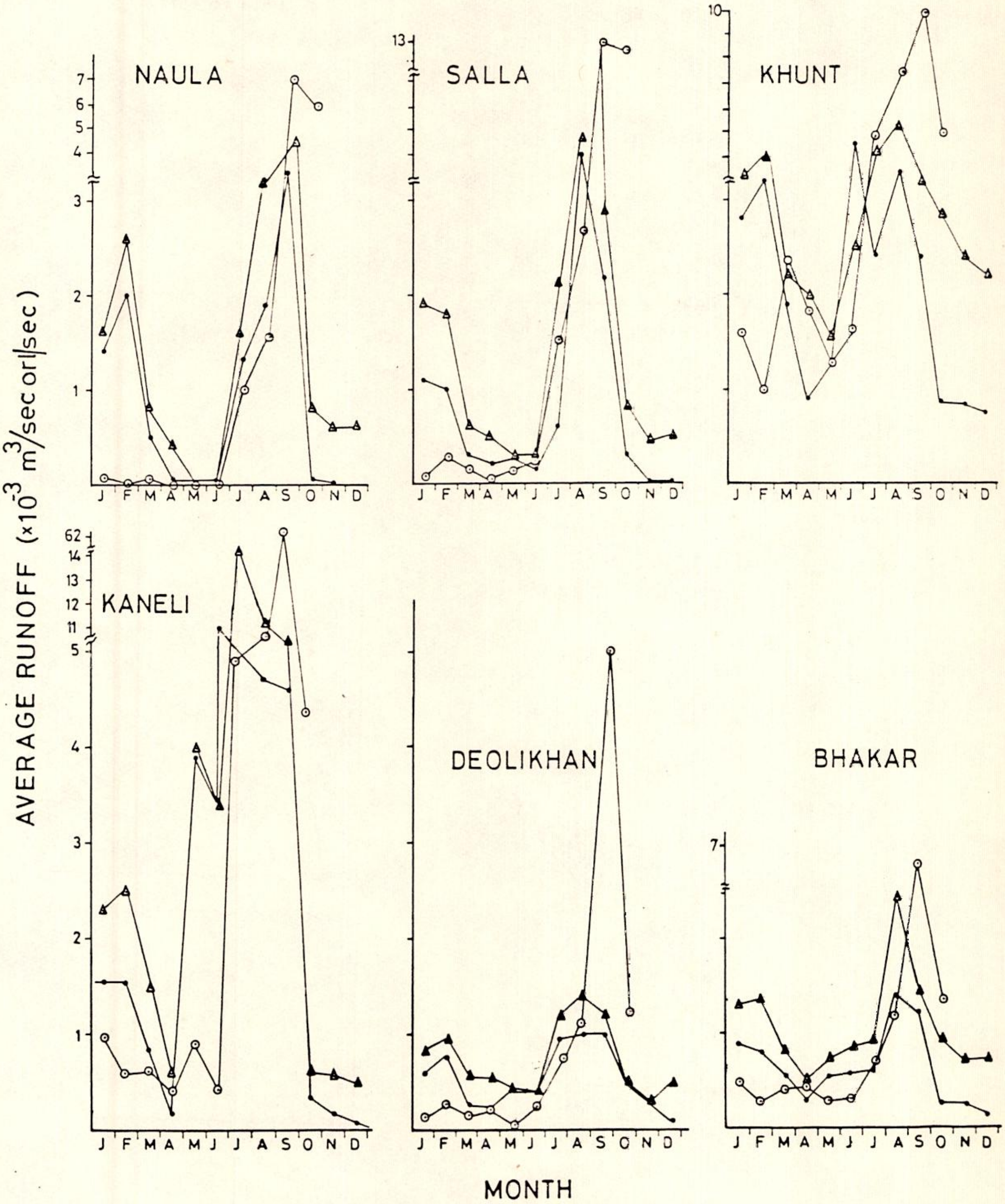

Figure 4. Stream hydrographs of various hydrological stations under ecologically different conditions.

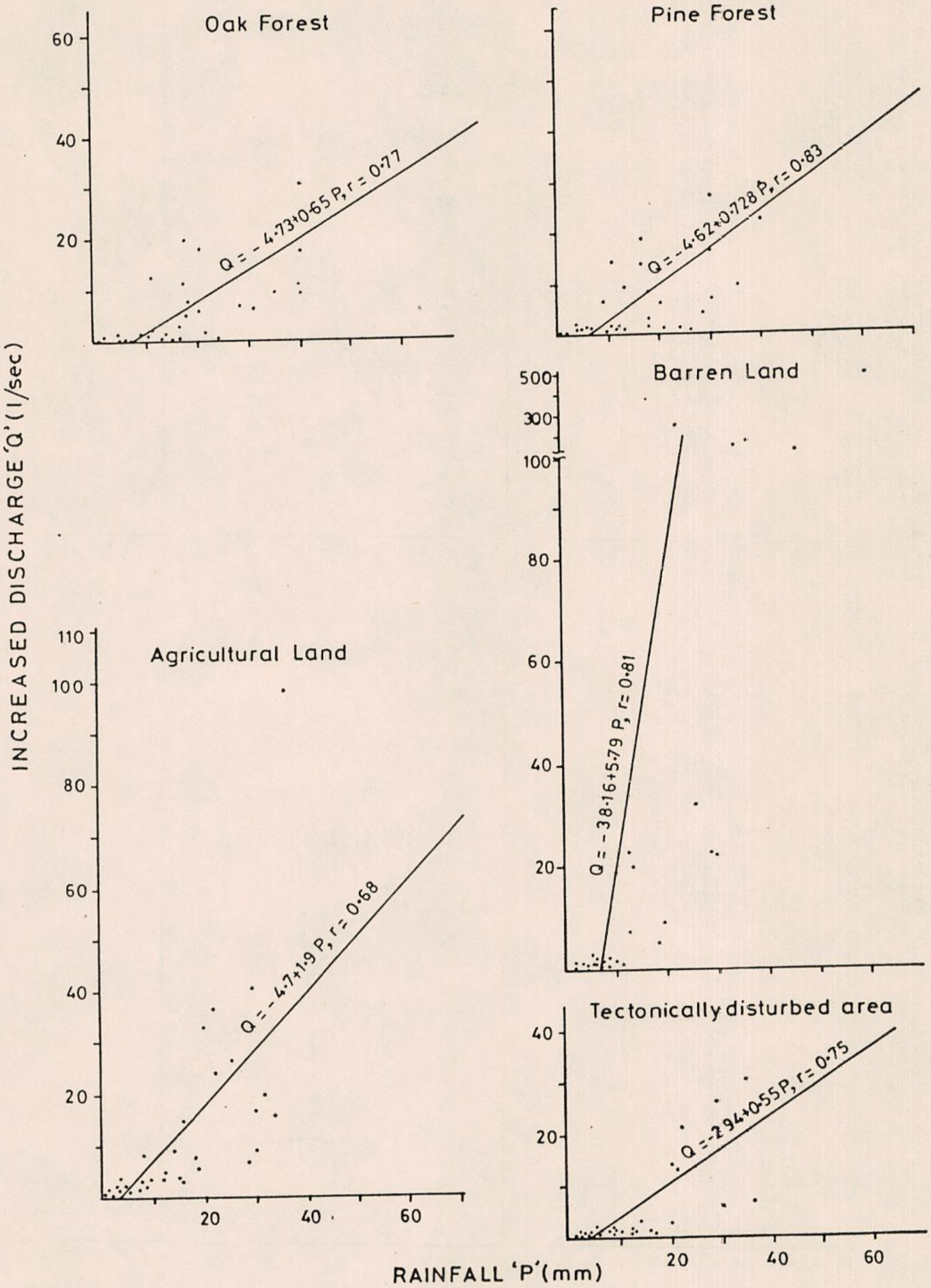

Figure 5. Regression models of rainfall (mm) and increase discharge (l/sec) in different microcatchments in the Khulgad Basin.

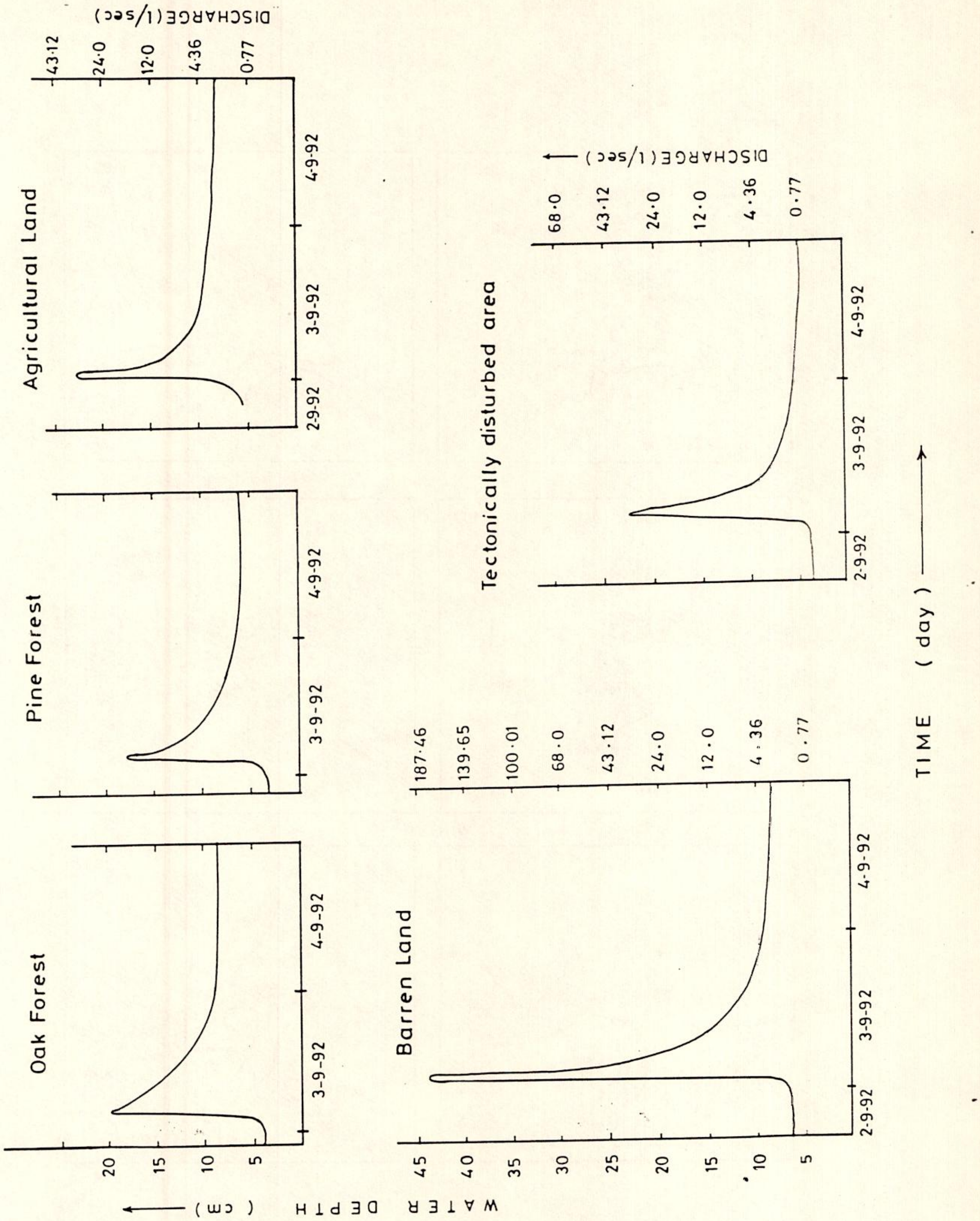

Figure 6. Recession curves under identical rainfall of streams in ecologically different conditions.

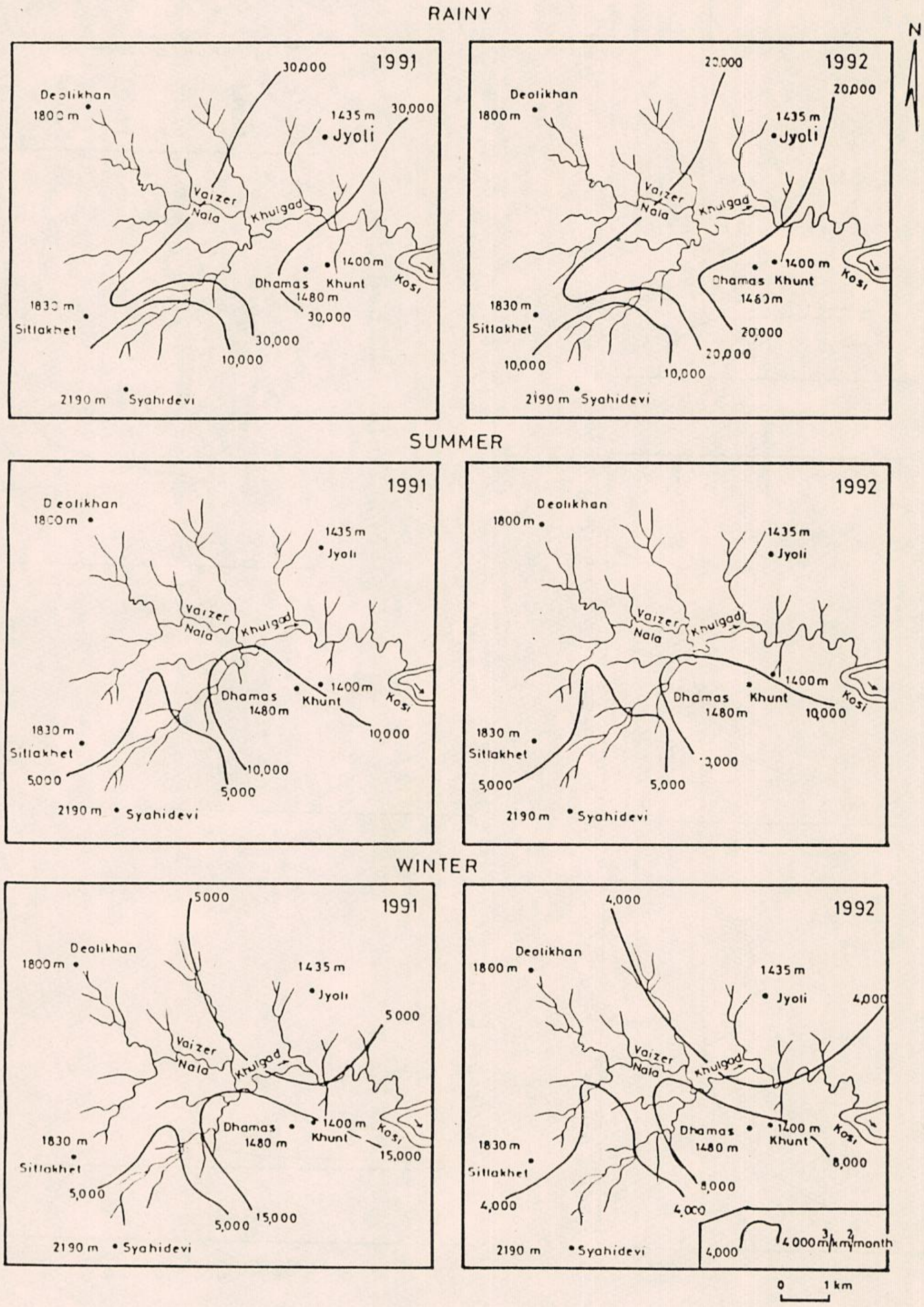

Figure 7. Maps showing rates of water delivery ($m^3/Km^2/month$) to channels in different seasons.