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Impact of Geology and Landuse on Sediment Yield in Micro-Watersheds of Himalayas

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Abstract : To monitor the impact of the geological set-up and landuse pattern on the delivery of total load (suspended, dissolved and bed load) were measured during 1991-1993 in six micro-watersheds of Khulgad watershed, a tributary of Kosi River. The two watersheds (i.e., W1 and W2) made up of Gneisses and covered with thick Oak and Pine forest discharged total load at the rate of 41 t/km^2/y and 135 t/km^2/y, respectively. The W3 micro-watershed consist of quartzite interbedded schist and granite (fractured due to fault) with agricultural land use delivered the total sediment at the 591 t/km^2/y. The three watersheds (W4, W5 and W6) made up of quartzite interbedded schist and having agricultural (W4 and W5) and barren land use (W6) pattern discharged the sediment at the rate of 419 t/km^2/y, 272 t/km^2/y and 268 t/km^2/y, respectively. The ratio of total load discharged comes out to be 1:3:14:10:7:7 for W1, W2, W3, W4, W5 and W6 watersheds. The highest sediment yield recorded from W3, which is tectonically disturbed (highly fractured and sheared rock condition). The W2 watershed made up of gneisses and having Pine forest cover discharged 3 times greater sediment load in comparison to Oak forested watershed i.e., W1. Thus results clearly indicate that Oak forest is more effective in controlling the erosion than the Pine. On the other hand, among all the six microwatersheds the maximum rate of sediment delivery from the W3 microwatershed clearly indicate that sediment yield is primarily controlled by geological setup of the watershed and landuse is the secondary factor in the Himalayas.

Key Words : Landuse, Geology, Sediment Yield, Microwatersheds, Lesser Himalaya

INTRODUCTION

The pressure of human and animal population on the scarce land resource in the Himalayan region has considerably intensified the erosion rate. The situation has aggravated due to improper land use, deforestation and faulty management practices (Valdiya, 1985). Estimation of various causes of sediment delivery from watershed is a necessity if adequate provision is to be made in the design of conservation structures to offset the ill effects of sedimentation during their lifetime. Soil and water conservation studies have indicated that changes in land use pattern effect the hydrological regime of Himalayan watersheds (Narayan and Rambabu, 1983; Pathak *et al.,* 1984; Joshi and Negi, 1996; Rai and Sharma, 1998; Rawat and Rawat, 1994, Rawat and Rai, 1997). According to Leopold *et al.* (1964) erodibility is a function of both geological set-up of area and the biotic condition of the ecosystem. The rocks of Himalayan region are cut by a multiplicity of faults and fractures with NW-SE, N-S and NE-SW trends, which play a very important role in the incidence of mass movements (Valdiya and Bartarya, 1989). The faults, fractures and joints play very significant role in promoting groundwater recharge as well as in accelerating erosion. The rocks that are shattered and crushed due to revival of neotectonic movements along faults are much more prone to erosion and the same time cause greater infiltration as well as discharge of groundwater (Rai, 1993). In the present paper an attempt has been made to estimate the sediment yield under varied land use conditions and tectonically disturbed (fault and thrust passing through watershed resulting in crushing and shearing of rock mass) micro- watersheds of the Khulgad watershed

STUDYAREA

The study area (Latitudes 29^0 34'30" N, and Longitudes $70^0$32' 15" E) is located about 15 km northwest of Almora Township in the Khulgad watershed, is a sub-watershed of Kosi River (Fig. 1). Khulgad watershed encompasses an area of 32 km^2 within altitude 1150 m and 2190 m, having temperate climate with an annual average temperature of 20°C and an average annual rainfall of 935 mm. Geomorphologically, the landforms are mature; valleys are fluvial eroded and are unusually wide, with terraces and alluvial fans (Rai, 1993). On the basis of landuse, Khulgad Watershed is divisible into eight sub watersheds (Rawat, 1992). About 26% area of the watershed is under poorly managed agriculture, 31% under unrestricted grazing, 4% under horticulture, and mostly forests of oak and pine cover 39%.

Khulgad watershed is situated on the southern limb of the synclinal Almora Nappe. The Almora Group that makes the Almora Nappe comprises three units -the Saryu formation, the Almora Granite and the Gumalikhet formation. The Saryu formation is classified in to (i) garnetiferous sericite-chlorite Schists (with or without graphite) and muscovite schist alternating with micaceous quartzite, which occupies 39% area of the watershed, (ii) the Dhamas Quartzite locally interbedded with micaceous schist, covering 18% of the area, (iii) the Deolikhan Member made up of very thinly bedded friable quartzite making 18% of the area (Rai, 1993). The Gumalikhet formation comprising darkish micaceous schists and phyllites interbedded with metagreywackes making 16% of the area in the north- west. The Syahidevi Gneiss, composed of extremely compressed and milled or sheared augen gneisses and old granites, forming 9% of the area in the south (Fig.2).

METHODOLOGY

To estimate the rate and pattern of erosion under different landuse and geological conditions, six micro-watersheds of Khulgad stream were selected (Rai, 1993). These watersheds have varied land use, geology and geomorphological characteristics but there is no significant variation in climatic parameters (Table 1). To measure the rainfall, evaporation, temperature and humidity, meteorological observatories were installed in all the micro-watersheds (Figure 1). To measure the runoff and sediment load generated from each microwatershed was provided with 90^0"V"-notch weir with a stilling pond and sediment trap. A standard chart-recording water level is also provided in the pond. Water samples were collected weekly during rainy season (June to September) and monthly in the remaining period of the year to determine suspended and dissolved concentrations from each of the microwatersheds. Suspended and dissolved loads were determined gravimetrically. Bed-load was monitored on monthly basis by clearing of the ponds constructed behind V notch and this operation gives total volume and was converted to weight of the collected bed-load material (Gregory and Walling, 1973).

RESULTS AND DISCUSSION

Six micro-watersheds having different land use and geological set-up were monitored (1991-1993) to estimate the impact of the tectonic disturbances and land use pattern on the sediment yield while the meteorological (such as rainfall, temperature and humidity) and geomorphological (such as soil type and slope etc) variations are negligible. The characteristics of suspended, dissolved and bed load and variation of sediment yield in the microwatersheds are discussed in details.

Suspended Load

Suspended sediment flow pattern (Fig. 2) reveals that W1 (Oak forest stream) and W2 (pine Forest Stream) streams transport sediment mainly in the months of July, August and September but W3 (tectonically disturbed land stream), W4, W5 (Agricultural land stream) and W6 (Barren Land

Table 1. Characteristics of micro-watersheds selected for hydrological studies in Khulgad Watershed

Parameters	Characteristics of Micro-watershed					
Name	W1	W2	W3	W4	W5	W6
Altitude at Gauging sites (m)	1700	1650	1700	1210	1700	1220
Watershed Area (km^2)	0.53	0.22	0.10	0.75	0.17	0.60
Land use						
Forest	100%	80%	-	-		-
Agriculture	-	20%	90%	80%	85%	15%
Barren	-	-	10%	20%	15%	85%
Rock type						
Granite-Gneiss	100%	90%	30%			-
Mica-Schist	-	10%	70%	100%	27%	100%
Meta-grewack	-	-	-	-	75%	-
Structure	Massive	Thrust	Faulted Stream	Shear	Contact of two Formations	Shear
Channel Slope						
Up slope	50°	16°	30°	28°	22°	30°
Down slope	30°	21°	25°	10°	20°	20°
Slope	1-46°	6-37°	3-18°	<1-30°	1-29°	3-28°
Stream Order	2nd	2nd	1st	2nd	1st	2nd
Length of Main Stream (m)	1359	796	384	986	379	1333
Total Length (m)	3090	1280	384	2720	379	2552
Basin Relief (m)	390	330	90	290	120	320
Relief Ratio	0.25	0.36	0.12	0.23	0.20	0.24
Relative Relief	0.11	0.15	0.05	0.08	0.07	0.09

Stream) carry sediment throughout the year with the maximum concentration in rainy months and the minimum in summer months. Among all the microwatersheds, the stream of W3 microwatershed carried sediment with maximum concentration. The W1and W2 micro-watersheds are consist of Almora granite and covered with Oak and Pine forest discharged suspended load with low concentration in comparison to four micro-watersheds composed of quartzite interbedded schist and having antropogenically disturbed land use. The maximum concentration from the tectonically disturbed micro-watershed (W3) shows that geology of the basin is important factor in generating the sediment load. The generation of low concentration of suspended load from the forest microwatersheds again shows combined effect of land use as well as granitic terrain.

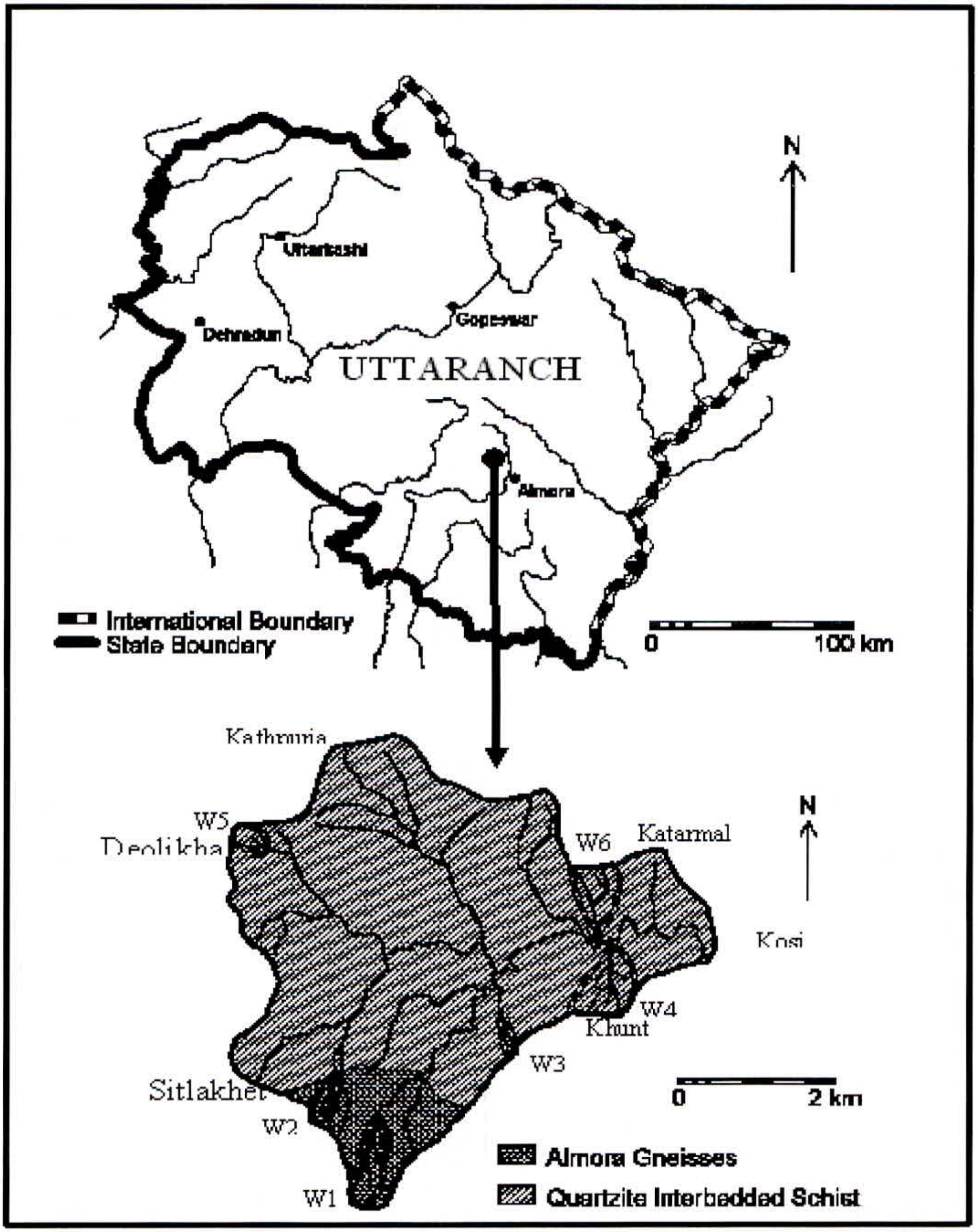

Fig. 1. Location of Khulgad watershed and its six micro-watersheds along with lithological details

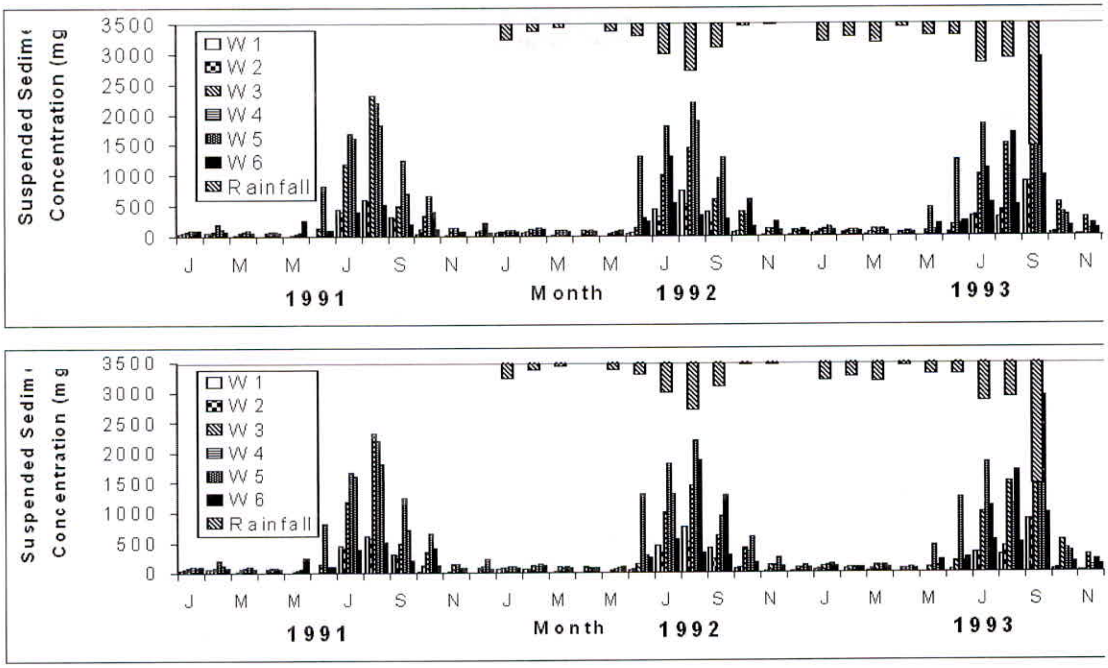

Fig. 2. Suspended and dissolved load concentration of different micro-watershed measured during study period

The average suspended sediment yield of different micro-watersheds varied from minimum 2 t/km^2/month in Oak forest microwatershed to maximum 27 t/km^2/month in tectonically disturbed watersheds (Table 2). The large part of the total annual suspended sediment i.e., 88% to 96% is transported during four months of rainy seasons (Table 3). In comparison to W1 watershed, tectonically disturbed watershed (W3) flowed 13.5 times higher and W4 and W5 flowed 5 to 6 times higher. The maximum delivery of suspended sediment from the tectonically disturbed land watershed and minimum from oak and Pine forest land streams reveals the impact of geology and landuse on soil erosion.

Dissolved Load

Dissolved load by streams is carried throughout the year and represents the pattern and intensity of chemical weathering in crystalline of Almora Nappe. The concentration of dissolved load in the streams reaches the maximum during summer months (i.e. March, April, May, June) and it decreases to the minimum in November and December (Fig. 3). The minimum concentration of dissolved load is recorded from W1 and W2 micro-watersheds because these watersheds are composed of Almora granite that is hard and resistant to chemical weathering in comparison to quartzite and schist bearing watersheds. Out of the total annual dissolved load, W1 watershed discharged 56% (minimum) and W3 micro-watershed discharged 79% (maximum) during rainy season.

The W1 watershed discharged dissolved load at the rate of about 1t/km^2/month while the stream of tectonically disturbed land (W3) carried 13 times higher (12.9 t/km^2/month). The W4, W5 and W6 watersheds composed of quartzite and schist

Table 2. Variation of suspended, dissolved and bed load (t/km²/month) in six microwatersheds during 1991-1993

Microwatersheds	Year	Suspended Load			Dissolved Load			Bed Load		
		Max	Min	Average	Max	Min	Average	Max	Min	Average
W1	1991	9.9	0.0	1.8	3.6	0.0	1.0	1.5	0.0	0.2
	1992	7.2	0.0	1.5	2.3	0.0	0.6	1.1	0.0	0.2
	1993	30.9	0.0	3.1	4.9	0.0	1.3	5.0	0.0	0.5
	Av.			2.1			0.9			0.3
W2	1991	31.8	0.0	4.8	9.0	0.7	2.5	4.1	0.0	0.7
	1992	21.5	0.0	2.9	7.2	0.0	1.6	4.1	0.0	0.6
	1993	139.7	0.0	13.9	27.7	0.1	4.8	13.7	0.0	1.5
	Av.			7.2			3.0			0.9
W3	1991	149.3	0.4	18.4	34.1	6.5	12.9	25.0	0.0	5.3
	1992	54.4	0.4	9.0	19.9	1.0	8.2	20.1	0.0	3.5
	1993	505.1	0.6	53.6	89.5	3.1	17.6	167.8	0.0	19.4
	Av.			27.0			12.9			9.4
W4	1991	37.7	0.3	7.8	7.2	2.8	4.2	16.5	0.2	3.2
	1992	25.9	0.2	5.9	6.3	0.9	3.2	13.7	0.0	2.1
	1993	501.6	0.2	48.9	74.3	1.0	10.7	189.0	0.0	18.8
	Av.			20.9			6.0			8.0
W5	1991	40.2	0.4	7.9	8.8	1.8	4.8	13.8	0.0	2.6
	1992	29.7	0.2	6.7	8.0	0.4	3.8	14.5	0.0	2.9
	1993	228.2	0.1	23.6	33.2	0.7	5.5	99.6	0.0	10.2
	Av.			12.7			4.7			5.2
W6	1991	26.0	0.1	5.5	19.6	0.5	5.0	9.3	0.0	1.8
	1992	26.5	0.0	3.9	15.0	0.1	3.8	4.8	0.0	1.1
	1993	264.1	0.1	24.8	72.6	0.6	8.5	134.9	0.0	12.6
	Av.			11.4			5.8			5.2

which are highly sheared and fractured, discharged dissolved load at the rate of, 6 t/km²/ month, 4.7 t/km²/ month and 5.7 t/km²/month, respectively (Table 2). These results clearly indicate that rate of chemical denudation is higher in W3 watershed in comparison to other watersheds. The tectonically disturbed watershed rocks are fractured and sheared which dissolves at higher rates in comparison to compact and less disturbed rocks of other watersheds. The results reveal that dissolved loads is 21 to 27 % of the total load.

Bed Load

Bed load is generated mainly during the rainy periods in all micro-watersheds. The average annual yield of bed load varies between 0.31 t/ km²/month (minimum) of W1 watershed to 9.4 t/ km²/month (maximum) of tectonically disturbed W3 watershed (Table 2). Bed load constitutes about 8% of the total load discharged through Oak and Pine microwatersheds and about 20 to 23% of other four microwatersheds.

Table 3. Annual sediment load and yield of six microwatershed of Khulgad

Microwatersheds	Year	Suspended Load		Dissolved Load		Bed Load		Total Load	
		t/yr	t/km^2/yr	t/yr	t/km^2/yr	t/yr	t/km^2/yr	t/yr	t/km^2/yr
Naula (W1)	1991	11.6	21.8	6.1	11.6	1.5	2.9	19.2	36.3
	1992	9.5	17.8	3.7	7.1	1.4	2.7	14.6	27.6
	1993	19.7	37.2	8.2	15.4	2.9	5.5	30.8	58.1
	Av.		25.6		11.3		3.7		40.7
Salla (W2)	1991	12.5	57.0	6.7	30.3	2.0	8.9	21.2	96.2
	1992	7.6	34.6	4.3	19.3	1.6	7.4	13.5	61.3
	1993	36.6	166.4	12.6	57.1	3.9	17.8	53.1	241.3
	Av.		86.0		35.6		11.4		132.9
Bhakar (W3)	1991	22.1	220.6	15.5	154.9	6.3	63.2	43.9	438.7
	1992	10.8	108.0	9.8	98.2	4.2	42.2	24.8	248.4
	1993	64.3	643.4	21.1	211.0	23.3	232.8	108.7	1087.2
	Av.		324.0		154.7		112.7		591.4
Khunt (W4)	1991	70.4	93.9	37.8	50.4	28.9	38.6	137.1	182.8
	1992	52.9	70.6	29.0	38.7	19.1	25.5	101.0	134.7
	1993	440.2	586.9	96.3	128.3	168.9	225.2	7.5.35	940.5
	Av.		250.4		72.5		96.4		419.3
Deolikhan (W5)	1991	16.1	94.9	9.8	57.7	5.3	31.4	31.3	184.0
	1992	13.6	79.9	7.8	45.9	5.9	34.8	27.3	160.6
	1993	48.1	282.9	11.3	66.4	20.8	122.3	80.2	471.6
	Av.		152.5		56.7		62.9		272.0
Kaneli (W6)	1991	39.3	65.5	36.4	60.6	13.3	22.2	89.0	148.3
	1992	28.3	47.2	27.0	45.0	7.7	12.8	63.0	104.9
	1993	178.9	298.2	61.3	102.1	90.9	151.5	331.1	551.8
	Av.		137.0		69.2		62.2		268.4

Variation of Total Load

On the average (1991-93) sediment yield in oak and pine forest microwatershed (W1 and W2) varied between 41 t/km²/yr to 133 t/km²/yr (Table 3, Fig. 2) while both the micro- watersheds are located in the same rock type (granitic gneisses) and having similar geomorphological and climatic conditions (Table 1) except difference in land use pattern. The minimum sediment yield in Oak forest clearly indicates that Oak forest is more effective in controlling the erosion than from Pine forest. The sediment yield is alarmingly high (591 t/km²/yr) in the W3 watershed, made-up of Dhamas quartzite and Gneisses have-been severely crushed and sheared practically to powdery state due to movement along the fault plane. Thus the tectonically disturbed area rocks are more prone to erosion and generating maximum sediment yield. The W4, W5 and W6 watersheds of agricultural and barren land use bearing quartzite interbedded schist discharged total load at the rate of 419 t/km2/yr, 272 t/km²/yr and 268 t/km²/yr, respectively. It is very evident from the above results that geological set-up of the area play major role in intensities and pattern of erosion of Himalayan watershed in comparison to land use pattern.

CONCLUSIONS

The results reveal that tectonically disturbed area rocks are more prone to erosion and generating maximum sediment yield. The W4, W5 and W6 watersheds of agricultural and barren land use bearing quartzite interbedded schist discharged total load at the rate. Therefore, erosion rate varies spatially due to variation in rock type, geological structure and land use conditions. However, the

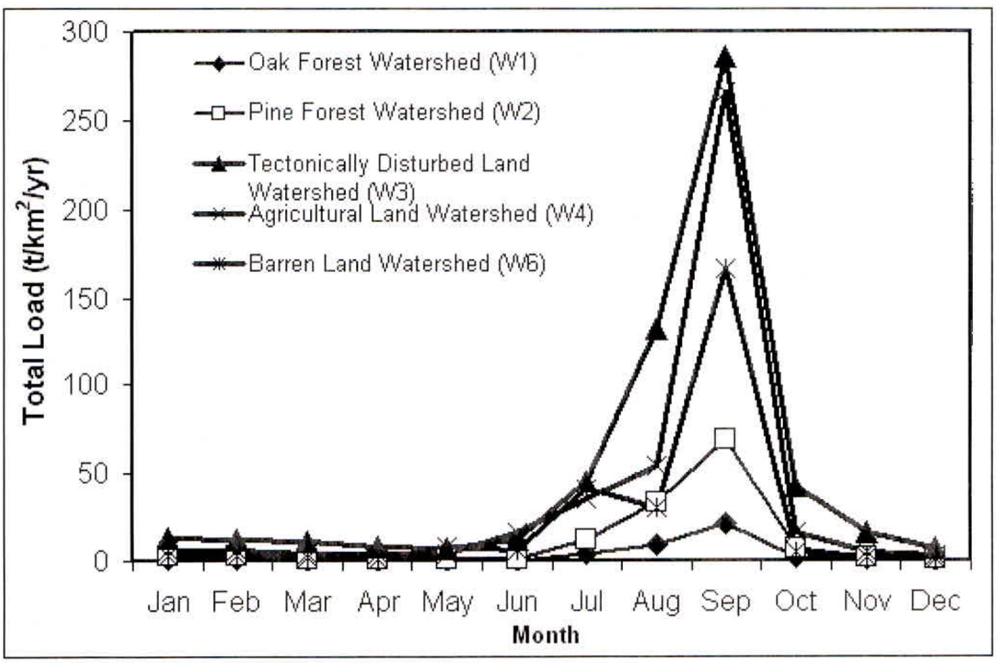

Fig. 3. Total sediment load (carried in the state of suspension, dissolved and bed load form) during 1991-1993 by streams emanating from micro watersheds with varied geo-ecological conditions

magnitude of rainfall impacts on the amount of sediment. It is very evident from the above results that geological set-up of the area play major role in intensities and pattern of erosion of Himalayan watershed in comparison to land use pattern.

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