Rainfall Variation and Soil Erosion in the Bheta Gad Watershed of Uttar Pradesh in the Central Himalayas

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Abstract

The rainfall variation and soil erosion were measured at different locations and under different land uses in a central Himalayan watershed, the Bheta Gad. The watershed covers an area of 23 sq.km. Five standard rain gauges were placed at different elevations and aspects to represent approximately equal areas of the watershed. The total annual mean precipitation for the water year 1998 (1st October 1997 to 30th September 1998) was 168 cm. The soil erosion and nutrient losses were measured at four erosion plots (20x5m), each under a different land use and within the areas covered by the gauged stations. Four factors affecting the rainfall distribution in the watershed were estimated: slope, aspect, elevation, and the shadow zone effect. The rainfall intensity, aspect, and land use type all influenced the runoff and soil loss. During the study period, the watershed recorded a total effective precipitation (the precipitation causing runoff) of 139 cm in 58.5 effective rainy days, with an estimated average soil loss of 3.8 t/ha and surface runoff of 1582 cu.m/ha. The land use studies showed that the rate of infiltration decreases with an increase in soil compactness thus promoting runoff, and the rate of soil loss is directly correlated with increasing biotic interference, surface denudation, and degradation of land.

Introduction

The orographic complexities of the Himalayan region mean that climates are not uniform, and an extensive rainfall measurement network is required to accurately characterise precipitation patterns. Significant regional differences and wide variations in rainfall distribution have been recorded by Domraes and Manfred (1977). However, the spatial distribution of rainfall over a complex terrain has received little attention to date (Collinge *et al*. 1968). The effect of topography, at least in a broad sense, is to enhance the rainfall on slopes facing the winds and to produce a rain shadow zone on the leeward side. The enhancement of precipitation occurs as a result of lifting of air following the disturbances caused by the orography; this leads to cooling, condensation, and precipitation of the moisture. Several other factors like horizontal convergence, convective instability, and microphysical processes also play an important role in the precipitation mechanism in mountain regions, and processes are highly complex (Sarkar *et al.* 1978). The role of soil as the reservoir of the nutrient and moisture reserves which influence bio-mass production has long been recognised (Klemmedson 1970). However, the natural biodiversity that can be supported by a given soil type is largely determined by the amount and distribution of precipitation (Rauzi and Hanson 1966). Surface runoff, water intake, and sediment transportation rates vary with land use management, soil type, and slope aspect and orientation, as well as with the biophysical processes within the land use system. Soil erosion is a selective process that diminishes soil fertility, plant growth, and crop production. The four erosion plots in this study were established on land used for different purposes with different physical attributes to allow the impact of various factors to be assessed.

The Study Area

The Bheta Gad watershed, a sub watershed of the Garur Ganga river, which is a tributary of the Gomati river in the Kumaun hills of the central Himalayas, was selected for this study (Figure 74). The watershed has an area of 23 sq. km. It is situated 60 km north of Almora in Uttar Pradesh (UP) between the coordinates 29°50'23" and 29°55'56" N and 79°02'59" and 79°30'04" E. The watershed lies between 1090 and 2520 masl and is characterised by a temperate climate with three pronounced seasons—summer, winter, and rainy. The Kumaun Himalaya can be divided into five WNW-ESE trend linear lithotectonic units, the Tethyan, Central, Garhwal, Kumaun, and Siwalik, each separated by major faults. The study area itself shows the development of stratigraphic sequences similar to those of Himachal and Garhwal, comprising a more or less continuous sequence of Late Precambrian to Early Cambrian formations. The Rameswar, Berinag quartzite, and Nagthat formations with their meta volcanic constituents are the extensive basal sedimentary formations. These are succeeded by the Pithoragarh (Tejam) formation, with Lower and Middle Riphean stromatolite-bearing Gangolihat Dolomite, followed by the Rautgora formation, which can be correlated with the Damtha group, and Simla slate. The carbonate horizons show prolific development of branching columnar stromatolites. The average aspect of the watershed is north-west, the shape elongated and the drainage pattern dendritic.

The watershed has a total population of 8,368 (1991 census). Agriculture is the main occupation. The major crops are rice, wheat, barley, millets, pulses, mustard, potatoes, and soya beans. Pine trees (*Pinus roxburghii*) are the dominant forest species.

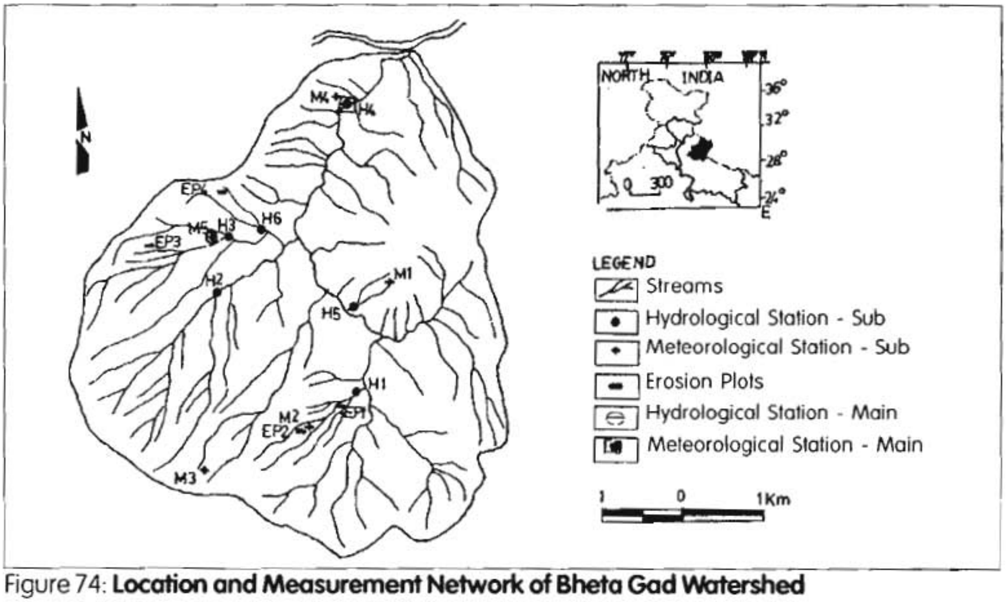

Figure 74: **Location and Measurement Network of Bheta Gad Watershed**

The Rainfall Pattern in the UP Central Himalayas

The spatial temporal distribution of rainfall in the UP Himalayas is highly variable, but most of the rainfall in the region is caused by the south-west monsoon and in general more than 80 per cent of the annual precipitation occurs during the three-month monsoon period from mid June to mid September. In the western hills of UP, 1576 mm of the 1969 mm average annual precipitation falls during this period (Statistical Diary 1973). Even within this period, the major part of the rainfall occurs in a few storms. When the monsoon winds arrive, they assume a south-westerly direction. In regional and general terms, the volume of rainfall gradually decreases from the south-west to the north-east.

Methodology

Rainfall Measurements

In order to obtain satisfactory data on rainfall distribution within the study watershed, a network of five standard non-recording rain gauges (Symon's rain gauge) was installed at different elevations. These instruments consist of a funnel with a beveled gunmetal rim 127 mm in diameter, and a receiver with a narrow neck and a splayed base which is fixed at 1m above ground level. The rainfall data was collected at 8:30 am (IST) every day. In addition, tipping bucket rain gauges were installed, four of them at the erosion plots, and one at the main station in Lawbanj. These instruments collect the rainfall and strain it through a metal gauge before passing it on to the tipping bucket mechanism. Tips of the bucket occur with each 0.2 mm of precipitation collected and each tip is recorded on a logger. The stored information was downloaded every few months to a portable computer.

For the analysis, the study area was divided into various zones based on the position of the meteorological observation stations (thus reflecting the influence of different factors) using Thiessen polygons (Figure 75).

Daily 24-hour rainfall was recorded from the gauge network. Monthly rainfall data from 1st October 1997 to 30th September 1998 were used in the analysis.

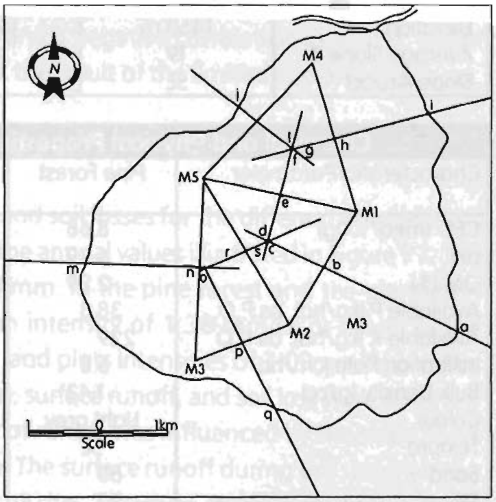

Figure 75: **Thiessen Mean Method to Calculate the Mean Annual Precipitation and Estimation of Influencing Area of Meteorological Observation Station**

The Erosion Plot Monitoring System

Four erosion plots were set-up, one each in a pine forest, tea-plantation (recently planted), on rainfed agricultural land, and degraded pasture land. The location and physico-chemical characteristics of the erosion plots are shown in Tables 64 and 65. The approximate slope of the erosion plots varied from 2 to 28 per cent. The pine forest, tea estate, and grazing plots were established on moderate to steep slopes, but the rainfed agricultural land was on a very gentle slope.

The methods of analysis followed those given in Jackson (1962) and Allen (1989). Each erosion plot was enclosed by a 50 cm high metal sheet coated with iron oxide, 20 cm of it inserted vertically into the ground and 30 cm above the surface. The surface runoff from each erosion plot was collected in two tanks via a gutter and a multi slot devisor. The gutter drains the runoff into a 200 litre tank, which overflows into a second tank via a seven slot multislot devisor which allowed 1/7th of the overflow into the second tank through the middle slot. The actual amount of overflow is determined from the amount in the second tank using a calibration curve. The total sediment (soil loss from the plot) was estimated using a composite sample collected from both tanks, after preliminary tests showed no significant difference between the mean of separate samples collected from each drum and a thrice replicated composite sample. The concentration of the suspended material was determined by a filtration method (Heron 1990; Hudson 1993). The sediment retained after filtration (Whatmann No.1 filter, pore size 1.2 mm) was dried at 105°C for 24 hours, weighed, and compared with an equal volume of pure water treated in the same way as a control. The weight of sediment was converted into sediment yield in t/ha (Heron1990; Hudson 1993). Nutrient loss was analysed following the methods of Jackson (1962).

Table 64: **Location and Characteristics of the Erosion Plots**

Characteristic/ Parameter	Pine Forest	Tea Plantation	Rainfed Agriculture	Degraded Pasture
Location	Majhar chaura	Gewar	Kaulaug	Khaderiya
Elevation	1460 m	1620 m	1390 m	1350 m
Average Slope %	19	20	2	28
Slope Aspect	SE	E	E	S

Table 65: **Chemical and Physical Properties of the Soil at the Erosion Plots**

Characteristic/Parameter	Pine Forest	Tea Plantation	Rainfed Agriculture	Degraded Pasture
CEC (meq/100g)	8.68	14.56	11.79	12.16
pH	6.39	6.16	6.24	6.84
OM (%)	2.29	2.55	3.04	1.64
Available P (kg/ha), as P_2O_5	38.3	38.3	22.9	11.8
Available K (kg/ha), as K_2O	229	286	315	137
Infiltration Rate (cm/hr)	5.8	8.7	4.2	10.6
Bulk Density (g/cc)	1.43	1.15	1.05	1.31
Colour	Light grey	Greyish Brown	Light Grey	Reddish Brown
Texture	SL	SL	SL	LS
Sand	63	66	61	73
Silt	22	25	23	16
Clay	15	09	16	11
WHC (%)	30.8	31.9	34.1	29.6

Note: CEC = Cation Exchange Capacity; OM= Organic Matter; SL= Sandy Loam; LS = Loamy Sand; WHC = Water Holding Capacity.

Results and Discussion

The Rainfall Variation in the Watershed

Table 66 shows the seasonal rainfall variation against elevation and aspect at the different meteorological observation sites in the watershed.

Overall the watershed received an annual total rainfall of 168 cm during the water year 1998, with maximum intensities for 30 minutes and 24 hours of 5.2 and 4.6 mm/hr respectively. The tea estate station (M2 at 1620m) received the highest monsoon, summer, and annual total rainfall (1117, 487, and 1748 mm respectively). The lowest elevation station Lohari (M4 at 1077mt) received the lowest annual total rainfall and monsoon rainfall (1576 and 963 mm respectively).

Table 66: **Seasonal Rainfall Variation Against Elevation and Aspect in the Bheta Gad Watershed**

Station No.	Location of Meteorological Station	Winter Rainfall (mm)	Summer Rainfall (mm)	Monsoon Rainfall (mm)	Annual Total Rainfall (mm)	Slope Aspect	Elevation (masl)
M4	Lohari	197.0	416.8	962.5	1576.3	NE	1077
M5	Lawbanj	185.2	417.0	1101.9	1704.3	NE	1349
M1	Patli	197.0	337.7	1093.8	1628.5	SW	1382
M2	Tea-Estate	145.0	486.7	1116.6	1748.3	NE	1620
M3	Kausani	183.9	467.7	1066.2	1717.8	NE	1840

Figure 76 shows plots of the rainfall against altitude in the three seasons winter, summer and monsoon. There was a positive correlation between the altitude and the amount of rainfall in the summer and monsoon seasons, and a negative correlation in winter. The R^2 values indicated that the regressions were poor, the result of the limited size of the data set.

Analysis of the Soil Erosion under Different Types of Land Use

The effective precipitation, surface runoff, and soil losses for the different erosion plots in the three seasons are shown in Table 67, and the annual values illustrated in Figure 77. The effective precipitation varied from 75 to 1020 mm. In the pine forest and tea-plantation plots, runoff was generated by storms with an intensity of 1.38 mm/hr or more; in the rainfed agricultural land and degraded pasture land plots intensities of 3.09mm/hr or more were required. The highest effective precipitation, surface runoff, and soil loss were observed in the monsoon season (Table 67). The amount of runoff was influenced by the slope, land use, and soil type, as well as by the precipitation. The surface runoff during the summer was considerably less than in the monsoon season at all sites. However, at the rainfed agricultural site the soil loss during the summer was disproportionately high, as were the runoff and soil loss during the winter, probably as a result of the direct impact of raindrops on a bare soil surface.

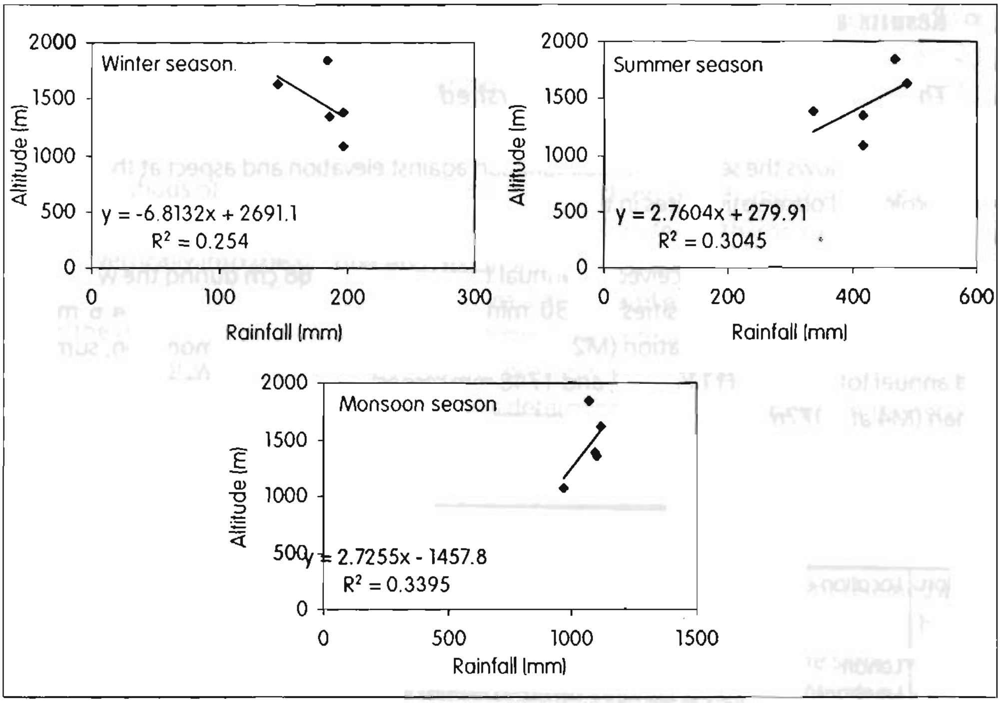

Figure 76: **Total Rainfall versus Altitude in the Winter, Summer and Monsoon Seasons**

Over the whole of the water year, the surface runoff was highest from the pine forest and least from the rainfed agriculture plot. The pine forest site was situated on a steep slope and had a compact soil surface, which promotes surface runoff. The findings are comparable with the observations of Mwendra and Saleem (1997).

During the winter and summer seasons, the highest soil losses were recorded at the tea plantation (1.8 t/ha and 2.2 t/ha respectively), and the lowest at the rainfed agriculture plot (0.3 t/ha and 0.2 t/ha). In the monsoon season, the highest soil loss was observed at the pine forest plot (4.0 t/ha) and the lowest at the rainfed agriculture plot (0.2 t/ha). The high soil loss at the tea plantation was probably the result of the bare soil in the inter-row strips—mulching would assist in controlling erosion from this area. The high soil loss during the monsoon season at the pine forest plot was the result of intensive grazing, litter collection practices, and the steep slope.

The nutrient losses for the different erosion plots in the three seasons are shown in Table 67. The relationship between the annual effective precipitation and loss of organic matter and total phosphorus for the four different land use types is illustrated in Figure 77(b). The nutrient loss estimates for the areas under different land use show a significant seasonal variation in soil organic matter loss (Table 67). There was no direct relationship between organic matter loss and soil loss in the tea plantation and pasture land. In the first case this resulted from the amended soil and weeding practices in the recently planted tea-plantation: the newly exposed nutrients were washed away in the first few storms. Samples collected

Table 67: **Seasonal Variation in Precipitation , Runoff, and Soil Losses for the Different Erosion Plots**

Erosion plot site	Effective precipitation (mm)			Surface Runoff (mm)			Soil Loss (t/ha)		
	Winter	Summer	Mon-soon	Winter	Summer	Mon-soon	Winter	Summer	Mon-soon
Pine Forest	144.1	381.9	938.1	26.4	105.9	179.9	1.2	1.4	4.0
Tea-plantation	144.1	381.1	924.6	23.0	60.8	77.5	1.8	2.2	2.3
Rainfed Agri. Land	74.5	302.8	776.2	9.3	4.2	16.8	0.3	0.2	0.2
Degra. Pas. Land	113.7	356.6	1019.6	13.0	34.2	81.8	0.4	0.5	0.9

Table 67: **Seasonal Variation in Precipitation , Runoff, and Soil Losses for the Different Erosion Plots (cont'd)**

Erosion plot site	Org. Matter Loss (kg/ha)			Total Phosphorus (kg/ha)		
	Winter	Summer	Mon-soon	Winter	Summer	Mon-soon
Pine Forest	92.1	47.5	171.8	2.5	2.3	5.8
Tea-plantation	193.2	100.8	112.1	5.0	3.6	2.0
Rainfed Agri. Land	21.8	15.7	10.1	0.7	0.5	0.5
Degra. Pas. Land	55.0	14.5	52.7	0.6	0.6	1.3

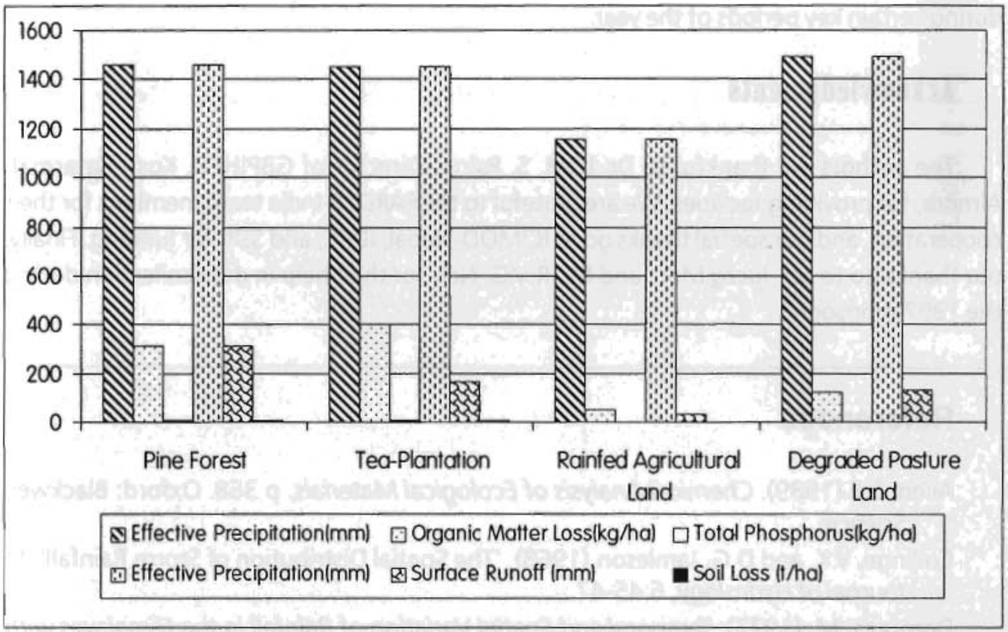

Figure 77: **Annual Precipitation, Runoff, and Soil and Nutrient Losses of the Erosion Plots**

later, in the monsoon, showed a lower organic matter loss but a higher soil loss. In the second case the degraded pasture land had little surface soil cover; the soil loss observed in the samples was mostly weathered rock mass. The area was kept open for grazing from winter to early monsoon and was closed by social fencing for a couple of months in the monsoon; thus the biomass residues decreased from winter to the summer when less organic matter loss was observed in the samples. The loss of phosphorus from the four different plots ranged from 0.5 to 5.8 kg/ha in the different seasons (Table 67).

Conclusions

Data from several successive water years is required for a significant comparative study. In this paper, an attempt has been made to present a few of the findings for the water year 1998 on the basis of meteorological and soil erosion data. Based on these very preliminary findings, some suggestions were made to farmers about suitable sowing times, crop irrigation requirements, the need for water storage for the dry periods, and the risk of potential losses of organic matter and other soil nutrients.

Tea gardens are being developed in the Bheta Gad watershed at an increasing rate, and both tea project staff and farmers need to be aware of the soil losses that can occur in new plantations. The precautionary measures needed to prevent runoff and subsequent soil loss are proper drainage, mulching, maintenance of gentle slopes, and possibly leguminous cover crops in the inter-row areas.

The high losses recorded in the pine forest plot suggest that serious thought needs to be given to some form of rotational system whereby litter collection and cattle grazing in areas of the forest vulnerable to runoff and soil loss (e.g., steep south westerly slopes) are restricted during certain key periods of the year.

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