Pattern and behaviour of gully erosion in Shiwaliks of lower Himalayas

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Abstract
A study on behaviour and pattern of gully erosion in foothills of Shiwaliks of lower Himalayas was conducted in 68 micro-catchments. The average gully density was 19.8 km/km^2 and the average gully texture was 839 /km^2 observed in the region. The average length of 1st order gullies, which are primary points of runoff water collection, was 60.7 %, whereas the average number of 1st order gullies was 74.3 %. A bifurcation ratio of 3.4 was observed between first and second order gullies for whole of the region. Temporal study of gully development suggests relatively higher increase in gully depth as compared to their length or width.

Key Words
Soil erosion, gully length, gully number, gully distribution

Introduction

The foothills of Shiwaliks covering an area of 2.14 m ha falls in four states of India i.e. Punjab (0.14 m ha), Haryana (0.06 m ha), Himachal Pradesh (1.14 m ha) and Jammu and Kashmir (0.80 m ha) and represents the most fragile ecosystem of Himalayan mountain range because of its peculiar geological formations and highly erodible soils (Singh and Khera 2009). Runoff and soil loss in the region varies from 35- 45% and 25-225 t/ha/year, respectively (Sur and Ghuman 1994). Among different types of soil erosion, gully erosion is the most serious one in the region as around 20% of the area is already under gullies (Kukal and Sur 1992). Ephemeral gully erosion has been reported to account for 48.5 to 72.8% of the total soil loss (Zheng *et al.* 2009). About 70-80% of the gully erosion control structures have failed in the region (Kukal *et al.* 2002). The reasons attributed for the failure of gully control structures in the region include lack of information on gully network including distribution and extent of different-ordered gullies, gully density, gully texture, behaviour and development of gullies in the region. Secondly, the installation of gully control structures is generally done in the highest-ordered gully on lower, middle and upper segments of the catchment. After some time, the gully control structure gets silted up along the upstream side, after which the runoff water starts falling down from the crest height of the structure and causes higher erosion losses. The lower ordered gullies are seldom tackled in the region while controlling the runoff and soil loss and are generally ignored in all the soil conservation programmes. The present study aims to have an insight into the behaviour and patterns of gully erosion in the foothills of lower Shiwaliks and to study the nature of gully development and distribution patterns in the region.

Methods

Study area

The study was carried out in 68 catchments in the Shiwaliks region of Lower Himalayas in North India. The region lies between 30^0 10' to 33^0 37' N latitude and 73^0 37' to 77^0 39' E longitude and stretches to about 530 km lengthwise and 25 – 95 km width wise.

Gully erosion survey

A detailed field survey for gully erosion was carried out by dividing catchments into grids of 50 × 50 m^2 each. For the detailed field survey, each gully line was sketched on the contour maps (at a scale of 1: 1000) manually after measuring the distance between wooden pegs laid out in the grids. The gullies up to the first-order were marked on the maps. Gullies were classified as 1st, 2nd, 3rd, 4th and 5th order gullies, depending upon extent of their bifurcation. The length of different ordered gullies was measured in each catchment from the gully erosion map. The total length of all the gullies in the catchment were expressed as "gully density" (km/km^2). The number of first-order gullies per unit area was expressed as "gully texture" (number/km^2).

Gully development process

Detailed gully development process was studied in four selected catchments in the region by selecting the strategic sites prone to gully erosion and monitoring the initiation process and gradual advancement of

gullies at different time intervals. The temporal variations in gully dimensions on both non-arable and arable land were observed after 21, 41 and 77 days with respect to the first day observation. The width, length and depth of the gullies were measured and from this total volume of the gully calculated.

Results

Extent of Gully Erosion

The extent of gully erosion expressed on the basis of gully density and gully texture is presented in Table 1. The average gully density was 19.85 km/km^2 and the average gully texture in the region was 839 number/km^2. The catchments of location I observed the highest value of gully density (30.52 km/km^2) and gully texture (1921.5/km^2) among all the sites.

Distribution of different-ordered gullies

The average length of 1st, 2nd and 3rd gullies was 60.7, 22.8 and 10.3% per cent, respectively with standard deviation of 8.66, 7.03 and 6.51 (Table 2). The average number of 1st, 2nd and 3rd order gullies was 74.3, 22.1 and 3.12%, respectively with standard deviation of 6.21, 4.99 and 2.06, respectively (Table 2). Unlike the length of first-ordered gullies (the main runoff collecting channels), the number of first-order gullies did not differ much among various catchments (72-77%). The first-ordered gullies collect runoff from the remotest points of the catchment and supply the same to the 2nd order gullies. The runoff is then conveyed further to 3rd, 4th and 5th ordered gullies and ultimately the highest order gully carries it out of the catchment.

There was a definite bifurcation ratio observed between first and second order gullies. A bifurcation ratio of 3.4 was observed for whole of the region. It could be used to predict the number of first order gullies from the number of second order gullies. A definite relation was observed between the gully order and mean length of gullies. The mean length of gullies increased with increase in gully order. The number of different ordered gullies draining into the higher order gullies shows that about 54, 29 and 17% of the 1st order gullies drained into the 2nd, 3rd and 4th order gullies, respectively whereas 64 and 36% of 2nd order gullies drained directly into 3rd and 4th order gullies, respectively.

Temporal variations

The gullies in the region have been observed to grow in all the three directions both on arable and non-arable lands with time leading to addition of the sediments in the running water. The width of the gullies in non-arable lands increased by 3.72 to 9.6% within a period of 77 days, whereas the length and depth of the gullies increased by 3.1 to 8.9% and 8.3 to 26.7%, respectively. The increase in gully depth was more conspicuous than gully width and length. It could be due to the reason that the subsoils in the region are more erodible than surface soils and once the surface soil gets eroded, the gully depth increases at a faster rate. This is true in case of gullies on arable land which are deeper than the gullies on the non-arable lands.

Table 1. Extent of gully erosion in the study catchments.

Location	Number of catchments	Gully density (km/km^2)			Gully Texture (number/km^2)		
		Range	Mean	SD	Range	Mean	SD
I	4	8.6 - 31.7	17.9	9.78	251.2 - 758.0	542.7	240.86
II	4	3.5 - 80.0	30.5	33.93	425.0 - 4966	1921.5	2058.06
III	16	3.2 - 45.1	15.6	13.45	157.1 - 1575	647.2	437.86
IV	20	2.8 - 62.8	20.3	16.01	93.6 - 2314.0	620.8	518.06
V	24	3.2 - 28.0	14.9	6.05	258.0 - 912.5	462.1	177.26

Table 2. Distribution of length of different ordered gullies in the study catchments.

Location	Gully Length (%)			Gully Number (%)		
	1st order	2nd order	3rd order	1st order	2nd order	3rd order
I	71.85	27.45	1.17	77.43	21.98	0.83
II	75.25	20.25	4.00	74.90	22.38	2.73
III	55.70	24.11	10.78	72.39	21.77	4.58
IV	52.47	19.76	18.76	73.24	21.71	4.15
V	47.80	22.48	16.75	73.37	22.50	3.30

Conclusion

The gully density ranged from 2.8 to 80 km/km^2 with a mean value of 19.8 km/km^2 and gully texture varied from 93.6 to 4966 /km^2 with a mean value of 840 /km^2 in the region. First order gullies dominated in the region and mean length of gullies increased with increase in gully order. Depth of gullies is comparatively higher both under arable and non-arable land uses.

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