

Hydrological Impacts of Rejuvenating Degraded Hilly Watershed in Shivalik Region

A. K. Tiwari and V. K. Bhatt

Abstract The Shivaliks of northwest states (Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, and Uttarakhand), spread over an area of more than three million hectares, perhaps represent the one of the most fragile ecosystems of India. The flora and fauna in these hills has been recklessly destroyed during the last two generation resulted in present state of severe degradation. The rainfall is satisfactory and seemingly the potential of restoration of these denuded hills. It was with a view to explore this potential and simultaneous creation of a database for the collection of quantified scientific information on the existing and changing pattern of water and sediment yields from degraded hilly watershed. A watershed of 21 ha almost devoid of vegetation was rehabilitated through control of erosion and improved vegetation and protection. The long-term (1964–2000) hydrological experiment could provide information about the hydrological behavior of hilly forest watershed with respect to temporal rainfall, and the impact of vegetation cover and the treatment of the watershed. The water yield from the watershed sustained at 10–15% of rainfall on an average basis. Sediment yield declined (from 37 to 3.7 Mg/ha) as a result of soil conservation measures and increased vegetation cover, suggesting the entirely positive impact of the recommended measures to restore the ecological environment in these hills.

Introduction

The Shivaliks of northwest states (Haryana, H.P., Jammu and Kashmir, Punjab, and Uttaranchal/UP), spread over an area of more than three million hectares, perhaps represent one of the most fragile ecosystems in the country. The elevation varies from 280 to 1500 m. The average annual rainfall of the region is 1100 mm where about 82% is received during monsoon, with average annual pan evaporation about

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2110 mm (Agnihotri 2000). Temperature varies from 2 to 43 °C. The Shivaliks are characterized by low hills, undulating topography, steep slopes, erodible soils and are dissected by numerous seasonal streams. In general, soils are coarse-textured and deep with pebbles and boulders on slopes near the foothills. The rain-fed areas of Shivaliks have no possibility of providing irrigation through conventional methods, and large amount of runoff not only goes waste from such lands but also creates problem of soil erosion and land degradation. Management of water resources in its various forms is key to environmental, economical, and social sustainability in Shivalik region. To address the above problems and to restore the ecological environment in this area, a hilly watershed typical of the region of 21 ha was brought under study in 1963 (year of start of Project).

Location of the Watershed

The selected watershed is located at the research farm of IISWC, Research Centre, Chandigarh, in Pinjore block of Panchkula district in Haryana. It is located at elevation of about 450 m (msl), at 30° 45'N latitudes and 76° 52'E longitudes. The research farm lies in the watershed, which drains into the Ghaggar River. The area of watershed is 21 ha and had scrub forest land initially which was further converted to a protected and treated forest land. The land slope in the watershed varies from 10% in some pockets to almost vertical cliffs near the ridges. The main drainage channel drops by 50 m in the first 200 m, and thereafter, the bed gradient gradually decreases to about 1.5% near the dam, with 10% average slope in the watershed.

Climate

The average annual rainfall of the region is 1117 mm. About eighty percent of this rainfall (889 mm) is received through southwest monsoon (June–September). The monsoon sets in last week of June and withdraws by middle of September. There is a wide variation in distribution of rainfall not only from year to year but also between the months. Late start and early recession of monsoon and wide dry spells are of common occurrence. Rainfall of long duration and high intensity (120 and 100 mm/hr for 15 and 30 min duration) is common. About 165 mm of rainfall is received during winter season (November–March) through northeast monsoon. The summers are hot, windy, and dry with the maximum temperature going up to 46 °C (mean maximum 40.4 °C in June). The winters are extremely cold with temperature touching freezing point (mean minimum 5.6 °C in January).

Geology

Geologically, the Shivaliks are made of sand stone, grits, conglomerates, and clay having the characters of fluviatile deposits of torrential streams and flood basin. The rocks are young, soft, and loose and are highly susceptible to erosion. The clay minerals are illite, chlorite kaolinite, and montmorillonite with quartz and feldspar in traces. Pink salt is dominant mostly in Haryana area, and coarse sediment composed of pebbles and sandstone is common in the foothills. The soils in the watershed are moderately to severely eroded, gravelly on the surface throughout the profile depth. Most of the area is under forests and rock outcrops. The pH varies from 7.2 to 7.5 in hilly areas. The soils in the watershed area are classified as Chandigarh Series 1, which are essentially sedimentary soils of marble with sandstone intrusions. The texture at the surface varies from sandy loam to loam with silty clay loam subsoils (Yadav et al. 2005a). The soils are well drained with organic carbon varying from 0.07 to 0.37% at the surface at the beginning. The land is mostly classified in class VII as per soil depth, topography, and extent of erosion.

Infiltration

Steady-state infiltration rates and cumulative infiltration were estimated at different reaches, viz. upper, middle, and lower. Litter deposition, soil texture, organic carbon, and clay content of soil were also measured to know the correlation between these soil properties with infiltration. Steady-state infiltration rates gradually decreased from upper to lower reaches as per the present data. Very slow-to-slow steady-state infiltration rates (0.11 and 0.14 cm/h), respectively, were observed in lower reaches of east- and north-facing slopes. Cumulative infiltration was also low (ranged from 0.61 to 5.2 cm) in east- and north-facing slopes than that of west- and south-facing slopes (ranged between 2.43 and 24.68 cm) (Yadav et al. 2005b).

Vegetation

Initially, it was a scrub forest land almost with very few trees of *Acacia catechu* (Khair) and *Dalbergia sissoo* (Shisham). Biotic interference in the area consisted of mostly scrub growth principally of *Hycanthes arbortristin* (Har singar), *Carissa opaca* (Karanda), and *Ziziphus numularia* (Ber). The scanty grass cover included *Heteropogon contortus*, *Chrysopogon fulvus*, *Dicanthium annulatum*, *Eulaliopsis binata*, and *Eucmopogon fovoalatus*. Afforestation was carried out predominantly by sowing of *A. catechu* (Khair) in pits and trenches. The tree species has proved to be very successful on the hillslopes. *D. sissoo* was also planted by seedlings and

root–shoot cuttings. *E. binata* (bhabhar) grass was sown on the berms of staggered trenches. Plantation also included *Dendrocalamus strictus* (bamboo), *Albizia lebbek* (sirris), and eucalyptus. The efforts for afforestation and imposition of soil and water conservation structures have resulted in covering whole of the watershed with dense forest rejuvenating the hilly watershed. At present status of vegetation, *A. catechu* recorded the maximum frequency (75%) followed by *D. sissoo* (16.67%); however, ingress of *Lantana camara* shrub in the watershed area after the 1990s resulted in the depletion of ground cover in the watershed. Grewal et al. (1996) reported that during 1980–85 luxurious growth of *E. binata* grass was obtained with the yield varying from 3 to 6 Mg ha⁻¹ (dry weight basis) giving a good revenue. After ingress of *L. camara*, there was an overall change in vegetation pattern with drastic reduction in grass yield.

Resource Conservation

The watershed was provided with full protection within the fencing of the research farm. The induced protection could eliminate the grazing as well as removal of shrubs and trees. Staggered contour trenches of size 30–45 cm deep with a length of 2–3 m were excavated along the contour for reducing the overland flow, moisture conservation, and survival of the vegetation. Brushwood wattling reinforced with *Agave bulbils* and *Arundo donax* was used to control the steep and long slopes. Brushwood check dams and traps were constructed across small gullies and drainage ways to arrest silt. Seven check dams were constructed in the upper watershed to act as debris trap. These check dams controlled the runoff and debris from the individual watersheds varying from 0.74 to 4.6 ha. In the year 1974, one more check dam of height 2.5 m and length 14 m with a watershed of 0.55 ha was constructed near the pondage area. The check dams helped to reduce the sediment yield into the storage reservoir downstream built under earthen dam (16 m length and a height of 5.5 m). These structures were provided with suitable spillways. Water spreaders were also provided with a 3-m-wide drains on the upstream side. These earthen embankments were sodded by *Cynodon dactylon* (Dub) and were provided with suitable spillways.

Runoff

Runoff and sediment flow from the watershed was recorded through weir was installed with an automatic water level recorder for measurement of the flow. Hydrographs were taken up and analyzed with the help of rating table to derive the discharge rate at different time, peak discharge, and total volume of runoff for each rainfall event. The runoff data were collected from the year 1964–2000. Observations of daily water level in the pond were taken to determine the total water yield of the watershed, the quantity retained, and storage losses from the pond.

Sediment Outflow

To compute the sediment yield in the pond every year, the contour survey was carried out to record the change in submergence area and capacity of the pond by getting the sediment yield accumulated in the pond.

The submergence area of the pond was surveyed in 1963 to determine the storage capacity and establish benchmark levels for the determination of the sediment trapped in the pond. As the pond bed was undulating with steep slope, the major portion of the ponding area was covered with 20 ft × 20 ft (6.1 m × 6.1 m) grid with permanent markers for monitoring the sediment deposited in the pond. This was supplemented with occasional analysis of runoff samples from the pond, the upstream channel, and outflow through the spillway.

Database

The annual rainfall, runoff, peak discharge, and the sediment yield were analyzed for the year 1964–65 to 1999–2000 and presented in Table 1. To have in-depth assessment of impact of the soil and water conservation measures and vegetative treatment, the data were analyzed on annual basis.

Table 1 Annual rainfall, runoff, peak discharge, and sedimentation yield from the watershed (Tiwari et al. 2012a)

S. No.	Water year	Rainfall	Runoff		Peak discharge (cumec/km ²)	Sediment (Mg/ha)
		mm	mm	As %of rainfall		
1	1964–65	1254.2	276.74	22.07	2.54	37.71
2	1965–66	718.2	119.23	16.60	2.62	26.27
3	1966–67	1174.6	166.51	14.18	5.52	12.38
4	1967–68	1455.5	165.76	11.39	0.00	9.66
5	1968–69	899.9	69.98	7.78	0.26	6.94
6	1969–70	885.3	58.44	6.60	1.24	5.54
7	1970–71	1122.8	165.10	14.70	5.52	6.94
8	1971–72	1664.5	168.67	10.13	4.81	8.26
9	1972–73	680.1	26.17	3.85	0.00	4.13
10	1973–74	1687.8	136.82	8.11	2.68	4.03
11	1974–75	813.9	60.98	7.49	0.93	2.91
12	1975–76	1197.3	159.76	13.34	1.24	2.81
13	1976–77	1092.7	93.72	8.58	3.20	2.72
14	1977–78	1214.5	93.77	7.72	2.08	2.53
15	1978–79	1592.9	112.05	7.03	4.54	1.66

(continued)

Table 1 (continued)

S. No.	Water year	Rainfall	Runoff		Peak discharge (cumec/km ²)	Sediment (Mg/ha)
		mm	mm	As %of rainfall		
16	1979–80	802.7	57.31	7.14	0.00	0.54
17	1980–81	1261.1	108.66	8.62	0.22	1.33
18	1981–82	1286.5	104.38	8.11	0.23	1.80
19	1982–83	1244.5	47.51	3.82	0.00	0.50
20	1983–84	1185.6	106.99	9.02	4.43	2.16
21	1984–85	673.9	29.94	4.44	0.00	0.30
22	1985–86	942.5	22.81	2.42	0.00	0.10
23	1986–87	1273.4	83.29	6.54	0.00	0.25
24	1987–88	423.0	4.22	1.00	0.00	0.01
25	1988–89	1732.3	267.56	15.45	1.78	1.45
26	1989–90	1326.7	177.45	13.38	4.68	3.43
27	1990–91	1509.2	206.84	13.71	2.77	2.80*
28	1991–92	912.9	64.09	7.02	0.00	2.80*
29	1992–93	918.1	91.19	9.93	2.18	2.80*
30	1993–94	887.2	81.00	9.13	0.00	2.80*
31	1994–95	1291.2	184.13	14.26	2.22	2.80*
32	1995–96	1572.7	328.60	20.89	6.57	9.50
33	1996–97	1354.7	272.40	20.11	7.40	7.20
34	1997–98	1279.7	152.90	11.95	1.68	3.90
35	1998–99	1433.8	202.40	14.11	2.77	5.40
36	1999–2000	1013.7	154.90	15.28	1.78	3.70

*Average value of the five years (1990–95) has been adopted

Results and Discussion

Water Yield

Variation of annual rainfall and water yield from the watershed is given in Fig. 1. The annual water yield varied between 4.22 mm (1% of rainfall) at low rainfall of 423 mm in the year 1987–88 to 328.60 mm (21% of rainfall) in the year 1995–96 and at high rainfall of 1527.7 mm. The data in the initial years were higher which had a declined trend there after up to 1987–88. Again, there was a rise in runoff for three consecutive high rainfall years 1988–1991, and then, again it declined to low level when the rainfall was less than 1000 mm. There was again a increasing trend in runoff from the year 1994 onward to 1999 being the year with rainfall more than 1000 mm. Year 1995–97 had again a runoff value of 20–21% of rainfall which rose the eyebrows of many people that how a treated and fully vegetated watershed can contribute the runoff up to 21% of rainfall (Fig. 2).

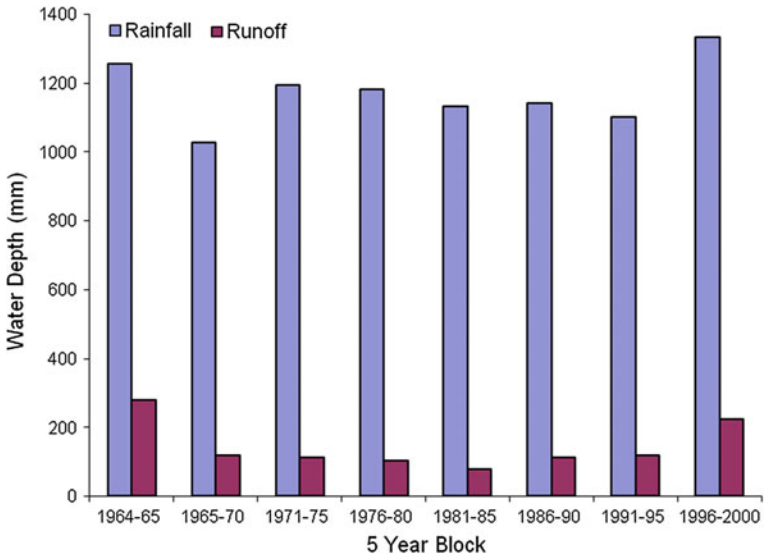


Fig. 1 Variation of average rainfall and runoff

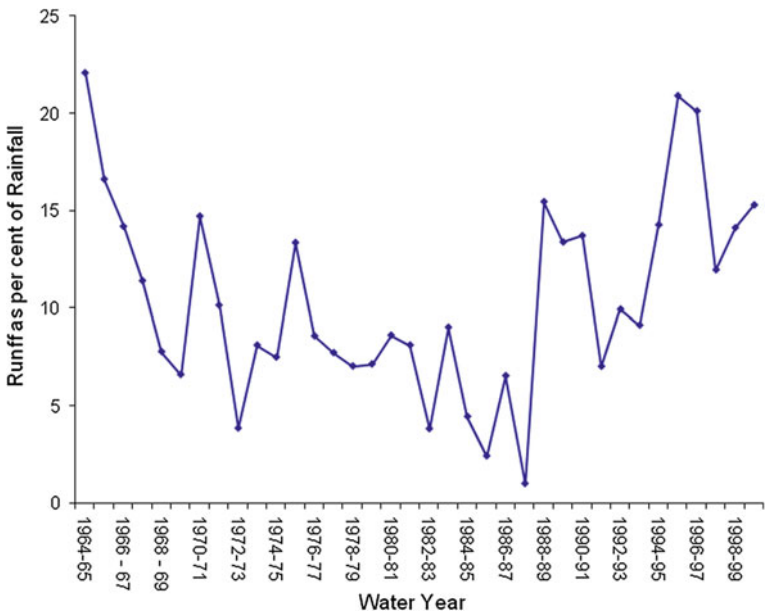


Fig. 2 Annual variation of runoff percentage of rainfall

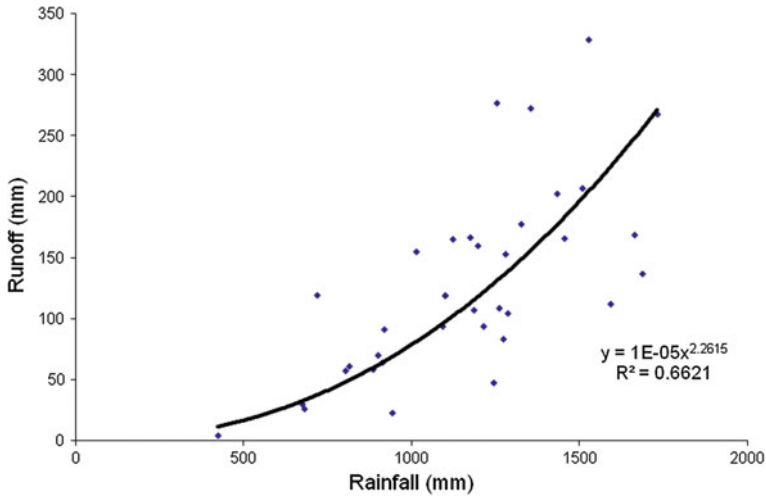


Fig. 3 Annual rainfall versus runoff in the watershed

Peak discharge did not show any trend as it totally depends upon the prior saturation, storm rain, and the intensity of rainfall. Discharge 7.40 cumec/km^2 was observed from the watershed being highest in the year 1996–97.

The annual values of runoff were plotted against the annual rainfall values (Fig. 3). The runoff was found to vary directly with the rainfall values. Following equation was obtained, in the exponential form

$$Y = 1E - 05 \times 2.2615(R^2 = 0.6621)$$

where

Y Runoff (mm)

X Rainfall (mm)

Figure 3 shows that at rainfall above 1200 mm, the curve becomes steeper, depicting higher rate of runoff at higher rainfall, which was found to be in agreement with higher runoff during the years with higher rainfall (>1200 mm). However, in no case, the runoff was more than 21%, and on an average, these hilly protected forest watersheds can have the water yield of about 10–20% of annual rainfall (Tiwari et al. 2012b).

Sediment Yield

Sediment yield followed the same trend as that of the runoff, and it varied from a value of 37 Mg/ha before treatment to practically zero after the treatment. There has

been slight increase in the later stage, but it was found to be well within limits after the treatment. The initial observed value was found to be 37.71 Mg/ha in the year 1964–65 as 276.74 mm of runoff (22% of rainfall) came down to practically zero percent in the year 1979–80; however, in later years, it started increasing.

Looking into Fig. 4 wherein grouped average value of 5 years has been shown for sediment yield, there was sharp decline at the initial stage due to the check dams and the contour trenches (soil and water conservation measures). The little rise at the tail end of the curve may be either due to siltation of soil conservation structures, supplemented by the depletion of ground cover resulting from ever-increasing infestation of lantana enhancing a little more erosion from the hills.

The five-year average sediment yield values were related to the runoff. Following relationship was obtained for sediment yield.

$$Y = 0.1448 \times -12.092(R^2 = 0.65)$$

where

Y Sediment yield (Mg/ha)

X Average 5-year runoff (mm)

Sediment yield was also compared with the peak discharge from the watershed. Usually, the heavy storms cause much erosion, and some times, even whole of the

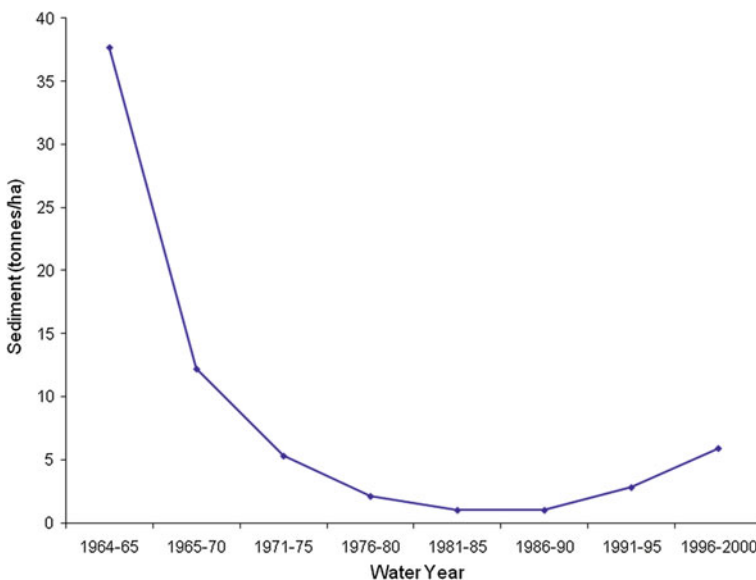


Fig. 4 Variation of sediment yield (1964–2000)

erosion might occur due to very few heavy storms. By analyzing the sediment yield and peak flow, it was seen that there was sharp rise in sediment yield beyond a peak discharge of 2.5 cumec/km².

Conclusions

The study provides the impact of resource conservation and afforestation on the long-term hydrology of the hilly watershed. Results indicate that the protected and treated hilly watersheds can provide the water yield to the tune of 10–20% of rainfall in the Shivalik belt. For rainfall up to 1000–1200 mm, the hydrological behavior does not have much change in the rainfall; however, for rainfall more than 1200 mm, this hilly watershed would contribute more runoff and become more vulnerable from the point of view of soil erosion. The soil conservation measures such as check dams and contour trenches combined with the plantations have a clear-cut impact on reducing the soil erosion from 37 Mg/ha/year to even less than 1 Mg/ha or within the permissible limits of soil erosion. Results further indicate that the barren hillocks even with the vertical cliffs can be rehabilitated through soil conservation measures and plantation activities along with protection. The increase of water yield and sediment yield (although within the permissible limit) in the later years has been due to the saturation of the sediment control structures. There might be a need to rejuvenate these structures through desilting and maintenance operations to keep their life effective. Infestation of lantana also needs to be controlled in these hilly watersheds, which is responsible for the depletion of ground cover in this watershed; the same may induce more of erosion. The rehabilitation process of the hills is to be watched carefully as the change in vegetation composition may also sometimes alter the hydrological behavior and increase vulnerability. The harvested rainwater from the hilly watershed in the pond can serve as good source of irrigation in the downstream areas through gravity flow. Water harvesting through these small structures assumes great importance in Shivaliks, where only 18% area is irrigated. For that, there has to be a sediment-free sustained water yield from these hilly watersheds in the Shivaliks.

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