Hydrological research in the Indian Himalayan mountains: Soil and water conservation

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Conservation and optimal use of soil and water resources assume prime importance in any region, particularly in the mountains. In the Indian Himalayan region (IHR), soil and water conservation (SWC) programme mainly relies upon engineering measures. Realizing the importance of land use and vegetation cover in SWC, hydrological research was initiated at different locations in the IHR. A review of published literature on micro-scale (run-off-plot level) and meso-scale (watershed level) studies on hydrology in the IHR suggests that although all the land uses have been attempted, only forests and a few micro-watersheds in the Central Himalayan region have been investigated in some detail. These limited studies reveal that grasslands lose more water; jhum cultivation loses both soil and water of greater magnitude, and forested land use loses smaller quantities of both soil and water. Agricultural land use, which is considered to lose much soil and water, was unfound. It seems that lack of uniform methodology, proper instrumentation and logistic facilities partly influence the data collected and do not lead to any definite conclusion with regard to effect of a particular land use/vegetation type desirable for SWC in this region. There is a strong need to undertake systematic and more careful studies to strengthen SWC efforts in the IHR.

THE three landmark publications on the hydrology of Himalayan mountains[1–3] have made it amply clear that the hydrological research conducted in this region so far is inadequate ('the so-called black-box') to generalize and oversimplify the commonly held notion that deforestation and other anthropogenic activities by the mountain inhabitants cause floods and associated damages in the adjacent plains. Despite its appeal to logic and conventional wisdom, this view has been challenged on the grounds that the effects of mountain inhabitants must be insignificant in comparison to the substantial geophysical processes involved[4,5]. The assertion that upland reforestation will control downstream floods does not hold for the Himalayan situation[6–10]. Extreme rainfall distributed over a large area (and glacial lake outbursts) may give rise to floods, and the absence or presence of forest cover becomes almost negligible. This controversy is largely a matter of scale and historical perspective[6].

There are special difficulties in the task of scaling in hydrology. These include: (a) the large number of variables and physical laws that govern the phenomena; (b) the spatial distribution of such properties as soil hydraulic conductivity and soil moisture condition; (c) the stochastic nature of such variables as storm intensity and storm attribute (topography, soils, etc.)[11]. This heterogeneity can have a significant impact on run-off generation at the catchment scale[12]. It is important to recognize that different physical processes may dominate at different scales. For example, hill-slope run-off processes may dominate at sub-catchment scale; the channel network geometry becomes important in meso-scale basins (up to the order of 100 km^2), while in large basins the spatial variability of precipitation becomes important[13].

Bruijnzeel and Bremmer[3], after examining the published work on hydrology of the Himalayan mountains summarize the following: (i) Vegetation and land use practices do exert clear influences on total water yield and timing (peak flows, dry season flows) of stream flow in catchment areas of less that 500 km^2, beyond which the effect tends to disappear. (ii) Conversion of forest land to agricultural uses (cropping, grazing) will lead to increased total water yield as a result of reduction in evapotranspirational (Et) demand. Dry season flow may increase or decrease following the conversion and resultant infiltration characteristics of the soil. (iii) Reforesting degraded grass or croplands with fast-growing trees will generally lead to reduced total and dry season flows, as the associated increase in water consumption will override the effect of improved rainfall infiltration. Bruijnzeel and Bremmer[3] raised the basic question; 'What is the forest and land use in the uplands with respect to flooding, dry season flows and sedimentation in the lowlands?' Alternatively, 'what downstream benefits can reasonably be expected in this regard from upland reforestation?' Regarding the two questions raised, Bruijnzeel and Bremmer made an important point that one first needs to define the scale for which one's statements are valid. They found that at a local level (micro-scale), sediment load is strongly affected by human activity, stream discharge characteristics much less. At the medium level (meso-scale) downstream of the catchment

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being impacted. At the macro-level in large basins, human impact in the upper watersheds is but one factor and is considered to have insignificant impact on lowland floods, low flows and sediment.

In this study, the literature on the hydrology of Indian Himalayan mountains (except studies on glaciers) during the recent two decades has been reviewed to (i) understand the micro-scale (run-off-plot level) and meso-scale (micro-watershed level) differences in hydrological responses, such as run-off/stream flow and sediment movement, and (ii) analyse the results from the standpoint of our ability to make decisions regarding soil and water conservation (SWC) programme in this region.

Micro-scale (run-off-plot level) studies

Forests

Our knowledge on hydrology of forests in the Indian Himalayan Region (IHR) is largely based on the work carried out at Kumaun University, Nainital[14–21], G. B. Pant Institute of Himalayan Environment and Development, Kosi-Almora[22–26] and Conifer Research Station, Shimla[27–29] (Table 1). In these studies data on hydrologic pathways such as throughfall, interception, stemflow, run-off and sediment movement under different forest types (from foothill broadleaf forests to high-altitude conifer forests) were collected. The studies found soil loss ranging between 0.012 and 0.057 t/ha (for rainy season) for high-altitude conifer forests in Eastern Himalaya and foothill sal (*Shorea robusta*, a broadleaf deciduous species) forests in Central Himalaya. The precipitation inputs were found to play a crucial role in the nutrient cycling of these forests[19,30]. In these studies, run-off accounted for ≤ 1% of the incident rainfall (range = 0.01–2.17%), and the lateral flow (caused due to impervious rocks beneath) was a major contributor to storm run-off. Thus, it was concluded that the Himalayan forested catchment areas are sub-surface flow systems[31], and prone to landslide and landslips when tree cover is lost. It was suggested that in these catchment areas dense forest cover, preferably oak (*Quercus* spp., an evergreen broadleaf species) is desirable for SWC.

Hydrology of the high-altitude forests of this region has been least investigated due to logistic problems. A reconnaissance study of three dominant forest types considered silver fir (*Abies pindrow*, an evergreen conifer species) as a suitable species for SWC, which permitted small quantities of both run-off (0.01% of the incident rainfall) and soil loss compared to other broadleaf species such as *Aesculus indica* (deciduous) and *Quercus semecarpifolia* (evergreen species)[21].

Incident rainfall on the forest canopy is disposed through interception, throughfall and stemflow. In the Central Himalayan forests, interception was found ranging between 2.4 and 93% of gross rainfall, when considered on individual rain-shower basis[16]. However, across several rain showers during monsoon, this value ranged between 7.9 (pine mixed-broadleaf forest) and 32.4% (pine forest). In the conifer forests of Himachal Pradesh, interception loss was recorded at 10–75% of monthly rainfall in *Pinus wallichiana* and *Cedrus deodara* forests[27]. The smaller rainfall shower permitted high interception loss. These studies show that in the conifer forests interception loss is high compared to broadleaf forests, and the throughfall (range = 66.5–87% of the incident rainfall) was inversely related to canopy interception. Stemflow was recorded ≥ 2% of the total rainfall, and the conifers recorded the minimum values. Infiltration studies on *A. pindrow* and *Picea smithiana* forests under two logging situations (viz. selective logging and clear-felled) indicated that under selective logging, infiltration rate was two times as much as that recorded for clear-felled system (i.e. 16.5 cm/h) during the first five minutes[27]. Similar results were obtained while comparing these two species and agricultural land in Himachal Pradesh[32]. Despite the above efforts, a significant component of hydrology, i.e. Et yet remains least understood. Under a 35-year-old teak plantation at Dehra Dun[33], Et was estimated as 840 mm/yr. Therefore, based on a limited number of studies on ecosystem-level hydrologic processes in these forests, no implications for SWC could be drawn.

Crop fields

Although the forest biomass-based traditional agriculture of the IHR has been much debated concerning the harm it inflicts upon SWC efforts in this region[34], a few studies are available on cropfield hydrology (Table 1). Studies at experimental farms of Central Soil and Water Research and Training Institute (CSWRTI), Dehra Dun[35,36] have reported maximum run-off and soil loss under conventional farming and minimum under conservation bench terraces. In Sikkim Himalaya, low soil loss (0.12 t/ha) and run-off (≈ 5% of incident rainfall) for maize crop fields and high soil loss (0.17 t/ha) and run-off (6%) for barren land were recorded[22]. Sen *et al.*[37] reported high soil loss under 6–10° slopes, which ranges between 6.1 and 64.4 t/ha/yr for finger-millet and potato in the high altitudes of Central Himalaya. Therefore, cultivation of cash crops (e.g. potato) at the expense of traditional crops implies high ecological cost in terms of soil erosion and loss of forests. In both the above studies[22,37], run-off-plot size was almost the same (3.0 m × 2.0 m and 2.5 m × 2.5 m). The crop fields of Kumaun Himalaya were found to be net exporters of carbon and are likely to lose productivity with the passage of time[38].

Table 1. Overview of micro-scale (run-off-plot method) hydrological studies in the Indian Himalayan mountains

Study site	Site description/land use/ experimental design	Stream flow/run-off (% of annual r.f.)	Sediment loss ($t\ ha^{-1}\ yr^{-1}$)	SWC implications
Khasi hills, Meghalaya, Northeast Himalaya[41]	Alt. 1500 m. Monsoon r. f. = 1900 mm. 2 m × 20 m run-off plots at 40° slopes. Four replications in 5-yr, 10-yr jhum cycle and terraced agriculture, observations monthly	*	34 (terraced cropping)–55 (5-year jhum)	Nutrient, soil loss and water loss were much lower in agriculture compared to jhum. With increasing fallow duration of jhum, soil loss and run-off reduce. In terms of nutrient losses, terracing also does not seem a viable option
Central Himalayan forests[15,70]	Six forest sites (329–2119 m alt.), 5–25° slope. Three run-off plots of 25 m^2 at each site. Overland flow and shower size were measured for 544 storms in rainy season (annual r.f. = 915–1364 mm)	0.38–1.6	0.015 (mixed oak pine forest)–0.057 (sal forest) t/ha	Nutrient loss through run-off and sediment is separately given. N (run-off) 0.04–0.13; N (sediment) 0.02–0.14 kg/ha/yr. Most of the nutrients move through sub-surface flow system
Cherrapunji, Northeast Himalaya[39]	Burned and unburned grasslands. 35–45° slope. Run-off collected from five 2 m × 20 m plots. r.f. = 10380 mm yr^{-1}	68–86	*	NO_3-N loss was 12.5–42.8 and PO_4-P 1.7–2.2 kg/ha. Water percolation 12.6% of r.f. Grassland types vary with nutrient losses through run-off and frequency of burn
Three Central Himalayan forests[20]	Oak/pine forests (alt. 1600–1980 m). Three run-off plots (25 m^2 each) at each forest. Data collected for monsoon season. Total r.f. =1966 mm	0.48–0.53	*	Partitioning of rainfall by these forests (which varied with leaf properties and structure) was marginally different
Mamlay WS, Sikkim Himalaya[22]	Site details given in ref. 23. Three run-off plots (3 m × 2 m) in different land use	4.27 (natural vegetation)–6.86 (barren land)	0.012 (natural forest)–0.17 (barren land) t/ha	N loss = 0.012 (natural forest)–0.192 (barren land) kg/ha. OC loss 0.035 (natural forest)–0.030 (barren land) kg/ha
Sirsa Nadi and Boli Yamuna WS, Shiwaliks, Haryana[71]	Annual r.f. ~ 1250 mm. 64 m × 45 m and 64 m × 27 m plots planted with forest spp. in V-ditch/scattered trench/pits, with and without vegetative barrier	2.32 (V-ditch)–16.32 (control) across both WS	3.92 (V-ditch)–28.85 (control)	V-ditch method for plantation is better with regard to SWC
Shiwaliks, Haryana[72]	Site details as above. 77 m × 45 m plots in above WS. Plantation of grass at different spacing	7.8 (vetiver + bhabbar grass)–17.5 (control)	9.6 (vetiver + bhabbar grass)–35.8 (control)	Combination of vetiver and bhabbar grass is most effective in SWC
CSWRTI, exp. farm, Dehra Dun[36]	R.f. = 1334 mm, maize–wheat cropping sequence. Pigeon pea raised as hedgerow and maintained by cutting	24–37	5.3–12.3 $t\ ha^{-1}$	Minimum run-off and soil loss was recorded for 50 cm cutting height of pigeon pea and incorporation of non-woody plant material in the plot prior to maize sowing recorded maximum soil loss and run-off
CSWRTI, exp. farm, Dehra Dun[35]	R.f. = 1483 mm, 20 m × 10 m run-off plot. Data taken for five cropping systems. Run-off and soil loss measured daily (1986–89)	1.3 (green manure–rice–wheat)–16.2 (fallow–wheat)	0 (green manure–rice–wheat)–3.2 (fallow–wheat) $t\ ha^{-1}$	Sunhemp (*Crotolaria juncea*) effectively reduces soil loss and run-off up to 100% (besides improving soil fertility) over control
Pranmati WS, Garhwal Himalaya[37]	Settled upland farming. Run-off plots 2.5 m × 2.5 m on average slope of cropland. Soil loss values are based on 1588 mm r.f. (from June to September)	10.9	Mean = 0.57, 4.34 and 36.97 $t\ ha^{-1}$ for low (< 2°), medium (2–6°) and high (6–10°) slope	Traditional crops (amaranth, buckwheat) were found superior over potato with regard to SWC
Pinder catchment, Kumaun Himalaya[21]	Three high-altitude forests. Annual r.f. 2400 mm. Alt. 2500 m. Three run-off plots of 25 m^2 at each forest. Observations on 14 rain events (229 mm r.f.) in August	0.01 (silver fir)–0.31 (kharsu oak forest)	0.009 (silver fir)–0.046 (horse chestnut forest) $t\ ha^{-1}$	Tree physiognomy-related hydrological responses have been emphasized. Silver-fir forest has been considered best for SWC

*, Data not collected. A number of studies in the IHR devoted to canopy/forest floor interception[16,29]; infiltration[27,73]; stem flow nutrients[30] have not been included.
Alt, Altitude (m asl); r. f., Rainfall; WS, Watershed, OC, Organic carbon.

Degraded grasslands

The only published study[39] on this land use from Cherrapunji reported run-off (69%) and percolation (12.6%) of the total rainfall. The loss of nutrients and related soil fertility status through run-off and percolation were dependent upon the frequency and intensity of burning of grasslands and consequent development of biomass. In a Central Himalayan grazing land, run-off accounted for 18.8% of rainfall (194.5 mm, received in 60 rain showers during rainy season), which was found greater than pine forest (16.2%) and bushland (14.9%)[40]. Rainfall intensity and run-off were found positively correlated for all the three land uses ($P < 0.01$). Bushland was found conducive with regard to SWC, over other land uses.

Slash and burn agriculture (jhum cultivation)

This land use has been most abusing the fragile mountains with regard to soil loss and run-off. In Meghalaya, a jhum cycle of ten years when compared with 5-year jhum cycle and terraced agriculture indicated that the loss of sediment, water and nutrients is greater under the latter[41]. Soil loss was found to range between 34 and 56 t/ha/yr for terraced cropping and 5-year jhum cycle. All losses were markedly reduced during fallow development (secondary succession). The shortening of jhum cycle, however, does not seem to have any effect on water percolation[42]. Terrace cultivation resulted in reduction of water and nutrient loss in the first year; but these losses increased during the second year. It was concluded that while jhum cannot be sustained with the shorter cycle, terracing does not seem to offer an alternative. Therefore, a long-term strategy for a shift in land use practice to plantation and horticultural crops was suggested.

Meso-scale studies

An appreciable number of hydrological studies have been conducted on micro-watersheds and watersheds (WS) in the IHR. However, Central Himalaya has been studied the most, compared to Western and Eastern Himalaya (Table 2.) At CSWRTI, Dehra Dun, experiments conducted on the effect of land use and land cover change on water yield and sediment transport from WS found that water yield declined by 28% after five years of treatment from scrubland to *Eucalyptus* spp. plantation compared to control[43–45]. When a cultivated catchment (applying soil conservation measures) was compared with forested control, 76% reduction in stormflow after 14 years in the cultivated catchment was recorded[46,47]. A paired catchment approach and treating a mini-watershed (sal-dominated) to 20% thinning could not detect any change in water yield after two years[48]. In the first five years, the 47% reduction on peakflow confirmed the impact of soil conservation measures on stormflow. Reviewing several studies in the subtropical region, Bruijnzeel[49] stated that with respect to the influence of forests on water yield (total streamflow), it is beyond doubt that both natural and man-made forests (mature) use more water that most agricultural crops or grasslands.

Studies on natural WS (i.e. without any alteration in land use/cover) are many (Table 2). The most revealing study in Lesser Himalaya and Shiwalik watersheds[50,51] emphasized that increased magnitude of soil loss and run-off was due to anthropogenic pressure, deforestation, road-cutting, etc. They found that the difference in the volume of water flowing down the rivers during dry and rainy seasons is commonly more than 1000 times, resulting in the too-little-and-too-much-water syndrome. Analysing streamflow data for 31 years (1950–81) it was revealed that during this period the discharge decreased by 77.4%, due to reduction in rainfall, utilization of upstream water for irrigation and other public demands. The soil denudation rate was found to be 1.7 mm yr^{-1}. Following the above study a number of university departments took up similar work in the Central Himalayan region. Studies[52,53] reported 33.8% streamflow (of the annual rainfall) for a WS with agricultural land use and 62.3% for a WS with oak pine forest in Kumaun Himalaya. The mean soil loss was estimated to be about 2 t/ha/yr. They concluded that deforestation and agricultural activities have reduced the water yield by 50% in this WS. In an adjacent Khulgad WS (Kumaun Himalaya), which has about 61% area under agriculture and 39% area covered by pine (*P. roxburghii*) and oak forests, sediment loss ranged from 0.4 to 5.0 t/ha/yr (average denudation rate = 0.07 mm/yr) for oak forest and tectonically disturbed land, and the streamflow varied from 9.7 to 36.2% (ref. 54). Similarly, in a paired WS dominated by oak and pine forests in Central Himalaya, where geology, geomorphology, soil and climate were identical, the annual water yield of oak WS was about 3.5 times more than the pine WS[18]. The annual discharge in pine and oak WS was 14 and 50% of the annual rainfall, respectively. The recession of peak flow was rapid in pine WS compared to oak WS. It was concluded that oak WS discharges more and constantly without much fluctuation in baseflow, except during the rainy season. In a similar study[17] around these sites, more than 60% discharge of total precipitation in oak forests was recorded.

In two micro-WS of Garhwal Himalaya (one with 10% area under pine forests and large wasteland and another with 50% area under oak forests and smaller wasteland) streamflow (of the annual rainfall) was recorded 41.5 and 18.1%, and the mean suspended sediment loss was 9.13 and 4.69 t/ha/yr, respectively[25]. Run-off peak was observed in August for the former WS, which was delayed by about one month in the latter WS. The rainfall, run-off and sediment loss were found to be positively related ($P < 0.05$).

Bater micro-watershed in Sirsa catchment, HP (Western Himalaya), which has only about 8% area under agri-

Table 2. Meso-scale (watershed level) hydrological studies in the Indian Himalayan mountains*

Study site	Major land use	WS area (km^2)	Alt. range (m)	Slope (degree)	Annual rainfall (mm)	Stream flow of annual rainfall (%)	Sediment transport ($t\ km^{-2}\ yr^{-1}$)	Reference
Western Himalaya								
Palampur, HP	Ag/Mix	0.26	1300	1–10	3000	33.2–65.0	362–2250	74
Giri river catchment, Shiwalik hills, HP	Mix	2600	440–3600	50–60	1675	23.2	957	56
Bater micro-WS, HP	Mix	0.14	500–560	12%	1465	30.4	3596	55
Central Himalaya								
Fakot, Garhwal Himalaya	For/Ag	3.7	650–2015	–	1900	42	110	46
Two micro-WS, Garhwal Himalaya	Ag/Wl	3.0	1200–1650	15–25	1689–2365	18.1–41.5	469–913	25
Gaula catchment, Kumaun Himalaya	For/Ag	597.2	500–2610	–	2090	76	3702.9	50
Nana Kosi, Kumaun Himalaya	Ag/Gl	55	1200–1900	–	804	28.8	200	52, 53
Khulgad, Kumaun Himalaya	Ag/For	32	1150–2190	–	841	–	185.8	54
Haigad, Kumaun Himalaya	For/Ag	9.5	1160–2338	–	1951	22.9	–	26
Binsar, Kumaun Himalaya (paired WS)	For	0.39–0.43	1650–2300	48–52	≈ 1175	14–50	–	18
Eastern Himalaya								
Mamlay WS, Sikkim Himalaya	For/Ag/Hor	30.1	300–2650	40	1222–1482	4.6	616.3	23, 24
Meghalaya	Mix	0.09–3.89	100–1000	30–53	1600–2552	1.12–1.39	67–246	75

Ag, Agriculture; Mix, Mixed; For, Forest; Hor, Horticulture; Wl, Wasteland.
*Five studies by CSWRTI, Dehra Dun devoted to experimental WS involving alteration in land use/cover have been cited in the text.
–, Data not available.

culture, and the remaining open scrubs, recorded 24.3% run-off (of the total 1206.4 mm rainfall in 1994) and sediment loss 12.7 t/ha/yr (ref. 55). In the following year, rainfall (total = 1723.5 mm) increased both run-off (36.6%) and soil loss (59.3 t/ha/yr). The threshold rainfall to produce run-off was found to be 7 mm and the average rate of soil denudation was 2.4 mm/yr. Daily rainfall discharge and sediment yield data of Giri river (a tributary of Yamuna river system) for twelve years (1981–92), analysed by Chaudhary and Sharma[56] found the mean run-off efficiency of the catchment to be 32.2% and the suspended sediment load 9.6 t/ha/yr (ranging between 1.9 and 17.4 t/ha for various years). They emphasized upon large-scale deforestation and grazing in the catchment areas as important anthropogenic factors contributing to burgeoning problem of soil erosion.

In Mamlay WS, a tributary of Tista river (Eastern Himalaya), among five micro-watersheds of different land uses, run-off and sediment loss (by implication nutrient loss also) were highest for cropped WS and lowest for forested WS[23,24]. Soil loss for different micro-watersheds was found to range from 0.18 to 5.71 t/ha/yr; for the whole WS it ranged from 4.2 to 8.8 t/ha/yr during different years. It was suggested that the upland micro-watersheds are hydrologically sustainable if good forest cover and dense forests with agroforestry are maintained.

Discussion: The need for more studies

Looking at the micro-scale hydrological studies conducted so far in different land use practices across the IHR, we find that only forests have been studied in some detail (Table 1). Studies on other important land uses such as agriculture, grassland, grazingland and jhum cultivation, and manipulating land use/cover are limited. Most of these studies have observed run-off and soil loss only for rainy season. Pre-monsoon and winter showers, which may produce sizeable run-off[40], have not been studied. Further, the run-off-plot size, replication of observations, season of study, and other micro-scale characteristics, particularly soil structure and geology[57], that are considered in each of these studies are different from each other. These discrepancies have resulted into data scattered over a wide range. For example, run-off (% of rainfall) value for croplands ranges from 1.3 to 37% and that in grasslands from 5 to 86% (Table 1). Similarly, soil loss values for cropland (0.3–37 t/ha/yr) and jhum–fallow cycle (1.9–565.3 t/ha/yr) present a wide range. With respect to both run-off (0.01–2.17%) and soil loss (0.009–0.057 t/ha), values reported for forests fall in a narrow range. This limited data set reveals that grasslands lose more water, jhum cultivation loses both water and soil of greater magnitude, and forested land use loses smaller quantities of soil and water through run-off. Agricultural land use presents an intermediate situation between these land uses.

Meso-scale studies in the IHR have considered 17 micro-watershed/WSs, out of which 12 studies were conducted in the middle montane belt of the Central Himalayan region, where anthropogenic influence on natural resources is intense[34]. Meso-scale studies have encompassed a wide range of catchment area (0.14-2600 km^2), altitude (300–3600 m asl), average slope of the catchment (12–60°) and annual rainfall (804–2552 mm). In general, both streamflow (range 1.12–76%) and sediment transport (0.002–36.9 t/km^2/yr) are not indicative of any trend in relation to WS characteristics. However, two observations were discernible: (i) Rate of soil erosion is greater in Shiwaliks compared to other physiographic regions of Himalaya, and (ii) both streamflow and sediment transport were found unrelated to WS area and annual rainfall (rainfall vs. streamflow, $r = 0.07$; WS area vs soil loss, $r = 0.09$; WS area vs streamflow, $r = 0.04$). Greater magnitude of soil loss in the Shiwaliks has been linked to immature geology and high degree of weathering of rocks[50].

An evaluation of the role of land use in determining streamflow and sedimentation patterns at the micro-and meso-scales is much more difficult. The micro-scale studies (involving small run-off-plots) may have covered only the ideal conditions of the land use, whereas in the meso-scale studies a variety of land use types, basin geomorphology and more importantly spatial and temporal distribution of rainfall would have played a dominant role on streamflow generation and sedimentation processes. For example, if one considers the area of different land uses in any of these micro-watersheds and then extrapolates the run-off and soil loss produced under the run-off-plot studies, the WS does not behave corresponding to the land use effect, which reveals that stream bed acts both as a source and sink for the sediment eroded from the hill slopes, as has been reported elsewhere[58]. Therefore, the telling effects of land use remains confined up to the run-off-plot level and in no way suggests using the results to estimate soil loss on a meso-scale.

In general, micro-scale and meso-scale studies undertaken in the IHR so far, indicate that although some micro-watersheds and land uses (e.g. forests) have been studied intensively, these studies do not provide much insight into the hydrologic processes. For example, the run-off recorded does not contain information on whether it is saturation excess (Dunne type)[59] or infiltration excess (Horton type)[60]. Effect of rainfall intensity and duration on these hydrological parameters has also not been studied, which alone seems to be a controlling factor of run-off and soil loss[55]. Similarly, a few studies have separated suspended, dissolved and rolling loads. Others have measured only suspended sediment. Studies[52] indicate that dissolved load could be as much as two-fold higher than the suspended load (85.6 vs 48.6 t/km^2/yr in Nana Kosi WS, Kumaun Himalaya). Studies on Et losses to incident rainfall are also much required. Further, all these studies were initiated by university departments, where facilities for work and proper instrumentation and manpower is always a constraint[52]. However, these studies have contributed markedly to the hitherto less investigated, yet crucial aspects of the mountain ecosystem. Some of them[44,47,48] have applied value if extended to the mountain conditions, as has been emphasized in the Mohank mountain conference[61].

The limited number of studies available in this region, have on the one hand, documented the commonly perceived problem of soil loss and quick-flow of rainwater from the mountain slopes, blaming anthropogenic pressure and deforestation; and have provided simplistic and generalized recommendations such as plantation of broadleaf species, ban on grazing, deforestation and other human activities to curb the problem of soil and water erosion[62,63] on the other. In many of these studies, it was seen that agricultural land use is most undesirable with regard to SWC[52,64,65]. Some studies involving smaller run-off-plots and a few rain showers have extrapolated the results over larger areas or to even an entire region. Looking at these data treatments, Bandopadhyay and Gyawali[2] commented that with its non-uniform rainfall, exceptional climatic and vegetation diversity, soil structure and geology, and hydrological behaviour dominated by the confluence of hundreds of streams and rivers, generalization would be a gigantic reductionist's folly. The natural processes in the Himalaya are so predominant that human intervention need not be considered as the cause of siltation[66]. For example, silt loads in a Kumaun river, Sarju were found to be 215 t/day (near human habitation) and those in Panar (far away from anthropogenic influence) were 8078 t/day (ref. 67), which explains the effect of natural factors. It can be stated that hydrological research in this region is still at its infancy and is inadequate to be used for SWC programmes[68]. It can be emphasized that hydrological investigations on major land use practices in the IHR are required, considering physiographic conditions, altitude, slope, soil, geological setting, rock type, rainfall and cropping practices, employing uniform methodology and instrumentation. Naturally, most of this work will need to be of an interdisciplinary nature, and should take full advantage of locally available environmental knowledge[69].

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