Environmental Conservation **28** (2): 95–98 © 2001 Foundation for Environmental Conservation

COMMENT

The need for micro-scale and meso-scale hydrological research in the Himalayan mountains

Mountains are fragile ecosystems and globally important as water towers of the earth. Sustainable use of mountains depends upon conservation and optimal use of soil and water resources (Ives & Messerli 1989). Despite regional and global efforts to understand the hydrology of the Himalayan region, soil and water conservation (SWC) programmes in this region mainly rely upon engineering measures. For want of cost-effective vegetative (bioengineering) measures (Deoja *et al.* 1991), and land use and land cover conducive to SWC, the fragile Himalayan watersheds continue to lose soil and water at alarming rates.

Studies on the hydrology of the Himalayan mountains (e.g. Bruijnzeel & Bremmer 1989; Alford 1992; Bandopadhyay & Gyawali 1994) have made it clear that the hydrological research conducted in this region so far is inadequate to support the commonly-held notion that deforestation and other anthropogenic activities by the mountain inhabitants cause floods in the adjacent plains. Despite its appeal to logic and conventional wisdom, this view has been challenged (Carson 1985; Hamilton 1987) on the grounds that the effects of mountain inhabitants must be insignificant in comparison to the substantial geophysical processes involved. This controversy is largely a matter of scale and historical perspective (Ives *et al.* 1987). The assertion that upland reforestation will control downstream floods does not hold for the Himalayan situation (Ives & Messerli 1989). Bruijnzeel and Bremmer (1989) pointed out that first it is necessary to define the scale to which such statements apply.

A scale problem arises in hydrology because different factors and processes are dominant at different scales. These include the large number of variables and physical laws that govern the phenomena, the spatial distribution of such properties as soil hydraulic conductivity and soil moisture condition, and the stochastic nature of such variables as storm intensity and other attributes (Lacey & Grayson 1998). This heterogeneity can have a significant impact on runoff generation at the catchment scale (Sharma *et al.* 1980). For example, hill slope runoff 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 (Gupta & Dawdy 1995). Therefore process descriptions that have been derived at the experimental plot do not necessarily hold true at the catchment scale (Bloschl *et al.* 1997). This comment reviews the state of micro-scale and meso-scale hydrological research in the Himalayan mountains with a special objective of assessing how such studies could contribute to the SWC efforts in this region.

Micro-scale (plot-level) studies in the Himalayan mountains

Hydrological studies on Himalayan forests involving runoff plots (e.g. Singh *et al.* 1983; Singh & Gupta 1989; Negi *et al.* 1998), agriculture (Sen *et al.* 1997), grassland (Ram & Ramakrishnan 1988) and slash-and-burn (*jhum*) agriculture (Toky & Ramakrishnan 1981) have observed runoff and soil loss mainly in the rainy season. Pre-monsoon and winter showers, which may produce sizeable runoff, have been ignored. Further, the runoff-plot size (2×2 m to 77×45 m), replication of observations, season of study, and other micro-scale characteristics differ among studies (e.g. Rai & Sharma 1998). Due attention has not been given to effects of geology and soil structure on hydrological responses. These discrepancies have resulted in runoff and soil loss data scattered over a wide range. For example, runoff for croplands ranges from 1.3–37% of rainfall and that in grassland from 5–86%. Similarly, soil loss from cropland (0.3–37 t ha^{-1} yr^{-1}) and *jhum* fallow land (1.9–565.3 t ha^{-1} yr^{-1}) present a wide range compared to runoff (0.01–2.17% of rainfall) and soil loss (0.009–0.057 t ha^{-1}) reported for forests during the rainy season. This limited data set reveals that grasslands lose more water; jhum cultivation loses both water and soil in greater magnitude, and forested land loses smaller quantities of soil and water through runoff. In

https://doi.org/10.1017/S0376892901000091 Published online by Cambridge University Press

summary, with this limited number of studies, it is difficult to establish the SWC value of any of these land uses.

Meso-scale (watershed-level) studies

Meso-scale studies in the region have encompassed a wide range of watershed areas (0.14–2600 km^2), altitudes (300–3600 m above sea level), average catchment slopes (12–60°), annual rainfall levels (804–2552 mm) and topographies. Most of the studied watersheds experience substantial anthropogenic influence on natural resources (e.g. Rawat & Rawat 1994; Joshi & Negi 1996; Chaudhary & Sharma 1999). In general, both streamflow (range 1.1–76% of annual rainfall; Valdiya & Bartarya 1989; Singh 1997) and sediment transport (0.67–37 t ha^{-1} yr^{-1}) are not indicative of any trend in relation to watershed characteristics. Both streamflow and sediment transport were found unrelated with watershed area ($r = 0.04$ and $r = 0.09$, respectively) and slope and annual rainfall were not significantly related ($r = 0.07$). Rate of soil erosion was found greater in the Shiwaliks (the youngest outer Himalayan mountains; Valdiya & Bartarya 1989; Rana & Subehia 1996) compared to other physiographic regions of the Himalaya (e.g. Sastry *et al.* 1983; Rawat & Rai 1997). Greater magnitude of soil loss in the Shiwaliks has been linked to immature and weak geology (Valdiya & Bartarya 1989). Studies on experimental watershed alteration of land use and forest cover either could not detect any change in water yield (Subba Rao *et al.* 1985) or recorded reduced water yield (e.g. Mathur *et al.* 1976).

Conclusion

Micro-scale and meso-scale studies reveal that although some micro-watersheds and land uses (e.g. forests) have been studied, these studies do not provide much insight into the hydrologic processes. For example, the runoff recorded does not contain information, whether it is saturation excess (Dunne type) or infiltration excess (Horton type). Effects of rainfall intensity on runoff, soil loss, infiltration and other hydrological parameters (e.g. evapotranspiration) are poorly understood. A few studies have separated suspended, dissolved and rolling load. Others have measured total sediment transport. These aspects need further research. University departments under constraints of facilities, instrumentation and manpower initiated studies that held human population pressure, including deforestation and traditional agricultural practices, responsible for soil loss and quick-flow (e.g. Rawat & Rawat 1994), and provided simplistic and generalized recommendations for management of plantations, grazing, tree cutting and other human activities to check soil and water erosion (e.g. Berry 1988). Some studies involving small runoff-plots and few rain showers have extrapolated results over larger areas or even entire regions.

An evaluation of the role of land use in determining streamflow and sedimentation patterns at the micro- and meso-scales is difficult. The micro-scale studies (involving small runoff-plots) may have covered only the idle conditions of land use, whereas in the meso-scale studies a variety of land use types, basin geomorphologies and rainfall distributions would have played a dominant role in streamflow generation and sedimentation processes (Haigh 1982). Therefore, the telling effects of the land use remain confined to the runoff-plot level and in no way suggest extrapolation to a meso-scale. Hydrological research in this region is still in its infancy and inadequate to be used for SWC programmes. Hydrological investigations on major land use practices in the Himalayan mountains are required, considering physiographic conditions, altitude, slope, soil, geological setting, rock type, rainfall and cropping practices, employing a uniform methodology and instrumentation. Such research should be conducted in a number of carefully-selected well-instrumented catchment areas over many years; this would enable statistically-sound techniques to be used for the evaluation of the hydrological effects of changes in land use or management.

References

Alford, D. (1992) Hydrological aspects of the Himalayan region. International Center for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal, Occasional Paper 18, 68 pp.

Bandopadhyay, J. & Gyawali, D. (1994) Himalayan water resources: ecological and political aspects of management. *Mountain Research & Development* **14**(1): 1-24.

Berry, A. (1988) Perspective plan of watershed management of Himalayan region. *Indian Forester* **114**(7): 349-361.

Bloschl, G., Sivapalan, S., Gupta, V., Beven, K. & Littenmaier, D. (1997) Preface to the special section on scale problems in hydrology. *Water Resources Research* **33**(12): 2881.

Bruijnzeel, L.A. & Bremmer, C.N. (1989) Highland-lowland interactions in the Ganges Brahmaputra river basin: review of published literature. ICIMOD, Kathmandu, Nepal, Occasional Paper 11, 136 pp.

Carson, B. (1985) Erosion and sedimentation processes in the Nepalese Himalaya. ICIMOD, Kathmandu, Nepal, Occasional Paper 1.

Chaudhary, R.S. & Sharma, P.D. (1999) Runoff and sediment yield from Giri river catchment in Himachal Pradesh. *Indian Journal of Soil Conservation* **27**(1): 1–9.

Deoja, B., Dhital, B., Thapa, A. & Wanger, A. (1991) *Mountain Risk Engineering Handbook*, *Part I*. Kathmandu, Nepal: ICIMOD: 537 pp.

Gupta, V.K. & Dawdy, D.R. (1995) Physical interpretations of regional variations in the scaling exponents of flood quintiles. *Hydrological Processes* **9**: 347–361.

Haigh, M. (1982) A comparison of sediment accumulations beneath forested and deforested microcatchments, Garhwal Himalaya. *Himalayan Research & Development* **1**(2): 118–120.

Hamilton, L.S. (1987) What are the impacts of Himalayan deforestation on the Ganges–Brahmaputra lowlands and delta? Assumptions and facts. *Mountain Research & Development* **7**: 256–263.

Ives, J.D. & Messerli, B. (1989) *The Himalayan Dilemma: Reconciling Development and Conservation.* London and New York: Routledge: 287 pp.

Ives, J.D., Messerli, B. & Thompson, M. (1987) Research strategy for the Himalayan region. Conference conclusions and overview. *Mountain Research & Development* **7**: 332–344.

Joshi, V. & Negi, G.C.S. (1996) Hydrometeorological studies in two land use practices of Garhwal Himalaya. In: *Studies in Indian Agroecosystems*, eds. P.S. Pathak & B. Gopal, pp. 15–21. New Delhi, India: National Institute of Ecology.

Lacey, G.C. & Grayson, R.B. (1998) Relating baseflow to catchment properties in south-eastern Australia. *Journal of Hydrology* **204**: 231–250.

Mathur, J.N., Ram Babu, Joshie, P. & Singh, B. (1976) Effect of clearfelling and reforestation on runoff and peak rates in small watersheds. *Indian Forester* **102**: 219–226.

Negi, G.C.S., Rikhari, H.C. & Garkoti, S.C. (1998) The hydrology of three high-altitude forests in Central Himalaya, India. A reconnaissance study. *Hydrological Processes* **12**: 343–350.

Rai, S.C. & Sharma, E. (1998) Comparative assessment of runoff characteristics under different land use pattern within a Himalayan watershed. *Hydrological Processes* **12**: 2235–2248.

Ram, S.C. & Ramakrishnan, P.S. (1988) Hydrology and soil fertility of degraded grasslands at Cherrapunji in northeastern India. *Environmental Conservation* **15**(1): 29–35.

Rana, R.S. & Subehia, S.K. (1996) Rainfall-runoff-soil loss relationships for Sirsa catchment in submontane zone of Himachal pradesh. *Indian Journal of Soil Conservation* **24**: 169–171.

Rawat, M.S. & Rawat, J.S. (1994) Accelerated erosion in the Nana Kosi watershed, Central Himalaya, India. Part I: Sediment load. *Mountain Research & Development* **14**(1): 25–38.

Rawat, J.S. & Rai, S.P. (1997) Pattern and intensity of erosion in the environmentally stressed Khulgad watershed, Kumaun Himalaya. *Journal of Geological Society of India* **50**: 331–338.

Sastry, G., Ram Babu & Puri, D.N. (1983) Studies on hydrological behavior of small watersheds under different landuses. In: *Annual Report 1983*, pp. 23–24. Dehra Dun, India: CSWCRTI.

Sen, K.K., Rao, K.S. & Saxena, K.G. (1997) Soil erosion due to settled upland farming in the Himalaya: a case study in Pranmati watershed. *International Journal of Sustainable Development & World Ecology* **4**: 65–74.

Sharma, M.L., Gander, G.A. & Hunt, C.G. (1980) Spatial variability of infiltration in a watershed. *Journal of Hydrology* **45**: 101–122.

Singh, A. (1997) Emerging concept on integrated research and development for watershed management. In: *Proceedings of International Symposium on Emerging Trends in Hydrology*, pp. 385–391. Roorkee, India: Roorkee University.

Singh, J.S., Pandey, A.N. & Pathak, P.C. (1983) A hypothesis to account for the major pathway of soil loss from Himalaya. *Environmental Conservation* **10**: 343–345.

Singh, R.P. & Gupta, M.K. (1989) Infiltration studies under different forestry management systems in Western Himalayas. *Indian Forester* **10**: 706–713.

Subba Rao, B.K., Ramola, B.C. & Sharda, V.N. (1985) Hydrologic response of a forested mountain watershed to thinning: a case study. *Indian Forester* **111**: 418–431.

Toky, O.P. & Ramakrishnan, P.S. (1981) Runoff and infiltration losses related to shifting agriculture (jhum) in north-eastern India. *Environmental Conservation* **8**: 313–321.

Valdiya, K.S. & Bartarya, S.K. (1989) Problem of mass movements in a part of Kumaun Himalaya. *Current Science* **58**(9): 486–491.

G.C.S. NEGI
Land and Water Resource Management Division
GB Pant Institute of Himalayan Environment and Development
Garhwal Unit, Post Box 92, Srinagar (Garhwal) 246 174, Uttaranchal, India
Tel: +91 01388 52603
Fax: +91 01388 52424
e-mail: gbpgu@nde.vsnl.net.in