IITR Project No. MOW-281-WRC
R&D Project

IDENTIFICATION OF VULNERABLE AREAS IN HIMALAYAN WATERSHEDS

Sponsored by

Indian National Committee for Hydrology (INCOH)
National Institute of Hydrology, Roorkee
(Ministry of Water Resources, Government of India)

Department of Water Resources Development and Management
Indian Institute of Technology Roorkee
Roorkee (Uttaranchal) 247 667, India

INTRODUCTION

Our country experiences soil erosion of the order of 5334 million tones (1653 tones / ha) every year due to agriculture and other associated human activities. Of this, about 2052 million tones (626 tones / ha) are carried by rivers, nearly 1572 million tones taken into the sea, and 480 million tones deposited in various multipurpose reservoirs, resulting in the loss of 1 to 2 % of the storage capacity. Thus, it adversely affects the availability of water for power generation, irrigation, domestic & industrial use. Since the process of soil erosion from the earth surface largely depends on topography, vegetation, soil, and climatic variables, it is a serious problem in lower Himalayas and foothill ecosystems. To circumvent, watershed management programs are taken up and these require an inventory of the quantitative soil loss erosion and the priority classification of watershed. Sediment yield from a catchment is the main criteria for assessing the vulnerability of a watershed to soil erosion. Since the measurement of sediment yield in a watershed at a fine grid scale is a cumbersome task, the geographic information systems (GIS) and remote sensing techniques are widely used for the assessment of sediment yield through rainfall-runoff-sediment yield models. In this study, Universal Soil Loss Equation (USLE) coupled with GIS is employed for soil loss estimation and, in turn, for identification of vulnerable areas in the Chaukhutia sub-watershed of Ramganga catchment.

METHODOLOGY

The methodology includes determination of soil erosion by USLE and then its transportation to the outlet using transport limited capacity. Use of USLE equation (E = RKLSCP, where E = computed soil loss per unit area in tons/ha/ yr), R = rainfall erosivity factor in MJ-mm/ha-hr, K= soil erodibility factor in tones-ha-hr/ha-MJ mm, L= slope length factor, S= slope steepness factor, C= cover and management factor, P= support practice factor) produces the estimates of gross soil erosion in each of the discretized grids of the catchment (Fig. 1). The eroded sediment from each grid (Fig. 1) follows a defined drainage path (as in Fig. 2 for a particular cell) to the catchment outlet. The rate of sediment transport from each of the discretized cell depends on the sediment transport capacity (T_C) of the flowing water. The sediment outflow from an area is equal to soil erosion in the cell plus contribution from upstream cells if transport capacity exceeds the sum. However, if T_C is less than this amount, the sediment excess of transport capacity gets deposited and sediment load equal to T_C is discharged to next downstream cell, as shown schematically in Fig.3. For the most part, the approach encompasses two computational steps: determination of mean annual sediment transport capacity and transport limited accumulation.

- **Mean annual sediment transport capacity (T_C):** The rate of sediment transport is governed by T_C (= K_{TC} R K $A^{(1/4)}$ $S^{(1/4)}$; where T_C is transport capacity (kg/m^2/yr), K_{TC} is the transport capacity coefficient depends on land use and reflects vegetation component within the transport capacity, A is the upslope contributing area per unit of contour length, and S is the slope gradient).
- **Transport Limited Accumulation (TLA):** The sediment is routed along the runoff pattern towards the river as shown in Figs. 1 & 2, taking into account the local T_C of each pixel. If the local T_C is smaller than the sediment flux, sediment deposition is modeled. This approach assumes that sediment transport is not necessarily restricted to a transport limited system. If T_C is higher than the sediment flux, sediment transport supply will be limited. Thus, by introducing K_{TC}, the overland sediment transport is simulated more realistically. The predicted sediment delivery is interpreted as the sediment delivery for the complete length of the river in the catchment.

General procedure of the proposed methodology can be described as follows:

i. Calculate rainfall erosivity factor R using meteorological data.
ii. Generate Digital Elevation Model (DEM), slope, flow accumulation, flow direction, and drainage network maps for the study area.
iii. Generate topographic factor LS Map
iv. Generate land use map of the study area using digital analysis of satellite data.

v. Generate soil map and its characteristic database from satellite data in GIS environment using ERDAS.
vi. Generate soil erodibility factor K, topographic factor LS, cover management factor C, and support practice factor P maps.
vii. Generate sediment transport capacity map.
viii. Generate maps for transport limited soil accumulation by routing sediment outflow from each discretized cell using GIS.
ix. Finally, generate soil erosion/deposition maps for identification of vulnerable areas.

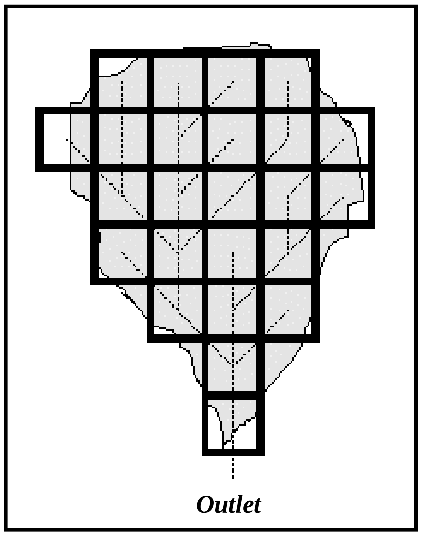


Fig. 1: Schematic showing discretized grid cells in a catchment

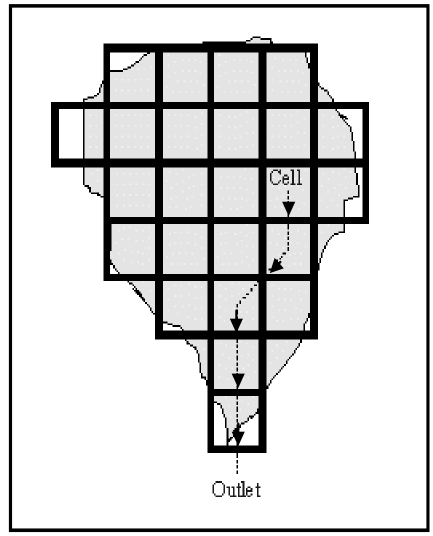


Fig. 2: Schematic showing a flow path

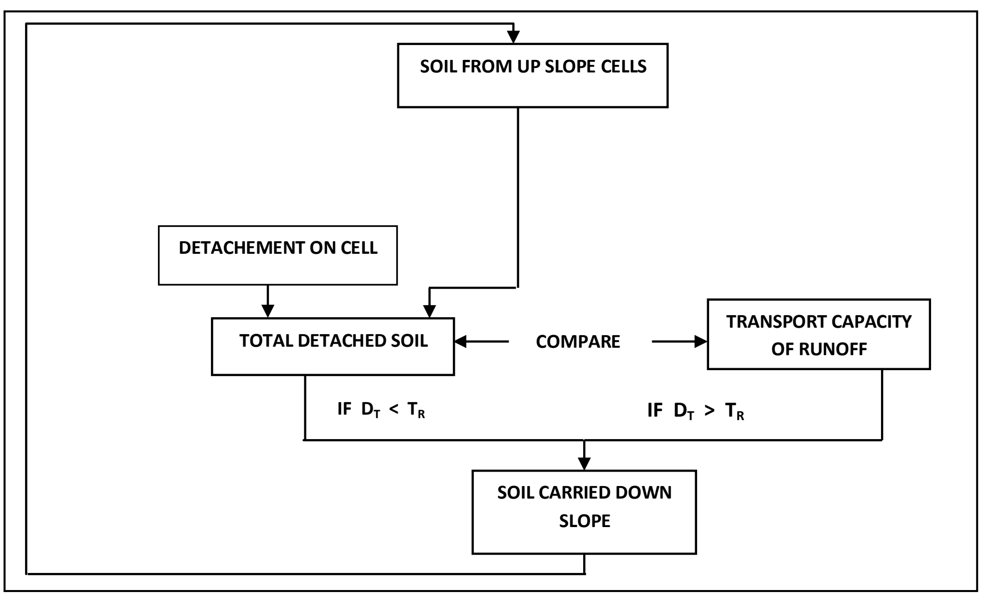


Fig. 3: Concepts of mathematical modelling of the process of soil erosion by flow of water

STUDY WATERSHED

The Chaukhutia watershed is the uppermost part of Ramganga catchment. Ramganga catchment is located in the foothills of Himalayas in the Uttarakhand state of India. The river Ramganga originates at Diwali Khel of Chamoli district. It is a major tributary of river Ganga and emerges out of the hills at Kalagarh (District Almora). The outlet of Chaukhutia watershed is located in Chaukhutia block headquarter under Ranikhet sub-division of Almora district. It is forest dominated, and geographically, it is bounded between latitudes of 29^0 46' 35" N to 30^0 06' 11" N and longitudes of 79^0 11' 23'' E to 79^0 31' 21" E. The drainage area above the gauging station at Chaukhutia, which is more or less rectangular shaped, covers an area of 452.25 km^2. The elevation of the watershed varies from 929 m to 3114 m above mean sea level. The climate of this watershed varies from sub-tropical in the lower region to sub-temperate and temperate in upper region with a mean annual temperature of 24.5^0C and a mean minimum temperature of 17.3^0C. The significant portion of total precipitation in the form of rainfall in the watershed occurs mainly during the four months of the monsoon, i.e. from June to September with a mean annual total precipitation of 1357.8 mm. In the watershed, the main soil type is clayey loam falling under hydrologic soil groups B & C and the landuse is forest dominated. Figs. 4 & 5 show the DEM and drainage network maps of the Chaukhutia watershed.

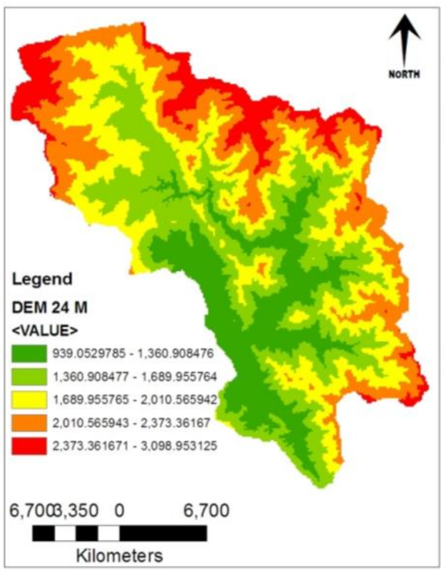


Fig. 4: DEM of Chaukhutia watershed

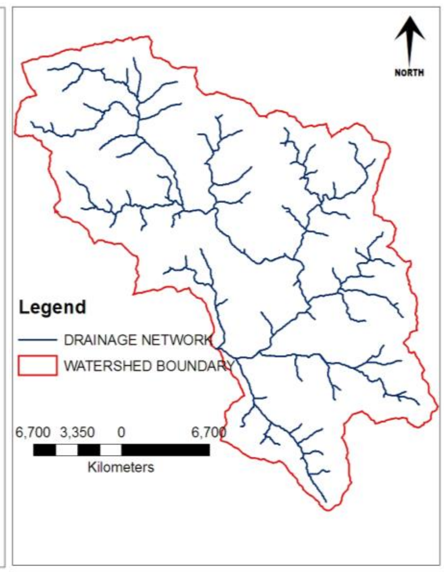
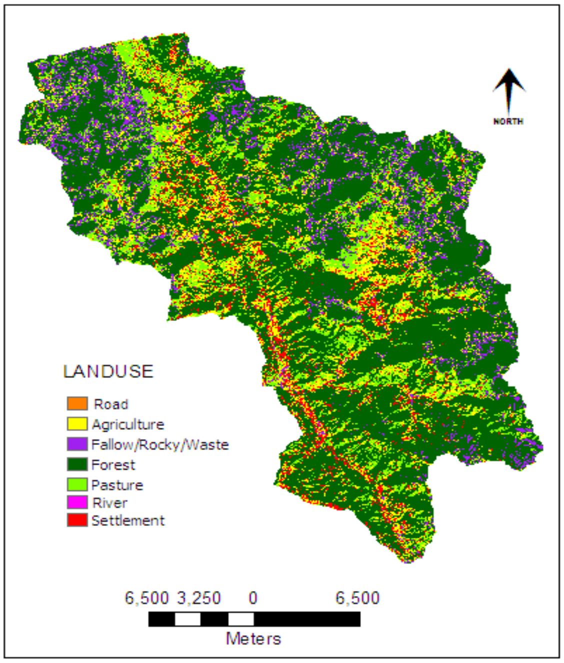


Fig. 5: Drainage network of Chaukhutia watershed

LAND USE AND SOIL MAPS

Satellite data of IRS LISS III sensor were geo-referenced and then, landuse/land cover map were prepared using ERDAS imagine and ArcGIS 9.1 software employing unsupervised classification. In this classification, data are clustered for given input numbers. These clusters are then reclassified into desired number of classes using merging operation. The Chaukhutia sub-catchment has been classified into seven major land use / land cover classes after merging different clusters as shown in Fig. 6. The soil map of the study area was digitized (Figure 7) using GIS Software 9.0 version from the scanned copy of the soil map available from National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Govt. of India. The digitized polygon map was then rasterized at 24 m grid cells using GIS Arc Toolbox.



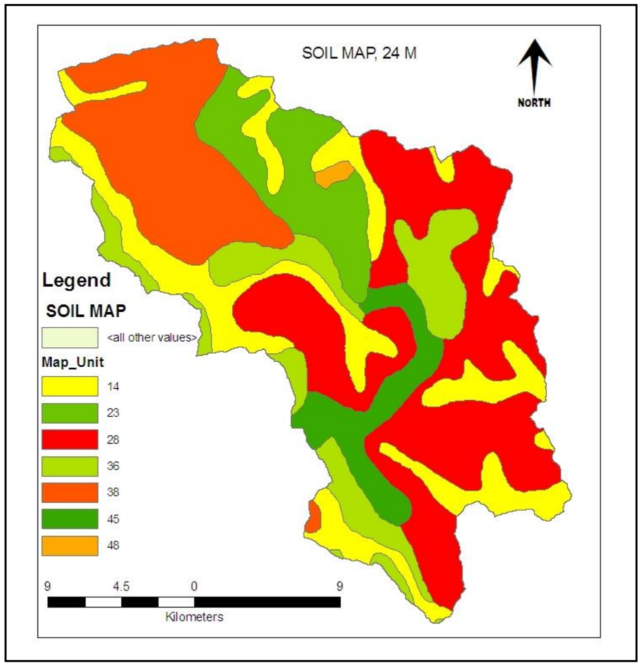


Fig. 6: Classified landuse map of Chaukhutia watershed

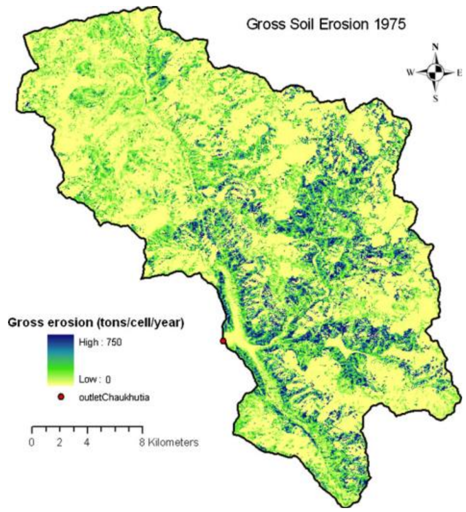
Fig.7: Soil map of Chaukhutia watershed

Estimation of soil erosion

Maps depicting gross amount of soil erosion from different discretized cells of the Chaukhutia catchment were computed by multiplication of the erosion potential map produced by integration of KLSCP maps with corresponding annual values of rainfall erosivity factor R. Fig. 8 depicts the gross soil erosion for the year 1975 as illustration. Such maps indicate the gross amount of soil erosion from each cell in a year.

Computation of Transport Limited Sediment Accumulation and Outflow

The gross erosion from each grid was routed downstream to generate map of the accumulated sediment yield limited by transport capacity and depicted in Fig. 9. Such maps provide the amount of sediment transported from the system at every grid and are useful for determination of sediment flowing out of the catchment at any location. The pixel value of the sediment outflow map denotes the amount of sediment leaving the current cell to the next downstream cell. The pixel value of the cell at the catchment outlet denotes the sediment coming out of the watershed.



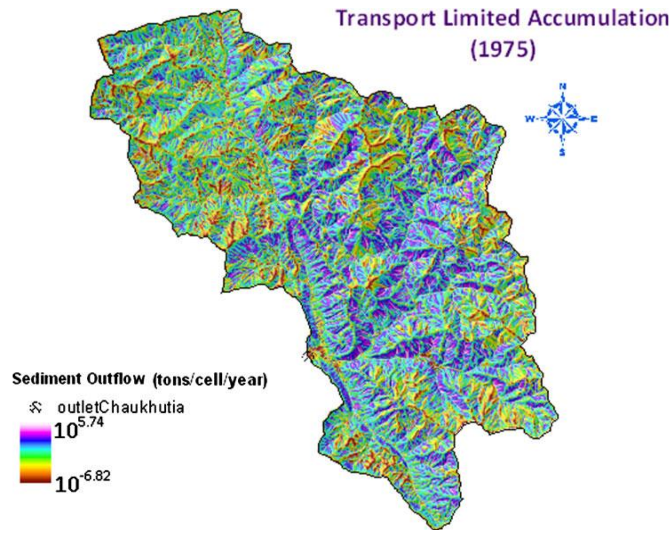


Fig. 8: Gross soil erosion map for the year 1975 **Fig. 9:** Transport limited sediment outflow for year 1975

Vulnerable Areas

Net erosion maps for different years were calculated by subtracting the deposition rates for each grid cell from the gross erosion rates for each grid cell. Negative values on the net erosion map are the areas where sediment deposition occurs (i.e. true sediment deposition), whereas positive values correspond to grid cells with net sediment erosion. High values of erosion/deposition in Fig. 10 represents the areas vulnerable to sediment erosion/deposition, respectively. As seen, deposition of sediment resulted at the grids where transport capacity was low, mostly by the sides of some of the stream reaches in valleys and flatter land areas found in the cultivated valley lands in the catchment. Such maps are extremely important in planning conservation measures, for the areas producing more sediment receive priority for their implementation.

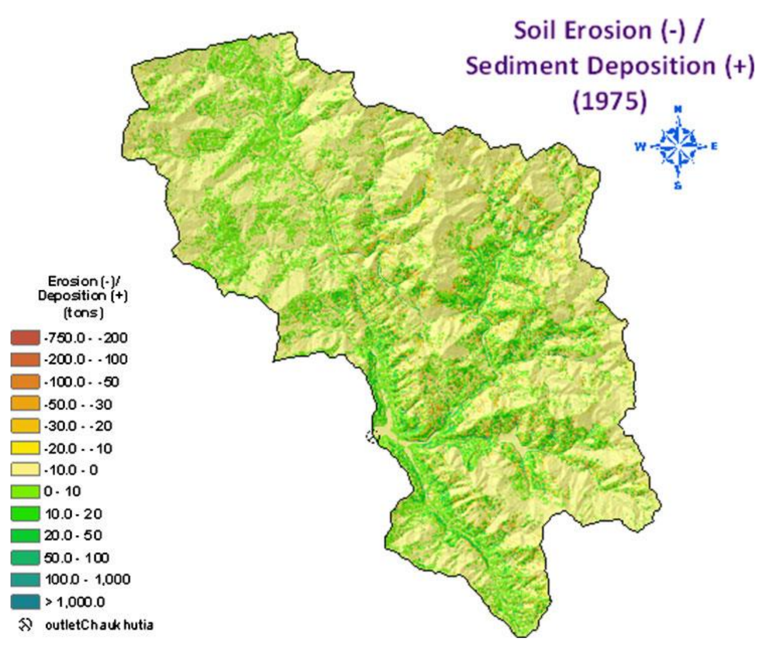


Fig. 10: Vulnerable areas in Chaukhutia watershed regarding soil erosion/sediment deposition for year 1975.

"Save Land and Water, both are Precious"

Project Team

Dr. Surendra Kumar Mishra Associate Professor Dept. of Water Resources Development and Management IIT Roorkee, Roorkee-247667 (UK)	Principal Investigator
Dr. Manoj Kumar Jain Assistant Professor Dept. of Hydrology IIT Roorkee, Roorkee-247667 (UK)	Co-Principal Investigator
Dr. Pushpendra Kumar Singh Dept. of Water Resources Development and Management IIT Roorkee, Roorkee-247667 (UK)	Research Associate
Mr. Sanjay Kumar Gupta Dept. of Hydrology IIT Roorkee, Roorkee-247667 (UK)	Senior Research Assistant
Mr. Soban Singh Rawat Dept. of Water Resources Development and Management IIT Roorkee, Roorkee-247667 (UK)	Research Scholar
Ms. Vibha Agarwal Dept. of Water Resources Development and Management IIT Roorkee, Roorkee-247667 (UK)	Project Staff