

Regional Scale Soil Erosion Modeling for Onservation Planning Using Remote Sensing and GIS Techniques - A Case Study in The Centre of Himalayan Ranges

ANH Luu The, Vietnam

Key words: NSCS, soil erosion modeling, Thornes, Chamoli

SUMMARY

This article presents the study result of soil erosion estimation in the Centre of Himalayan Ranges using Regional Scale Erosion Model of Thornes (1985, 1989). This study explores the practicability of Regional Scale Erosion Model as a demonstration to geographical term of the steep hill area of Himalaya. However, the extent of the problem is hard to quantify as field measurements of erosion are rare, time consuming and are usually only acquired over restricted temporal and spatial scales. The soil erosion model parameters were generated from temporal MODIS NDVI, daily precipitation data (Climatic Prediction Centre), soil map of Uttarakhand state at a scale of 1:500,000 prepared and published by NBSS&LUP, SRTM DEM (90m resolution). The results of modeling study show that, slope and vegetation cover is the most sensitive parameter; soil erodibility is the least sensitive parameter. Overland flow is a relatively sensitive variable and certainly the one it is hardest to estimate. Soil erosion rate per rain day of 35 days in monsoon season (15 days of July, 10 days of August and 10 days of September 2006, respectively) were computed. The study results show that, average soil erosion rate per rain day equals 1.26 tons/ha in the rain period of 35 days. The maximum, minimum and mean of soil erosion rate in 35 rain days are 2379 tons/ha, 0.004 tons/ha and 44 tons/ha, respectively. It is also recommended that the vegetation cover should be maintained in order to avoid soil erosion. However in areas where cultivation is inevitable, then strict soil conservation measures should be taken for minimizing soil erosion hazard.

TÓM TẮT

Bài báo trình bày kết quả tính toán xói mòn đất ở vùng trung tâm dãy Himalaya bằng Mô hình xói mòn đất của Thornes (1985, 1989). Nghiên cứu này nhằm thử nghiệm Mô hình xói mòn đất quy mô vùng lãnh thổ trong điều kiện địa hình núi cao và dốc của dãy Himalaya. Tuy nhiên, vấn đề khó khăn gặp phải trong quy mô nghiên cứu rộng là thiếu những số liệu quan trắc trực tiếp trên thực địa lượng đất xói mòn theo không gian và thời gian và nếu có thực hiện được thì cũng rất mất thời gian. Các thông số đầu vào cho mô hình như chỉ số NDVI được triết tách từ tư liệu ảnh MODIS, số liệu mưa của Trung tâm Dự báo Khí tượng, bản đồ đất của bang Uttarakhand tỷ lệ 1:500.000, DEM SRTM độ phân giải 90 mét. Kết quả nghiên cứu cho thấy, lớp phủ thực vật là một thông số nhạy cảm và dễ bị thay đổi nhất; chỉ số xói mòn của đất ít bị biến động nhất; dòng chảy tràn bề mặt của nước mưa cũng khó tính toán. Lượng đất xói mòn trung bình ngày của 35 ngày trong mùa mưa là 1,26 tấn/ha (tháng 7: 15 ngày, tháng 8: 10 ngày và tháng 9: 10 ngày). Tổng lượng đất xói mòn trung bình lớn nhất của 35 ngày mưa là 2379 tấn/ha; trung bình nhỏ nhất là 0,004 tấn/ha và trung bình là 44 tấn/ha. Từ kết quả nghiên cứu cho thấy, cần duy trì và bảo vệ lớp phủ thực vật và áp dụng biện pháp chống xói mòn trên đất dốc trong canh tác nông nghiệp để hạn chế tối đa lượng đất xói mòn.

TS 6F – Mapping, Aerial Survey and Remote Sensing I

1/15

ANH Luu The, Vietnam

Regional Scale Soil Erosion Modeling for Onservation Planning Using Remote Sensing and GIS Techniques - A Case Study in The Centre of Himalayan Ranges

7th FIG Regional Conference

Spatial Data Serving People: Land Governance and the Environment – Building the Capacity
Hanoi, Vietnam, 19-22 October 2009

Regional Scale Soil Erosion Modeling for Onservation Planning Using Remote Sensing and GIS Techniques - A Case Study in The Centre of Himalayan Ranges

ANH Luu The, Vietnam

1. INTRODUCTION

Soil erosion is a global urgent phenomenon because of its severe adverse economic and environmental impacts. It is major threats for sustainable land management, and its serious effects on agricultural productivity, ecological and environmental quality. Soil erosion is a natural process but some land management practices have the potential to greatly increase the rate at which this occurs. The actual amount of erosion that occurs will depend on the different factors such as rainfall erosivity, vegetation cover, soil erodibility and topography. As a consequence, there is a need for modeling and quantitative estimation of erosion processes on these landscapes for both on-site and off-site assessment of its impact. In the last 60 years, much models have been built (empirical, conceptual or physically based) such as former models of USLE (Wischmeier and Smith, 1958, 1978), RUSLE (Renard et al. 1997), latter models of WEPP (Flanagan et al., 2001), EUROSEM (Morgan et al., 1998) in order to represent and to quantify the process of detachment transport and deposition of eroded soil with the aim of implementing assessment tools for either scientific or planning purposes. These models have been developed only for fine study scale (field or catchment scale) along with assistance of remote sensing and GIS techniques in combination with low data demanding model makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger scales. They may not be directly applied to regional scale. It is really difficult to model soil erosion at regional scale because the loss of spatial heterogeneity associated with a reduction in spatial scale provides a substantial obstacle to large scale modeling. It is important to consider ways of reproducing such small scale heterogeneity from large scale measurement (Zhang et al., 2001). However, the results of such models provide useful information for decision maker and planners to take appropriate land management measures. Although simulation models working at regional scale may be less accurate than soil erosion predictions at plot or field scale. This study explores potential application of Regional Scale Erosion Model of Thornes (1985, 1989) based on the integration of Remotely sensed data and GIS for the central region of Himalayan ranges.

2. METHODOLOGY AND DATA USED

In this study, Regional Scale Model of Soil Erosion (Thornes 1985, 1989) was used to compute annual soil loss rate. The equation as bellow:

$$E = k * OF^2 * s^{1.67} * e^{-0.07*v} \quad (1)$$

Where:

E is erosion (mm/day or mm/month depending on the time step of the model);

TS 6F – Mapping, Aerial Survey and Remote Sensing I

2/15

ANH Luu The, Vietnam

Regional Scale Soil Erosion Modeling for Onservation Planning Using Remote Sensing and GIS Techniques - A Case Study in The Centre of Himalayan Ranges

7th FIG Regional Conference

Spatial Data Serving People: Land Governance and the Environment – Building the Capacity

Hanoi, Vietnam, 19-22 October 2009

k is a soil erodibility coefficient calculated from soil grain size;

OF is overland flow (mm per time step) derived from sub-models of varying complexity;

s is the slope (m/m); and

v is the vegetation cover (%).

2.1. Soil data and soil erodibility factor

Soil erodibility (k) is controlled primarily by soil texture and organic matter content and to a lesser extent by structure and permeability. The coefficient k is computed from map of soil properties. There is no detailed soil map of the study area, so the soil map of Uttar Pradesh at scale of 1:500,000 prepared and published by National Bureau of Soil Survey and Land Use Planning, India in 1999 was obtained for the study purpose. Soil mapping units were updated and revised based on the study of additional 10 soil profiles. The soil samples of different layer were collected from these soil profiles for analyzing physical and chemical properties.

2.2. Slope factor map

There are numerous global DEMs available at different scales (e.g., 10 minute, 5 minute and 30 arc seconds) from which slope can generated using GIS technology. The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of the Earth. Slope factor map of the study area was generated from SRTM DEM 90m.

2.3. Vegetation cover factor

Numerous authors have found a relationship between either total of green vegetation cover and Normalized Different Vegetation Index (NDVI). The result from some formal studies shows it is clear that there is a strong relationship between v and NDVI (Drake et al., 1995 and Zhang, 1999). Malthus et al., (1993) and Blackburn and Milton (1995) produced the highest correlations. However, this relationship varies, with field measurements using radiometers and spectroradiometers providing higher NDVI values than those obtained from ground measurements correlated to AVHRR imagery. This due to atmospheric effects that affect the satellite based measurements but not the spectroradiometer data. Because there is no atmospheric correction was applied to the AVHRR imagery. The vegetation cover index (v) can be converted from NDVI of AVHRR data using the following regression equation:

$$v = 93.07466 * NDVI + 8.79815 \quad (2)$$

Equation (2) is applied to AVHRR NDVI. But in this study, the author use MODIS/Terra vegetation indices 16 days with spatial resolution of 250m for vegetation cover index calculation. So that, the relationship between MODIS and AVHRR NDVI values was found down. This relationship was evaluated with a linear regression model:

$$NDVI_M = \beta_0 + \beta_1(NDVI_A) + \varepsilon \quad (3)$$

Where:

NDVI_M is the MODIS NDVI; NDVI_A is the AVHRR NDVI;

β_0 is the intercept;

β_1 is the slope, and

ε is the random error.

Regression analyses included (a) samples of individual land cover types and (b) all samples with all land cover types combined to facilitate overall comparisons between the individual sensors. If the compared data sets were identical, i.e., the NDVI values of the MODIS and AVHRR sensors were equal for all samples, the value of the slope would equal 1.0, the intercept would equal 0.0, and the coefficient of determination (r^2) value would equal 1.0.

Amount of 40 random samples of land use/ land cover types were studied to extract MODIS and AVHRR NDVI values for their relationship estimation.

2.4. Overland flow

The Natural Resources Conservation Service (NSCS) runoff curve number model (US Dept. of Agriculture, 1972) has been selected as it requires few parameters and is both realistic and robust. This is based on some empirical formula and basic inputs like CN, slope information, land cover and hydrological soil group (HSG), etc. In this model, they have developed relationship between the rainfall and overland flow. Curve number is the watershed coefficient, which is an index that represents the combination of HSG and land cover (Chow et al., 1988; Mishra et al., 2006). The main criticism of the CN method was that the amount of simulation overland flow was not sensitive to rainfall intensity (Terzoudi et al., 2007).

The empirical NSCS runoff curve number model was developed by studying overland flow in many small experimental watersheds. In the NRCS runoff equation, the ratio of amount of actual retention to watershed storage is assumed to be equal to the ratio of actual direct overland flow to the effective storm rainfall (total rainfall minus initial abstraction). The assumed relationship in mathematical form is (USDA, 1972):

$$\frac{F}{S} = \frac{OF}{P - I} \quad (4)$$

Where:

F is actual retention (mm);

S is initial abstraction and maximum losses after overland flow begins (mm);

OF is the overland flow in a rainfall event or actual direct runoff (mm);

P is total rainfall (mm); and I initial abstraction (mm).

Overland flow (OF) to be computed using the following equation:

$$OF = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (P > 0.2S) \quad (5)$$

Since overland flow (OF) will occur when P exceeds 0.2S value (P being the rainfall per rain day or month), the following is applied when this occurs. The parameter S in equation (5) is related to CN by US Soil Conservation Services Model (Murth, 2004):

$$S = \frac{25400}{CN} - 254 \text{ (mm)} \quad (6)$$

CN is the runoff curve number. The CN is a dimensionless runoff index determined based on HSG, land use, land treatment, hydrologic conditions and antecedent moisture condition (AMC). The CN method is able to reflect the effect of changes in land use on runoff. The CN values range between 1 and 100. Higher values of CN indicate higher runoff. The NRCS runoff equation is widely used in estimating direct runoff because of its simplicity, flexibility and versatility.

AMC is an indicator of wetness and availability of soil storage prior to a storm. Moisture content at the time of rainfall plays a very important role for determining OF and the moisture conditions are expressed as AMC I for dry (wilting point), AMC II for normal (average moisture condition); and AMC III for wet (field capacity) conditions). In NSCS model, slope correction was done using the Slope Corrected Empirical Formula as below:

$$CN_{2s} = 1/3 (CN_3 - CN_2)[1 - 2\exp(-13.86S)] + CN_2 \quad (7)$$

Where:

CN_{2s} is the moisture condition II curve number adjusted slope;

CN_3 is the moisture condition III curve number for the default 5% slope;

CN_2 is the moisture condition II curve number of the default 5% slope; and

S is the average slope (in percent)

$$\text{- For AMC I:} \quad CN_{1s} = \frac{(4.2 * CN_2)}{(10 - 0.058 * CN_2)} \quad (8)$$

$$\text{- For AMC II:} \quad CN_2 = \frac{25400}{254 + S} \quad (9)$$

$$\text{- For AMC III:} \quad CN_{3s} = \frac{23 * CN_{2s}}{(10 + 0.13 * CN_{2s})} \quad (10)$$

In this study, daily overland flow to be computed for AMC III using daily rainfall data of CPC (Climatic Prediction Centre) in three months of July, August and September 2006. So equation (10) was considered and applied to the study area.

Soils have been classified into four HSGs (A, B, C and D) considering their hydrologic properties according to their minimum infiltration rate, which is obtained for a bare soil after prolonged. Soils in group A have lowest runoff potential; this group includes deep sands with very little silt and clay and deep, rapidly permeable loam with high infiltration rates; these

soils have a rapid rate of water transmission (greater than 8mm/hr). Soils in group B have moderately low runoff potential; this group includes sandy and loam soils less deep or with less aggregate than group A having moderate infiltration rate when thoroughly wetted; these soils have a rapid to moderate rate of water transmission (4 - 8mm/hr). Soils in group C have moderately high runoff potential; this group consists of moderately deep to deep, moderately well to well - drained soil with moderately fine to moderately coarse textures; these soils contain considerable clay and colloids, though less than those of group D and have low infiltration rates when thoroughly wetted and have a moderate rate of water transmission (1 - 4mm/hr). Soils in group D soils have the highest runoff potential; this group consists of chiefly clay soils with high swelling potentials having very low infiltration rates when thoroughly wetted; soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious materials fall under this group; these soils in this group have very low infiltration rate (less than 1mm/hr).

CN is an index that represents the combination of HSG and land cover (Chow et al., 1998 and Mishra et al., 2006). HSG depends upon soil texture, soil depth, drainage, permeability and water table depth. In this study, HSG is derived by using geomorphology, soil texture and depth of the study area. Standard HSG according to soil texture (Chow et al., 1988).

Geomorphology, soil texture and soil depth of the area has been crossed with each other and according to which HSG is assigned for the study area. After assigned the HSG to soil texture, merged with land cover map to prepare hydrological soil cover complex and assigned the CN.

3. GENERAL DESCRIPTION OF THE STUDY AREA

The study was conducted in Chamoli district which is located in the Centre of Himalayan ranges with total area of 796 sq. km; stretching from 29° 45' N to 31° 00' N latitude and from 79° 00' E to 80° 15' E longitude. The northern part is occupied by higher ranges and snow covered peaks consist entirely of medium to high grade metamorphic rocks. The southern part consists of sedimentary and low grade metamorphic rock. The elevation of district ranges from 629m to 7243m. Topographically, the direction of folding in these mountain masses is generally North to South and is finely separated with steep slope to very steep slope

The climate of the study area very largely depends on altitude. The winter season is from about mid November to March. The rainfall is being heaviest in the monsoon from June to September. Most of the rainfall occurs during the period June to September when 70 to 80% of the annual precipitation is accounted for in the southern half of the district and 55 to 65% in the northern half.

Soil resources of the study area has 29 soil units according to Soil Taxonomy Classification System; in which the unit of coarse loam soils is dominant with area of 103,383.36 ha (13%); followed by sandy skeletal soils 94,634.44 ha (11.88%) and glaciers 95,808.96 ha (12.03%).

The study area is predominantly under snow cover (43.89%) followed by rock outcrop (13.83%), dense forest (12.64%), open forest (12.06%), and crop land (10.5%), respectively.

Due to limited conditions of sloping topography, terraced field is dominant agricultural cultivation in the study area. This practice method is most suitable for the mountainous area to protect soil from water erosion. The main cropping season is rainy period, when there is enough rain to grow paddy. During winter season, water scarcity is a problem and climate is also not favorable for growing crops. The study area is criss-crossed by several important rivers and their tributaries. Alaknanda Devprayag and constituting the Ganga, which is the major river. The system of rivers of Chamoli district generally flow with great force in steep and narrow channels often resulting in excessive erosion and collapse of the banks.

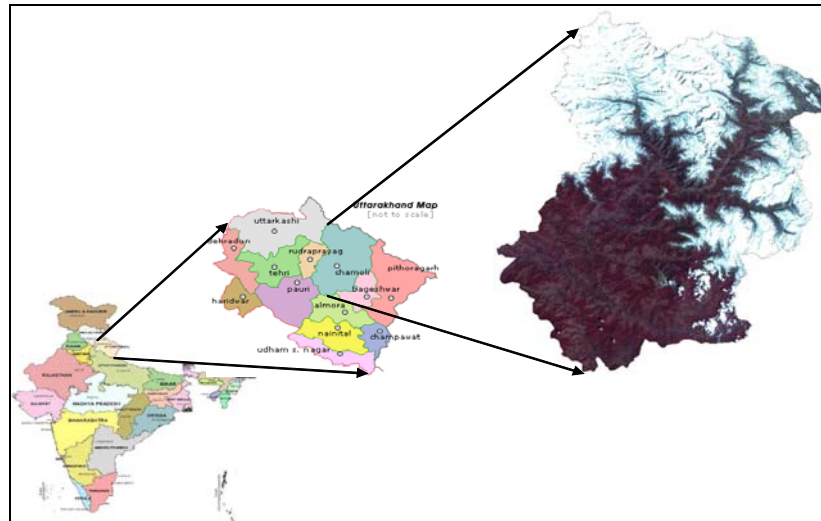


Fig. 1: Location map of the study area

4. RESULTS AND DISCUSSIONS

After correcting gaps in SRTM DEM 90m, slope map was generated from the revised DEM. Slope map was then divided into 9 priority classes from near level to very highly steep slope class. The results show in the study area, highly steep slope class is dominant with its area of 220,108.49 ha (27.6%) followed by very highly steep slope class with area of 151,036.42 ha (19%) and steep slope class with area of 128,135.58 ha (16%), respectively.

The result of physical and chemical properties analysis of soil samples was used for soil erodibility factor (K) mapping. The study consulted also the table of Mitchel and Bubenzer (1980) to convert maps of texture and organic matter data into spatially distributed K values. The estimated results show the value of soil erodibility ranges in value from 0.12 to 0.48 in the study area (Fig. 2).

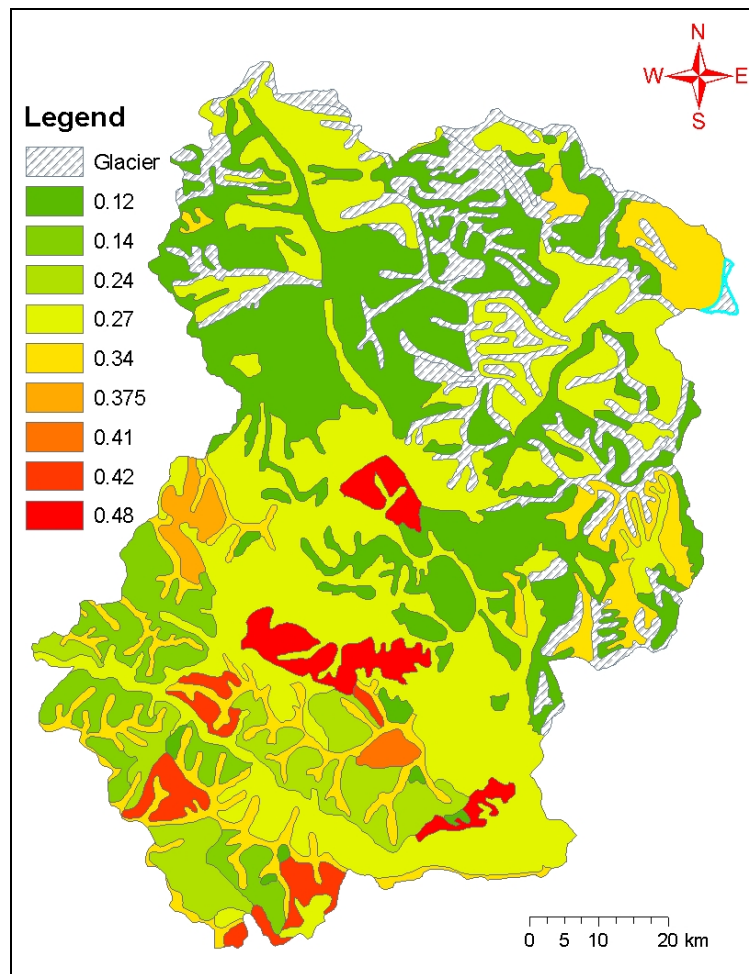


Fig. 2: Soil erodibility (K) map of the study area

Linear relationship between MODIS and AVHRR NDVI was established from 40 random points with coefficient regression of $R^2 = 0.6177$. It is clear that MODIS NDVI values are always higher than AVHRR NDVI. This differential value of NDVI can be explained by the disproportion of spatial resolution between two satellite images of MODIS (250m) and AVHRR (8000m). After determining the linear relationship equations, the model parameter of vegetation cover (v) was converted from MODIS NDVI using equation (2). Monthly vegetation cover index for July, August and September 2006 ranges from - 1.61% to 97.99%; from - 3.73% to 100% and from - 3.9% to 100% respectively.

Based on the HSG, soil units in the study area were grouped into two HSGs of C and D, in which the maximum area of Chamoli district was observed to be under hydrological soil group C (47.06%) followed by (41.06 %) group D. By intersecting the land use/ land cover and soil map, the CN was assigned to the each combination of land use and soil type. Relationship between land use/ land cover classes/ HSG and runoff CN for AMC II given in following table (Tab. 1).

Tab. 1: Relationship between land cover/ hydrological soil group combinations and runoff curve numbers (for AMC II) of the study area

No.	Land use/ land cover class	HSG C	HSG D
1	Dense forest	70	77
2	Open forest	73	79
3	Scrubland	77	83
4	Terraced agriculture	78	81
5	Fallow cultivated land	91	94
6	Settlement	90	92
7	Rock outcrop	91	94
8	River	100	100
9	Snow cover	91	94

In order to estimate overland flow, slope map was used along with equation (8), (9) and (10) to adjust runoff CN value. Runoff CN adjusted slope maps shows the adjusted value of CN ranges from 49.49 to 100, from 70 to 100 and from 84.4 to 100 for AMC I, AMC II and AMC III conditions respectively. In this study, CN₃ for AMC III (wet condition) was used for overland flow estimation.

As for the precipitation data of Climatic Prediction Centre, all of daily rain maps for monsoon season 2006 have rainfall satisfying the condition ($P > 0.2S$) for equation (7) were used for overland flow and soil erosion rate estimation. That mean since overland flow (OF) will occur when P exceeds $0.2S$ value, the following is applied when this occurs. There are total 35 rain days (July: 15 days, August: 10 days and September: 10 days respectively) meet the demand of this condition. These days have highest intensive rainfall in rainy season with total maximum rainfall of 1851mm. The study results show overland flow only will form when average daily rainfall is over 14 mm.

Amount of 35 rain days were divided into three levels: high (> 100 mm/day); medium (50 - 100 mm/day) and low rainfall (14 - 50 mm/day) for estimation of overland flow and soil erosion rate. The daily overland flow map of the study area was computed using equation (7) for the estimation of daily soil erosion rate. The calculated overland flow was found out to be 47% in average, 97% in maximum and 18% in minimum of the total rainfall for 35 rain days of the year 2006.

After estimating all model parameters of soil erodibility, slope factor, vegetation cover and overland flow, soil erosion rate for every 35 rain days were computed along with Regional scale erosion model of Thornes (equation 1). The computed results were presented in Tab. 2.

For three days with high intensity rainfall of 127mm/day (on 15, 22 and 23 September 2006) the maximum, minimum and mean erosion rate are 924.078 tons/ha, 0.001 tons/ha and 5.514 tons/ha respectively.

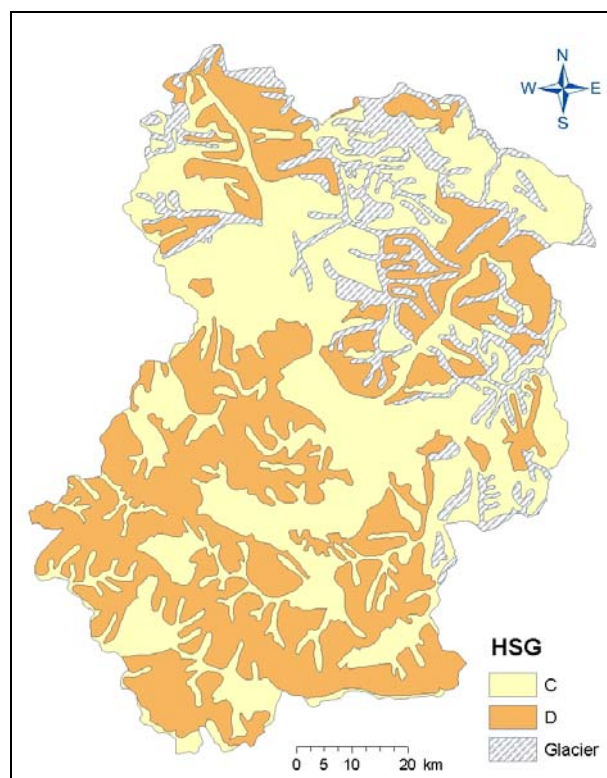


Fig. 3: HSG map of Chamoli district

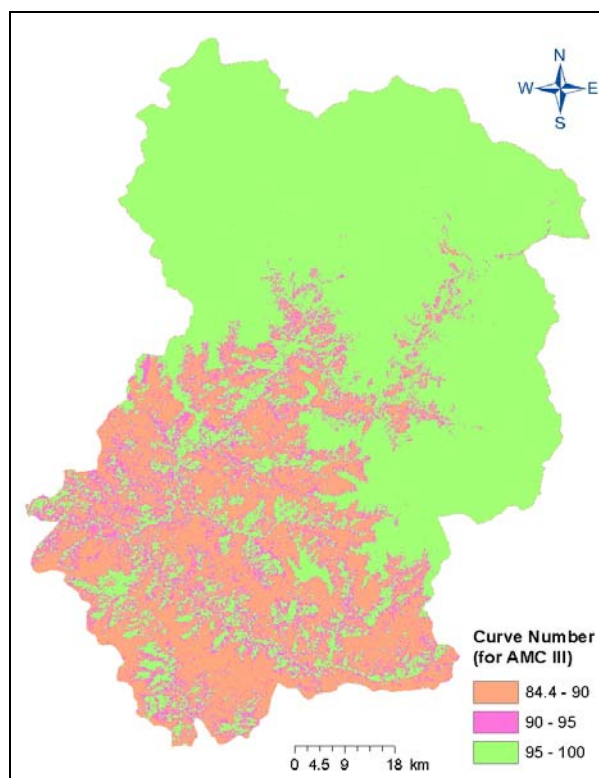


Fig. 4: CN adjusted slope map of Chamoli district (for AMC III)

For ten days with medium rainfall from 50 to 100mm/day the maximum, minimum and mean erosion rate are 1404.42 tons/ha, 0.0029 tons/ha and 28.956 tons/ha respectively.

For twenty two days with low rainfall from 14 to 50mm/day the maximum, minimum and mean erosion rate are 50.699 tons/ha, 0.0001 tons/ha and 9.54 tons/ha respectively.

Tab. 2: Max, min and mean soil erosion rate for different rainfall level presents in the study area

Duration	Rain days	Total rainfall (mm)	Rainfall (mm/rain day)		Soil erosion rate (tons/ha)		
			Classes	Values	Max	Min	Mean
Jul. to Sept. of 2006	3	381	High	> 100	924.078	0.0010	5.514
	10	741	Medium	50 - 100	1,404.420	0.0029	28.956
	22	729	Low	< 50	50.699	0.0001	9.540
Total	35	1851			2,379.197	0.0040	44.010

Total erosion rate of 35 days was divided in to six priority erosion classes from very low to very high given in Tab. 3, in which the classes under dominant area are very high erosion rate (15.22%) followed by high erosion (7.62%), low erosion (4.81%).

Tab. 3: Spatial distribution of priority soil erosion classes for 35 rain days presents in the study area

No.	Priority soil erosion classes	Area (ha)	Percent (%)
1	Very low	29,520.00	3.71
2	Low	38,317.12	4.81
3	Medium	30,693.12	3.85
4	Moderately high	54,218.56	6.81
5	High	60,728.61	7.62
6	Very high	121,236.48	15.22
7	Snow cover	349,593.70	43.89
8	Rock outcrop	110,172.61	13.83
9	River	2,080.80	0.26
Total		796,561.00	100.00

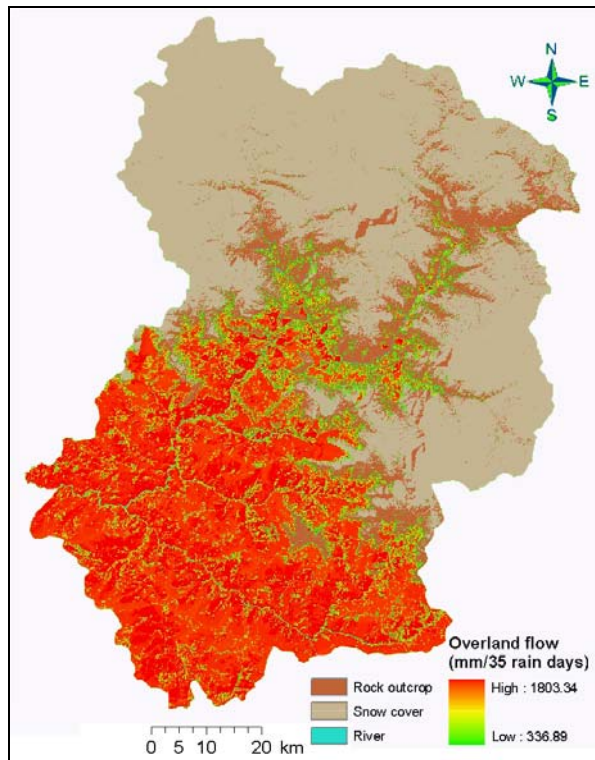


Fig. 5: Overland flow map for 35 days with total rainfall of 1851 mm

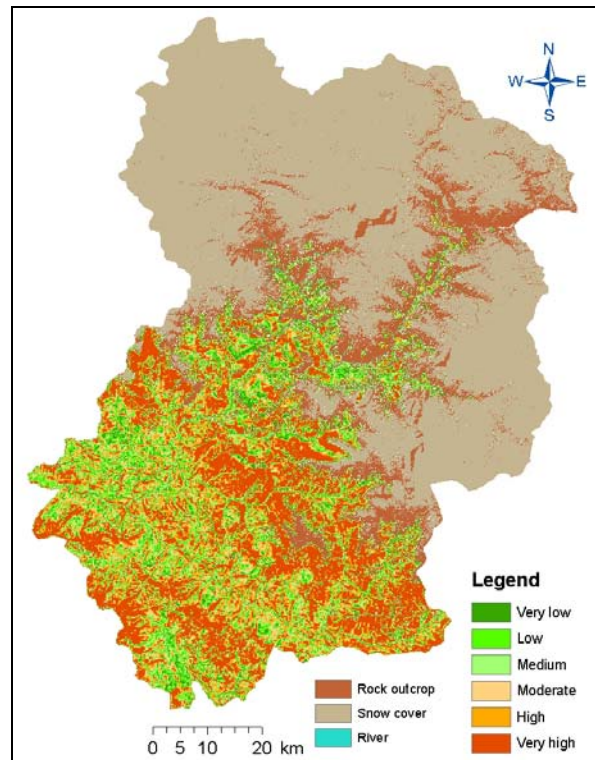


Figure 6: Priority soil erosion class map for 35 rain days presents in study area

CONCLUSIONS

The results show that regional scale erosion modeling can provide a general picture of the source areas of erosion in Chamoli district, the Centre of Himalayan ranges. The model presented here provides a more direct method for estimating soil erosion per rain day using daily rain map of Climatic Prediction Centre with pixel size of 10km. However the true accuracy and precision of the model, and of many the input parameters have not been assessed.

Overland flow will occur when rainfall per day is greater than 14 mm. The study found down that there are 35 rain days with P exceeds 0.2S value, the following is applied when this occurs.

The study results of soil erosion rate for 35 rain days in three months (July: 15 days, August: 10 day and September: 10 days) 2006 show average soil erosion rate per day equals 1.26 tons/ha. The maximum, minimum and mean of soil erosion rate for 35 rain days are 2379 tons/ha, 0.004 tons/ha and 44 tons/ha, respectively

At regional scale there has been a limited validation of model parameters as well as outputs. For all of model parameters, slope and vegetation cover is the most sensitive parameter; soil

erodibility is the least sensitive parameter. Overland flow is a relatively sensitive variable and certainly the one it is hardest to estimate.

Due to the fact that there are limitations to each scale at which soil erosion models can be applied using remote sensing and GIS an operational monitoring system could use all scales. These could be monitored using regional scale modeling and areas that are identified as having accelerating erosion could be subjected to local scale modeling image acquired just before large erosion events identified by the regional scale modeling to gain a more accurate estimate of erosion.

REFERENCES

- Blackburn, G.A. and Milton, E.J., 1995. Seasonal variations in the spectral reflectance of deciduous tree canopies. *International Journal of Remote Sensing*, 16, pp. 709 - 721.
- Chow et al., 1988. *Applied Hydrology*, McGraw - Hill Book Company.
- Drake, N.A., Vafeidis, A., Wainwright, J. and Zhang, X., 1995. Modelling soil erosion using remote sensing and GIS techniques. *Proceedings of the 1995 RSS Annual Symposium: Remote Sensing in Action*, 11 - 14 September 1995, Southampton, pp. 217 - 224.
- Flanagan DC, Ascough JC, Nearing MA, Laflen JM., 2001. The Water Erosion Prediction Project model. In *Landscape Erosion and Evolution Modelling*, Harmon RS, Doe WW (eds.) Kluwer: New York; pp. 145 - 199.
- Malthus, T.J., Andrieu, B., Danson, M.F., Jaggard, K.W. and Steven, M.D., 1993. Cadidate high spectral resolution infrared indices for crop cover, *Remote Sensing of Environment*, 46, pp. 204 - 212.
- Morgan, R. P. C., Morgan, D. D. V., and Finney, H. J., 1984. A Predictive Model for the Assessment of Soil Erosion Risk. *Journal Agricultural Engineering Research* 30, pp. 245 - 253.
- Morgan, R. P. C., 1986. *Soil Erosion and Conservation*, Longman Group Limited.
- Morgan RPC, Quinton JN, Smith RE, Govers G, Poesen JWA, Auerswald K, Chisci G, Torri D, Styczen ME. 1998. The European Soil Erosion Model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. *Earth Surface Processes and Landforms* 23(6); pp. 527 - 544.
- Mitchell, J.K. and Bubenzer, G.D. 1980. Soil loss estimation. In: Kirkby, M. J. and Morgan, R. P. C. (eds.). *Soil Erosion*. John Wiley and Sons Ltd., London. pp. 17-62.
- Mitchell, J.K., Bubenzer, G.D., McHenry, J.R. and Ritchie, J.C. 1980. Soil loss estimation from fallout Cesium - 137 measurements. In: De Boodt, M. and Gabriels, D. (eds.). *Assessment of Erosion*. John Wiley and Sons Ltd., London. pp. 393-401.
- Mishra et al., 2006. SCS-CN-Based Modeling of Sediment Yield, *Journal of Hydrology*, Vol. 324, pp. 301-322.
- Murthy, 2004. *Land and water management engineering* (4th de.), Kalyani Publishers, New Delhi, pp. 39-42.
- Nick A. Drake, Xiaoyang Zhang, et al., 1999. Modelling Soil erosion at global and regional scale using Remote Sensing and GIS techniques. *Advance in Remote Sensing and GIS analysis*. John Wiley & Sons Ltd., pp. 241 - 261.
- Terzoudi et al., 2007. Application of an Empirical Runoff Estimation Method in Central Greence, *Soil and Tillage Research*, Vol. 92, pp. 198-212.
- Tideman, E.M., 2000. *Watershed management - Guidelines for Indian Conditions*. Omega Scientific Publishers, New Delhi.
- Thornes, J.B., 1985. The ecology of erosion, *Geography*, 70, pp. 222 - 234.

- Thornes, J.B., 1989. Erosional equilibria under grazing, in J. Bintliff, D. Davidson and E. Grant (eds), *Conceptual Issues in Environmental Archaeology* (Edinburgh: University Press), pp. 193 - 210.
- Wischmeier W.H., Smith D.D., 1958. Rainfall energy and its relationship to soil loss. *Transactions - American Geophysical Union* 39, pp. 285 - 291.
- Wischmeier, W.H. & Smith, D.D., 1978. *Predicting Rainfall Erosion Losses*. Agricultural Handbook no. 537, USDA, Washington DC, USA.
- Zhang X.C., Nearing M.A., Risse L.M., McGregor K.C., 1996. Evaluation of runoff and soil loss predictions using natural runoff plot data. *Transactions of the ASAE* 39, pp. 855 - 863.
- Zhang, X.C, 1999. *Remote sensing and GIS for modeling soil erosion at the global scale*. PhD Dissertation Thesis, Kings College London, London, UK.
- Zhang, X., Drake, N.A., and Wainwright, J.M., 2002. Scaling land - surface parameters for global scale soil erosion estimation. *Water Resources Research*, 38, pp. 1180 - 1189.

CONTACTS:

Luu The Anh
 Department of Remote Sensing and GIS
 Institute of Geography (IG)
 Vietnam Academy of Science and Technology
 18 Hoang Quoc Viet Str., Cau Giay Dist., Hanoi - Vietnam
 Tel: (+84-4) 38362607; Fax: (+84-4) 38361192
 Mobile: 0942140454; E-mail: luutheanhmt@yahoo.com