VNU Journal of Science, Earth Sciences 27 (2011) 199-207

Application of N-SPECT model and GIS for Soil erosion assessment in Sapa district, Lao Cai province

Nguyen Hieu*, Dang Kinh Bac, Dang Van Bao

Faculty of Geography, VNU University of Science, 334 Nguyen Trai, Hanoi, Vietnam

Received 9 September 2011; received in revised form 10 October 2011

Abstract. Sapa is a mountainous district in the western of Lao Cai province. Most of the area is mountainous terrain with steep slopes, annual precipitation of 1500 mm, plus the pressure of development activities to landforms, especially the farming operations on slope land leveling and infrastructure development, increasing the risk that the occurrence of natural disasters in this growing, including soil erosion.

The erosion of longstanding research in general and a number of studies on the Sa Pa area is largely based on the universal soil loss model of Wischmeier and Schmid (USLE) to calculate the amount of land is separated from the rib, which not only place / space of the distribution of material erosion and soil loss is real - the flow was sent. To address these limitations, the paper used N-SPECT model combined with GIS technology to assess risk of soil erosion along the stream basin system of Sa Pa. Evaluation results show that soil erosion in Sapa concentrated along the Dum, Bo Rivers. Volume erosion can be up to over 1.5 t / (ha.year), concentrated in areas with slopes greater length and poor vegetation cover, as areas in the west of San Sa Ho, Lao Chai, Su Pan, the area in the south of Ban Ho commune.

Keywords: Soil erosion, GIS, N-Spect, Sa Pa.

1. Introduction

Sapa is a mountainous district in the western of Lao Cai province, with 68,329.09 ha of natural forest area, equivalent to 10.70% of the province natural area. Most of the area is mountainous terrain with the slope which is more than 25^0, thick weathered crust, topography which has been cleaved strongly, was influenced of many faults was developed from the northwestern to the southeastern. Average annual rainfall in Sapa is very high, average about 1500 mm per year, to over 3500mm rainfall in some years. Sapa's natural conditions create comfortable conditions for the development of soil erosion issue. In addition, Sapa is one of the famous eco-tourism places with the rapid development in recent times. The demands of agricultural and cultivated activities on the high slope areas have been increased, many new roads are opened or expanded, and recently series of hydroelectric plants to be deployed in this district, etc... This makes more opportunities for the risk of soil erosion becomes more serious.

* Corresponding author. Tel.: 84-986138289.
E-mail: nguyenhieu@hus.edu.vn

The erosion research in general and some studies on the Sapa area mostly made paintings which have been had general qualities about the possibility of soil erosion. The results of those assessments are based largely on the Universal Soil Loss Equation of Wischmeier and Schmid (USLE), calculated the amount of soil is separated from the mountain-side, which did not indicate or specializer the distribution of soil eroded materials and did not calculate the actually amount of soil lost - was flowed to streams. In order to solve these limitations, this report used N-SPECT model combined with GIS technology to assess risk of soil erosion, along the drainage basin system in Sa Pa which is the basis for the prevention and minimize damage from natural disasters in this district. Research results are important scientific basis for planning, using of natural resources, protecting the local environment, particularly in the context of the complex climate change.

2. Materials and Evaluation Model

2.1. Materials

The used data for research include: Terrain data from the cadastral base map in 1:25,000 scale which was published from Department of Survey and Mapping Vietnam, was built by geodetic methods with airline documentation which had taken in 1999, data have a very high detail with basic contours are 20 m, the coordinate system is WGS84, zone 48; Land cover data was extracted and referenced from land use map in 2007, aerial photographs document, LANDSAT 7 ETM satellite image was taken in 20/09/2007, resolution 30m; Rainfall data of many stations in the district and many stations surrounding Sapa was collected by the Department of Meteorology, Hydrology and Oceanography, Hanoi University of Sciences. Rainfall data collected during the period from 1990 to 2006; Soil data from soil maps scale 1: 50,000, were established from the Ministry of Natural Resources - Environment in 2005.

2.2. Evaluation model

N-SPECT model and GIS was used to assess the risk of soil erosion in study area. N-SPECT model is developed based on Universal Soil Loss Equation of Wischmeier and Schmid (USLE) and is integrated into the GIS software - ArcGIS - which is based programming language Visual Basic and ArcObjects (the library tools in ArcGIS). The input data is the main factor which control the soil erosion process as the elements of weather, climate, the basic properties of soil (such as floor thickness, permeability or components of particle...), the morphological characteristics and the land cover as well as management processes, land use of human. The special features of the N-SPECT model is allow calculating the flow on the surface by the rainfall precipitation curve method (curve number) - the method has been Natural and Resources Conservation Service (NRCS) under the US. Department of Agriculture (USDA) (USA) have been developed to predict directly flow from the beyond the limits of the rain (USDA, 1986). This method is extended to predict the flow on the surface from event storms, as well as average annual rainfall. The number of rainfall curve (also known as curve number, CN) is a parameter related to the kind of soil and the kind of land cover in the area.

N-SPECT is a complex tool, have been built for the resource & environment management, which is particularly effective for assessment of soil erosion in drainage basin, streams with the main function :

- To estimate surface flow, accumulation sediment

- Estimated amount of soil washed away through erosion and sediment accumulation rates, was calculated by the Revised Universal Soil Loss Equation (Revised USLE) and Modified Universal Soil Loss Equation (Modified USLE).

- Identify the sensitive areas to soil erosion by water

- Impact assessment of land use change with the different scenarios.

In order to apply the calculation model to soil erosion in Sapa, outside the standardized parameters, the input data are important locally which are necessary to build and estimates include:

- Building DEM to calculate the slope length (LS) and evaluate rainfall factor (R)

- Land covers data (raster format)

- Rainfall data (raster format)

- Soil data (shapefile format)

- Rainfall factor (R) of the local (raster): is established from the relationship between rainfall and topographic factors.

The detail evaluation process of N-SPCET model is shown in figure 1.

3. Results and discussion

3.1. Evaluate the input parameters of the model

Soil erosion factor by the morphological characteristics and slope length (LS)

L and S factor essentially is two separate factors. L is the slope length factor and S is the slope factor. Two factors are specific to the influence of morphology and topography to erosion and calculations in GIS have many similarities for each other, so they are often combined and called the LS factor.

LS factors are calculated by following formula:

LS = [0065 + 0.0456 (slope) + 0.006541 (slope) 2] x (slope_length ÷ const) NN

In that: const = 1.22 m and NN are calculated using table 1.

In the rain scenario building for Sapa area, besides average annual rainfall data, N-SPECT model also requires annual average number of rainy days and rain type of study area. The average number of rainy days for calculating the total surface flow under the annual average rainfall (Annual Precipitation) is 110 days Sa Pa/year. Type of rain at Sapa is identified as type II (most intense short duration rainfall) [1]. The results of rainfall interpolation show Sapa area with mean annual rainfall over most of 1200 mm/year in the east, increases westward, reaching over 2,000 mm/year. The distribution of rainfall depends on the direction of the terrain and has many changes from downstream to upstream rivers. By analyzing the flow direction, N-SPECT offers the distribution maps of water after rain - this is necessary for data to calculate a centralized location and not concentrated in the wet season.

Erosion factors and soil cover (K)

These factors show the relationship between coating and soil erosion or the possibility that the vulnerability of land to erosion. Factor K depends on the nature of the soil: the viscosity of the soil particles, soil mechanical composition, and ability to wet the soil, grain diameter and organic content in soil.

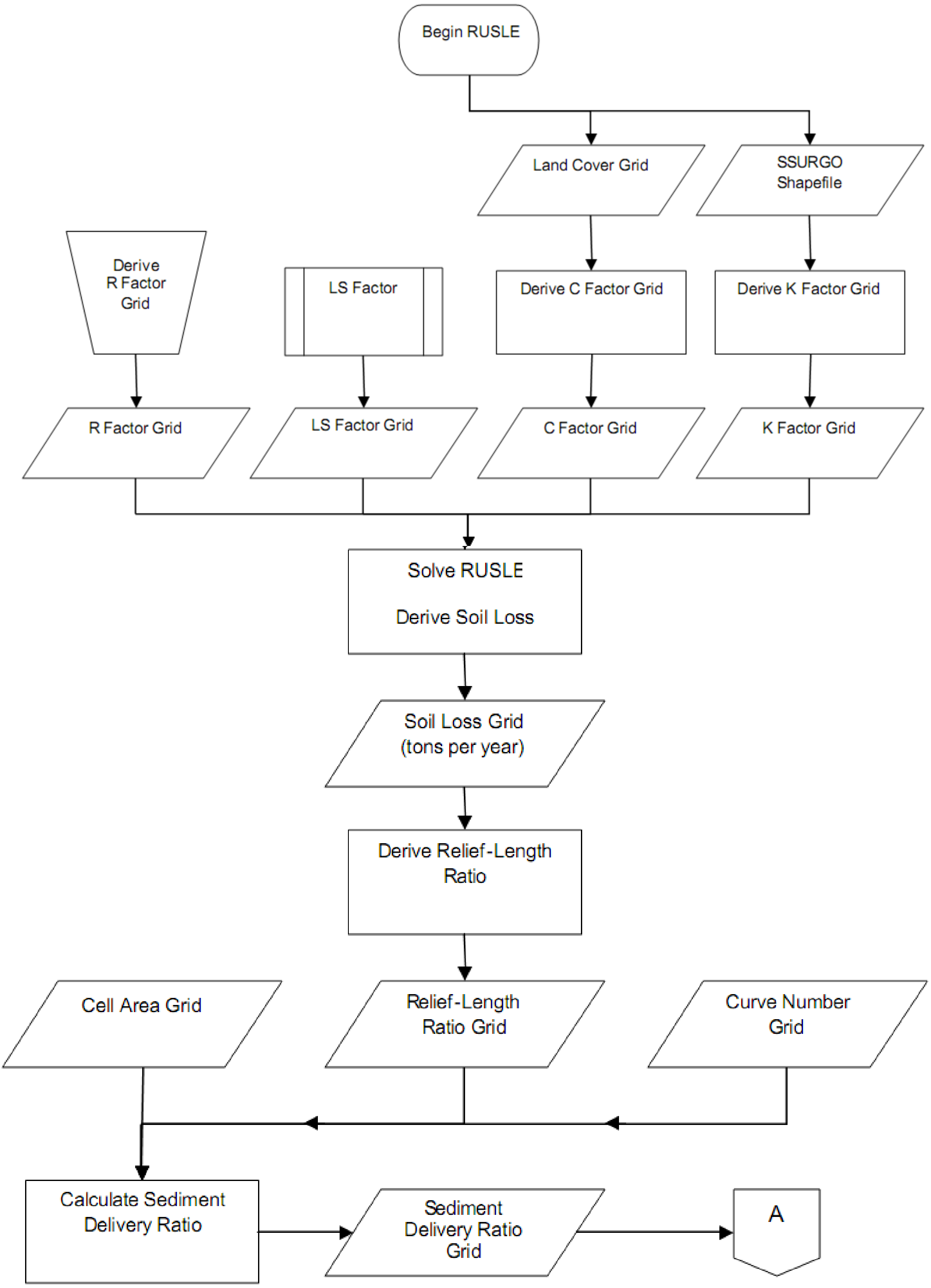

Fig. 1. The evaluation process of soil erosion N-SPECT [2].

Table 1. Table NN values by the slope [3]

S	< 1	1 ≤ Slope < 3	3 ≤ Slope < 5	≥ 5
NN	0.2	0.3	0.4	0.5

According Stroosnijder (1993), the organic solution is key to reducing runoff, increasing water permeability of the soil, reduce soil erosion significantly. De Ploye J. et al (1993) asserted that the land has severe mechanical composition and organic content of soil is high, the amount of erosion is very low.

In 1969, Wischmeier given formula coefficient of soil erosion based on the physical and mechanical soil:

100K = 2,1.10-4M1, 14 (12 - OS) + 3.25 (A - 2) + 2.5 (D - 3)

Here: K - coefficient of soil erosion, M - Weight particles, OS - concentration of organic matter in soil, D - coefficient of permeability depends of the ability to land, A - coefficient depends on the form, arrangement and type of structure.

To make ease to the calculations, Wischmeier and Smith made nomograph based on the above formula to investigate the coefficient K. Thanks to the experimental nomograph which, combined with studies of Nguyen Quang My and many previous authors [4,5], the corresponding coefficient K for each soil type in the study area was established based on the characteristics of their constituent (Table 2).

Table 2. The soils in the area Sapa and the corresponding coefficient K [6]

Count	**Types of soil**	**Symbol**	**K factor**
1	Crude peat humus soil on high mountain	A	0.26
2	Yellow alit humus on granit	Ha	0.12
3	Yellow alit humus on metamorphic	Hj	0.12
4	Yellow – brown alit humus on limestone	Hv	0.28
5	Gray – yellow humus on granit	HFa	0.16
6	Gray – yellow humus on metamorphic	HFj	0.16
7	Red – brown humus on limestone	HFv	0.43
8	Red - yellow feralit soil on granit	Fa	0.23
9	Red – yellow feralit soil on metamorphic	Fj	0.22
10	Yellow – red soil changed by cutivation	Fl	0.22
11	Multi-origin deluvial soil	D	0.38
12	Deluvial soil on limestone	Dv	0.17
13	Alluvial soil	P	0.44

Besides K factor, N-SPECT model requires additional data about permeability of each soil unit, is assessed according to four levels A, B, C, D. Thus, the model will evaluate how the water permeability for each soil type is fast, accurate analysis to possibility of erosion for each soil unit. Results of K factor mapping in Sapa area shows the vulnerability of erosion at the highest concentration near the rivers to flow regularly irregular.

Erosion vegetation cover factor (C)

Sapa is a mountainous district with many agricultural activities and tourism, a growing diversity. This also makes the vegetation cover in this quickly changing. The forest area is declining due to deforestation of the people during the 20^{th} century, forest cover decreased from 28.5% in 1987 down to 23.5% in 1990, instead logging activities forest clearance for agriculture, creating some vacant land, build houses, cut mountain road... It is these activities has increased the ability to destroy the earth as rain. Direct raindrop impact on soil mantle where there is no vegetation cover, and lead to soil particle detachment occurs faster. At the same time, reducing vegetation cover makes the surface flow easily formed without any encumbrance, to involve a multitude of soil particles down slope. Although until now, the area of forest cover has improved a lot but the problem of erosion due to vegetation cover is still a concern at many points in the study area.

According to the USLE equation, vegetation cover data of Sa Pa is the value calculated results NDVI (vegetation index) from the Red and NIR channels of Landsat ETM with 30m spatial resolution. Factor C is calculated by the following empirical formula:

$$C = \exp\left[(-\alpha \times NDVI) / (\beta - NDVI)\right]$$

Here: $\alpha = 2$, $\beta = 1$. After calculation, the map will be in the form factor C raster with the distribution of values in the chart (Figure 2). Factor values of C and NDVI values will fit opposite relationship between erosion factors by vegetation cover and vegetation cover factor. Areas with greater vegetation cover, the ability of this erosion in the lower and vice versa. Thereby, the calculation results clearly factors C are the areas with poor vegetation cover, bare areas – concentrated downstream of the river basin in Sapa the index high C, the remaining area of primary forest in the mountains or forest land is recovered by a low C values.

Landuse management factor (P)

In the assessment model of soil erosion, the P characteristics for reducing the level of erosion of farming practices. The P only mean sharply with the agricultural sector. Table Patio investigated by the International Soil Science Society is shown in table 3.

The determination of the cultivation methods for river basin in the study area is difficult. The area of paddy land is not more concentrated in the flat area along the streams. Most of the lands for planting annual crops are maize, cassava and some cash crops.

3.2. Assessment of soil erosion

The assessment process of N-SPECT made by following process:

- Calculation of soil detachment from the slopes through the Universal Soil Loss Equation (USLE) is revised in the land use and the slope length factors. Maps of actual soil erosion (Fig. 2) and potential soil erosion (Fig. 3) were built in this step.

Table 3. Correlations with P values of terrain slope and the cultivation methods [1]

Slope (%)	Cultivate due to contour	Cultivate due to contour and plants on ice	Cultivate due to bed
1 - 2	0.6	0.3	0.12
3 - 8	0.5	0.25	0.1
9 - 12	0.6	0.3	0.12
13 - 16	0.7	0.35	0.14
17 - 20	0.8	0.4	0.16
21 - 25	0.9	0.45	0.18

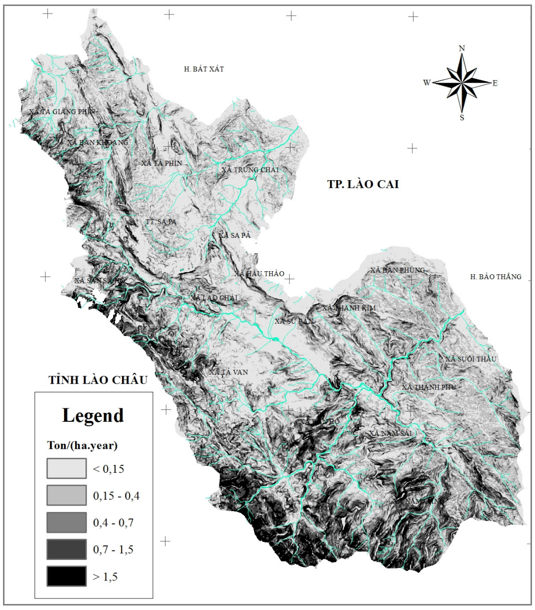

Fig. 2. Real Soil Erosion in Sapa.

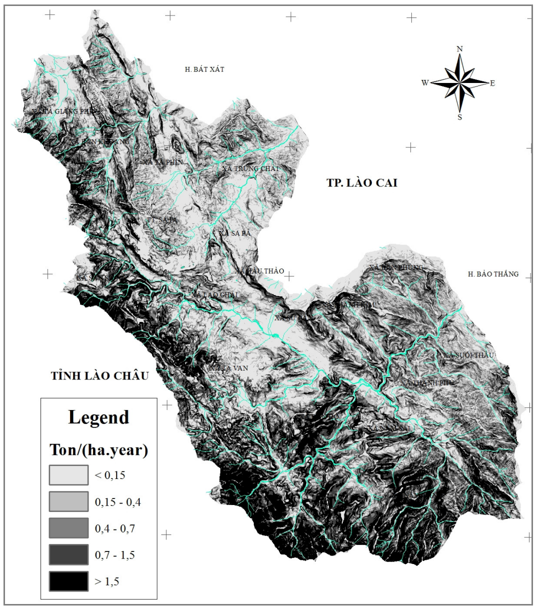

Fig. 3. Potential Soil Erosion in Sapa.

The map showed a picture about actual erosion Sapa area in different levels, from low level to harmful level of this hazard. According to calculation results, most of region in the study area have been eroded at low and medium, about 0.4 tons/ha.year (Table 4).

Somewhere have the harmful level of erosion hazard (over 1.5 tons/ ha.year) gain an small area, about 4.9% total square and is concentrated in the western communes, such as: San Sa Ho, Lao Chai, Ta Van and in the southern of Ban Ho commune. All of them have steep terrain, slope length, can be concentrated high amount of rainfall in a short time.

- Actually, not all of the soils are detached from slopes washed out, and then they are transported down by overflow and deposited along the slopes. In the N-SPECT model, base on the topography parameters (Digital Elevation Models, Slope, Slope Length and Rainfall), which allows users to analyze flow direction, the accumulation water along basins and the energy of overflow. After that, these analysis results are compared with the assessment results of the erosion in order to build accumulation sediment maps of study area (Fig. 4, Table 5).

Table 4. Square of real soil erosion areas with the different levels in the Sapa district by the USLE calculation

No	Soil Erosion levels	Soil Erosion volume (ton/ha/year)	Square (ha)	Percent(%)
1	Low Soil Erosion	under 0.15	2.395	35.43
2	Medium Soil Erosion	0.15 – 0.4	2.262	33.45
3	High Soil Erosion	0.4 – 0.7	1.013	14.97
4	Very high Soil Erosion	0.7 – 1.5	0.761	11.25
5	Harmful Soil Erosion	upper 1.5	0.329	4.9

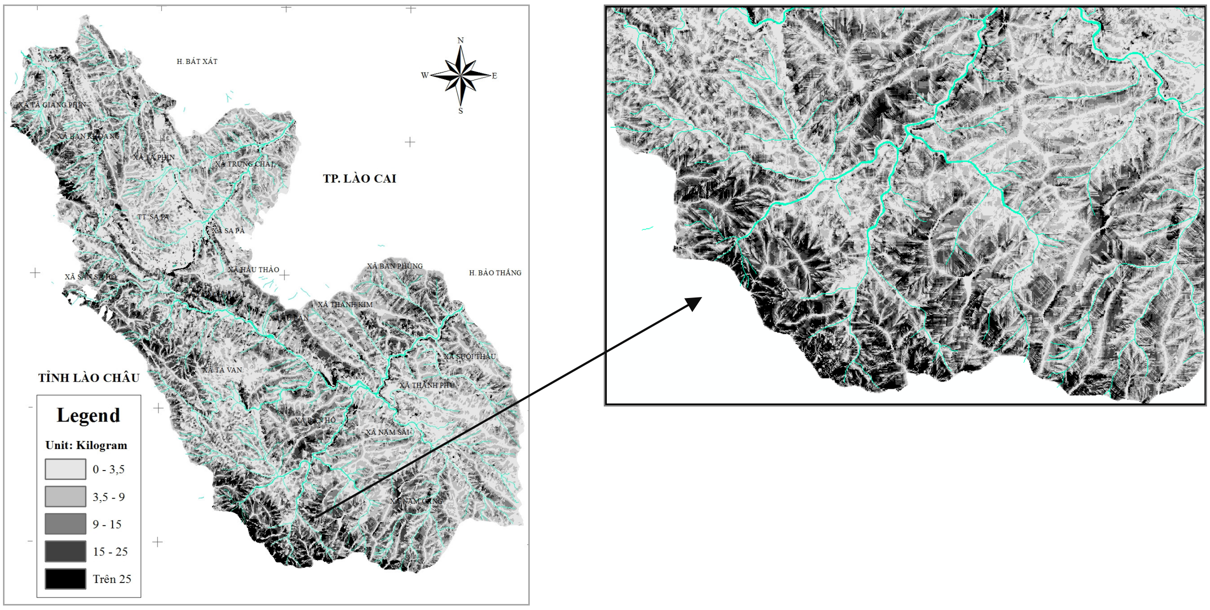

Fig. 4. Sediment accumulation map in Sapa district was calculated by N-SPECT model.

Sediment accumulation map calculated from the N-SPECT model (Fig. 5), is the result which represents a new perspective of soil erosion. If in the previous of time, the calculation results from the Universal Soil Loss Equation of Wischmeier and Schmid (USLE) only saw the potential soil loss at different levels, then the calculated results by N-SPECT model, we can identify clearly the movement and re-deposit of eroded material in each small basin. Some regions where have harmful level (over 25 kg/ha) is only about 4% and is concentrated in some communes, such as: Lao Chai, Su Pan and Ban Ho, southern of the Ban Khoang commune, especially in the Southern of Ban Ho commune. These are just some areas where land cover is poor, bad land use.

Table 5. Statistics erosion area N-SPECT model in Sapa district

No	Soil Erosion levels	Soil Erosion volume (Kg/ha)	Square (ha)	Percent(%)
1	Low Soil Erosion	under 3.5	2.263	35
2	Medium Soil Erosion	3.5 - 9	2.216	34
3	High Soil Erosion	9 - 15	1.179	17
4	Very high Soil Erosion	15 - 25	0.604	9
5	Harmful Soil Erosion	upper 25	0.264	4

Results of this study can be used effectively for land use management as well as prevention and reducing damage caused by natural disasters local. From a map of sediment accumulation can clearly see the relationship between soil erosion areas generated and the areas affected.

4. Conclusion

With the use of N-SPECT model, based on geomorphological studies with the help of remote sensing and GIS technology, the project has established maps of erosion and potential erosion for district Sa Pa. Research results show that the erosion in high level of risk is concentrated along Bo river, belong to Lao Chai, Su Pan and Ban Ho communes, especially in the southern of Ban Ho commune, there are over 1.5 tons/ha.nam.

Not all of the soils detached from slopes is lost as assessed by USLE formula, which are transported down by overflow and deposited along the slopes. In the N-SPECT model, base on the topography parameters (Digital Elevation Models, Slope, Slope Length and Rainfall), which allows users to analyze flow direction, the accumulation water along basins and the energy of overflow and build accumulation sediment maps of study area.

Acknowledgments

The article is completed under the bilateral project Vietnam-Belgium: "*Studying the impact of socio-economic activities to the landuse changes and natural environment in the context of climate change (case studies in the Red River Delta and the mountainous northwestern Vietnam)*".

References

[1] NOAA Coastal Services Center, 2008, *Nonpoint-Source Pollution and erosion Comparison Tool* (N-SPECT): Technical Guide, National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center.

[2] Nguyen Hieu, Dinh Van Hung, “Application of GISS and N-Spect model for soil erosion assessment in Yen Chau district, Sơn La province”, *Proceedings of the 5th National Scientific Conference of Geography,* Ha Noi 6/2010, pp.1395-1403.

[3] Tran Van Y, Nguyen Quang My, Nguyen Van Nhung, "*Using Geographic Information System built potential erosion in Vietnam, 1:1000.000 scale*" Appication Remote Sensing Application and Geographic Information System in environmental planning, Hanoi, 1999.

[4] Nguyen Quang My, "*Modern erosion and erosion control measures*", Publishing House, Hanoi National University, Hanoi, 2005.

[5] Vietnam Institute of Soil Science, "*Land of Vietnam*", Agriculture Publishing House, Hanoi, 2000.

[6] Robert Hickey, School of Spatial Sciences, Curtin University of Technology, “*Slope Angle and Slope Length Solutions for GIS*”, 14 p.