Application of remote sensing, GIS and topographical data for establishing soil erosion map

Son NGUYEN PHI, Thuy NGUYEN THANH, Tuan NGUYEN ANH, Vietnam

SUMMARY:
Soil erosion is estimated by using the Revised Universal Soil Loss Equation (RUSLE) model based on the R, K, LS, C, and P factors maps. In the scope of this paper, the use of VNREDSAT-1 imagery support is to determine C and P factor maps. The combination of the calculated C and P with the R, K, LS factors from the data of climate, topography, soil, and land use establishes soil loss caused by rainfall in Uong Bi city, Quang Ninh province.

Keywords: Remote sensing, GIS, RUSLE, soil erosion

1. INTRODUCTION

Soil erosion is a natural process caused by natural physical forces of water, wind, or farming activities which is one of the leading reasons for land degradation. Factors affecting soil erosion process include rainfall, wind speed, slope, soil types, vegetation cover, and human activities. There are two group models: empirical and knowledge models that are normally used to assess soil erosion. Many countries are using the RUSLE as the most popular emirical model. Vietnam is not an exception. In Vietnam, RUSLE is the official model used to establish soil erosion map caused by rain stipulated in Circular No. 14/2012/TT-BTNMT by Ministry of Natural Resources and Environment (MONRE). The soil erosion map shows the estimated long-term average annual soil loss (A). The equation of RUSLE is:

$$A = R \times K \times LS \times C \times P \qquad (1)$$

where: A is expressed in ton per hectare per year ($t.ha^{-1}.yr^{-1}$); R is rainfall erosivity factor expressed in $MJ.mm.ha^{-1}.h^{-1}$ per year ($MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$); K is soil erodibility factor (expressed in $t.h.ha^{-1}.MJ^{-1}.mm^{-1}$); LS is the topographic factor; C (Cover management factor) and P (Conservation practice factor) are cropping management factors.

R, K, LS factor maps are easily created using meteorological, topographical, soil characteristic, land use, and experiment data (Hoang, H.L et al.2011; Manh, H.N et al., 2013; Quoc, V.T et al., 2011). The C factor definition based on the field survey about the detail types of land use for each land unit and the total of months in the year has the highest tree canopy density. The P factor is determined according to the types of support practices, slope, land use. In particular, the kinds of support practice are defined in the field to evaluate P. Both C and P values are referenced from C and P tables of the International Union of Soil Sciences. The different processes to determine C and P is time consuming and costly. Consequently, it is difficult to apply in large areas. Therefore, in many studies, the default P factor value was set up 1, and the C factor values assigned to each type of land use in the land use status map (De Jong, S.M., 1994; Hoang, H.L et al., 2011; Manh, H.N et al., 2013; Quoc, V.T et al., 2011; Wojciech Drzewiecki, 2013).

The high-resolution satellite imagery can be used to not only effectively identify detailed features, but also easily distinguish and separate the structures related to farming and soil conservation (contouring, strip cropping, and terracing, road structures prevent soil erosion). Thus, there are several studies used the high-resolution remote sensing imagery to map the C and P factors (Karydas C.G et al., 2009; Prasannakumar V, Vijith H., Geetha N., Shiny R., 2011; Renard K.G, Foster G.R., 1997; Vrieling A., 2006). In the studies (Karydas C.G et al., 2009; Prasannakumar V, Vijith H., Geetha N., Shiny R., 2011), the C factor is calculated by using Normalized Difference Vegetation Index (NDVI), and the P factor is calculated based on each landscape structures classified using object-based image analysis method.

VNREDSAT-1 is the first optical Earth Observing Satellite of Vietnam, was launched on 7 May 2013 to monitor and study the effects of climate change and to predict, take measures for natural disaster prevention and the country natural resources' management optimization. VNREDSAT-1 captures images at 2.5m in the panchromatic mode, and 10m in the multi-spectral mode (4 bands: R, G, B, NIR) with three-day revisit time. Hence, the objective of this paper is to use VNREDSAT-1 images calculating C and P factors in combination with R, K, SL factors to map soil erosion caused by rainfall.

2. STUDY AREA

Uong Bi is a city in western Quang Ninh province (25,546.41ha) with elevation from 1 to 1.068m above the sea level. There are two-thirds of hills and mountains slope from the North to South of the city with featuring three main landforms: the high mountains (65.04%), valley (1.2%), and flat (26.9%) (Figure1). As the geographical location and terrain lie in the bow of Dong Trieu - Mong Cai, there are both mountainous and coastal climates in the city. The annual average temperature is 22.2^{0}C, the highest 34-36^{0}C, the lowest 7-12^{0}C. The average relative humidity is 81%, the lowest relative humidity is 50.8%. Total annual rainfall is 1,600mm, and the highest is 2,200mm. The city's broad range of elevation with a diversity climate, land use, and land cover changes are typical conditions for soil erosion study.

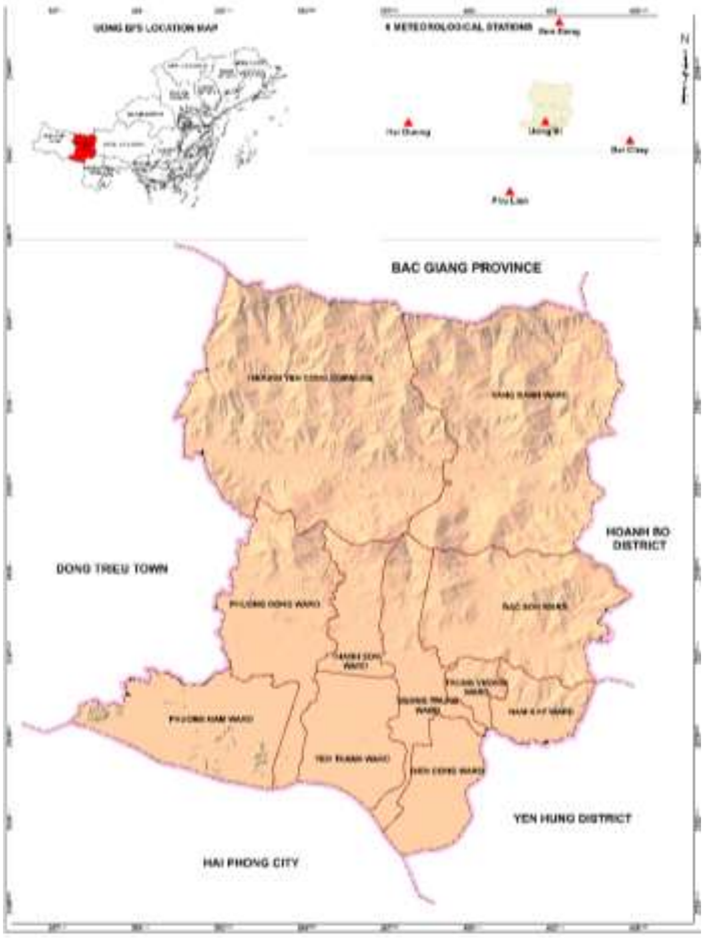

Figure 1. The location of Uong Bi

3. METHODOLOGY

3.1. Data

The data of Uong Bi used to calculate average annual soil loss (A) in this study include: 3 VNREDSAT-1 scenes captured on 9 October 2013 and 11 November 2013 at 2.5m and 10m corresponding with panchromatic and multi-spectral modes; digital elevation model (DEM) interpolated from terrain data of topographic maps at scales 1:2.000, 1:5.000, 1:10.000 with cell size 5m×5m; meteorological data (rainfall) in 2013; land mapping unit in 2013.

3.2. Cover management map

Cover management factor measures the combined effect of all interrelated vegetative cover and management variables. According to RUSLE, C is the most important factor. ... shows the conditions for preventing soil erosion. The C map is established based on De Jong's formula (De Jong, 1994) as follows:

$$C = 0.431 - 0.805 \times NDVI \qquad (2)$$

Where: NDVI = (NIR-RED)/(NIR+RED), NIR and RED correspond with the spectral reflectance measurements acquired near infrared and red regions. NDVI range from -1 to 1.

3.3. Conservation practice map

The RUSLE's P factor reflects the impact of support practices an annual erosion rate, which is the ratio of soil loss with contouring and strip cropping to that with straight row farming up and downslope.

The Vietnam standard TCVN 5299:2009 (MOST, 2009) indicates a table (Appendix B) of popular empirical values of P associated with each type of support practices and slope steepness. The problem is how to be solved how to define the support practices for the large areas rapidly. The high-resolution VNREDSAT-1 images, three days repeated time, which could be applied for classifying and interpreting the structures such as contouring, terracing cultivations, forest, and others. All of these structures are divided into the strip and none-strip cropping cultivations. The slope steepness is made from DEM. Each combination of support practices and slope steepness provides a P value referenced in Appendix B.

3.4. Establishing rainfall erosivity map

This paper uses Ha Nguyen Trong's formula proposed using linear regression (Ha, T. N., 1996) to calculate the correlation coefficient between R and P, as follows:

$$R = 0{,}5485 \times R_a - 59{,}9 \qquad (3)$$

Where: R is rainfall erosivity factor (J/m^2); R_a is average annual rainfall (mm/year) interpolated from meteorological data.

3.5. Establishing soil erodibility map

Each type of soils has differential erodibility. The degree of soil erodibility depends on the linkage of soil components presented by K factor. The K factor defined by Wischmeier and Smith's formula (Wischmeier WH, Smith DD., 1978):

$$100K = 2.1 \times 10^{-4} M^{1.14} \times (12 - OS) + 3.25 \times (S_{si} - 2) + 2.5 \times (D - 3) \qquad (4)$$

where: K is soil erodibility factor; M = (% silt + % very fine sand) × (100% - % clay); OS is organic matter content (%); S_{si} is soil structure index, D is soil permeability index.

3.6. Slope length and steepness map

SL factor represents the effects of topography on soil erosion. Where slope length (L) is the distance from the point of origin of overland flow to place with a velocity of slope decreases, and material occurs deposition. Slope steepness (S) shows that the higher slope, the greater soil loss. There are many ways to define LS factor in previous studies however this paper uses the Helena Mitasova's formula at a point r = (x,y) (Mitasova, H., Mitas, L., 1999) as follows:

$$LS(r) = (m + 1) \times [A(r)/a_0]^m \times [\sin b(r)/b_0]^n \qquad (5)$$

where: A is upslope contributing area per unit contour width; b (in degree) is the slope; m, n are experimental parameters; and a_0 = 22.1m is the length and b_0 = 0.09 = 9% = 5.16 degree is the slope of the standard USLE plot. Values of m = 0.6, n = 1.3 are results that is consistent with the RUSLE. The formula (6) expanded from (5) used for GIS software.

$$LS = 1.6 \times ([Flowacc] \times Resolution/22.13)^{0.6} \times ((Sin([Slope] \times 0.01745))/0.09)^{1.3} \quad (6)$$

Where: Flowacc shows the Flow Accumulation; Resolution is the size of a cell.

4. RESULTS

Estimating the long-term average annual soil loss can be implemented by using GIS for overlying, integrating, and calculating the input factor data mentioned in RULSE. This study used ArcGIS for analyzing and presenting maps.

4.1. Establishing rainfall erosivity map

In this paper, the rainfall erosivity factor values calculated from average annual rainfall data of 5 meteorological stations (Son Dong, Uong Bi, Bai Chay, Phu Lien, Hai Duong) using Ha Nguyen Trong's equation 3.

Table 1. Rainfall erosivity factor values
at five meteorological stations around Uong Bi

No	Stations	R_a (mm/year)	R (J/m^2)
1	Uong Bi (Quang Ninh)	1,900.17	982.34
2	Bai Chay (Quang Ninh)	1,934.69	1,001.28
3	Phu Lien (Hai Phong)	1,616.96	827
4	Hai Duong (Hai Duong)	1,532.99	780.94
5	Son Dong (Bac Giang)	1,738.23	893.52

The R data is interpolated from five R values in Table 1 using Kriging tool in ArcGIS. Then the rainfall erosivity data for the whole Uong Bi area uses clip tool in ArcGIS base on the Uong Bi's boundary polygon. The Uong Bi's rainfall erosivity map shown in Figure 2.

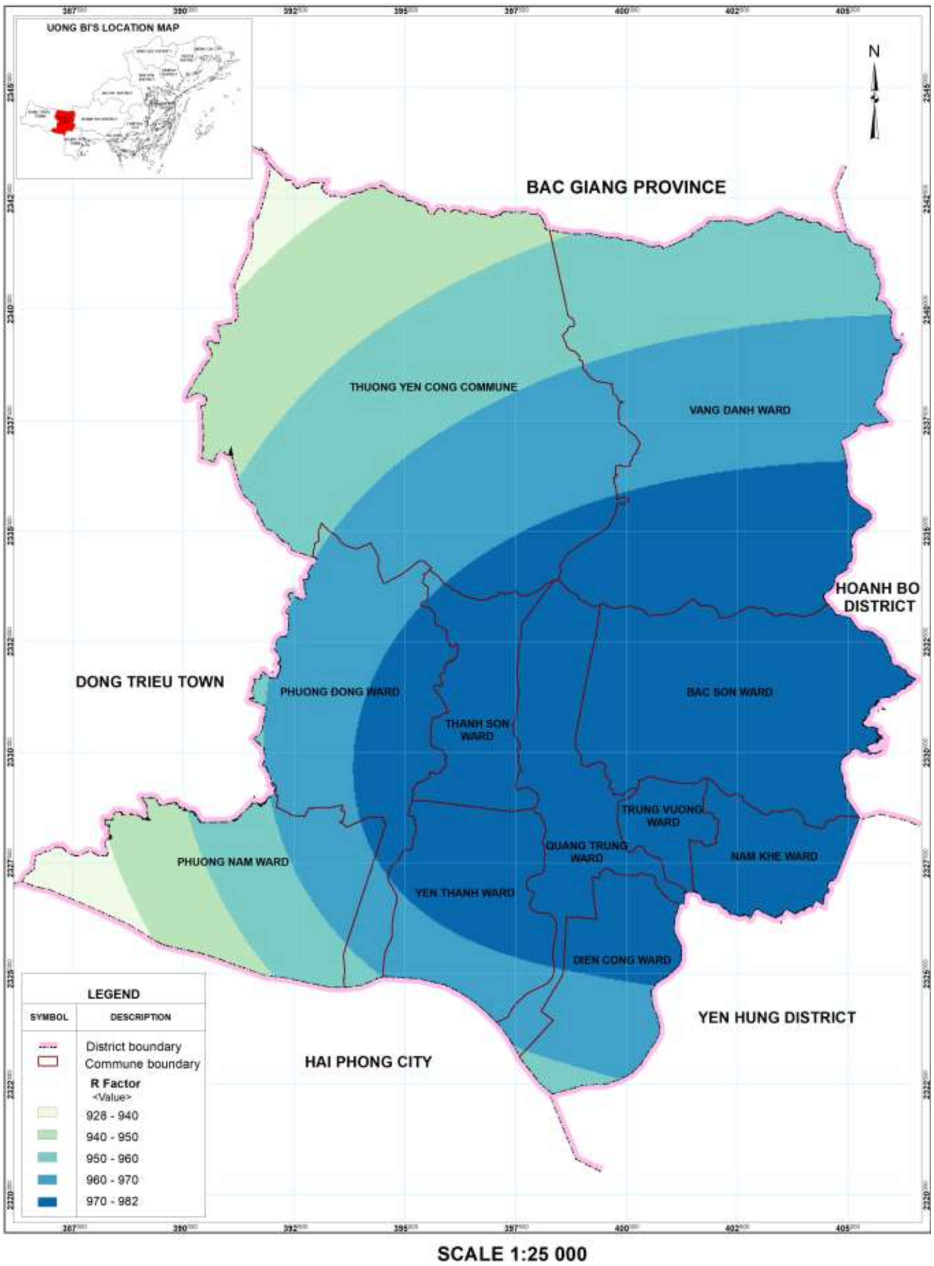

Figure 2. Uong Bi's rainfall erosivity map

4.2. Establishing soil erodibility map

To establish soil erodibility map, all parcels in the land mapping unit must contain the infomation about M, OS, S_{si}, D in formula 4. In that, M and OS (percentages of silt, sand, and clay) value derived from analysing soil samples; S_{si} calculated using soil texture angle (USDA, 2018), and D referenced from the empirical permeability for each soil structure (USDA, 1983). This paper uses the extracted information from 21 analyzed soil samples and using ArcGIS to assign that to all the same characteristic parcels in the land mapping unit and calculating K. Then convert land mapping unit from polygon to raster, base on K value field, with cell size is 5m×5m to prepaire for estimating long-term average annual soil loss (A). Soil erodibility map shown in Figure 3.

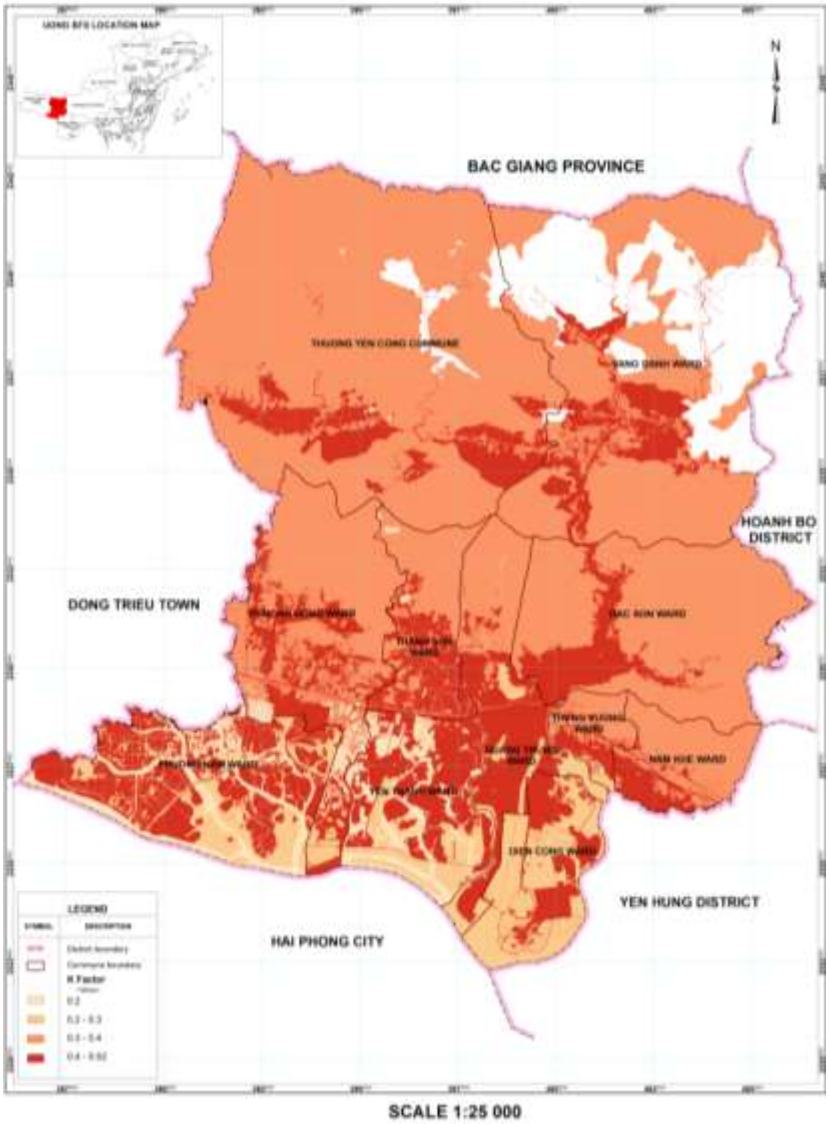

Figure 3. Uong Bi's soil erodibility map

4.3. Slope length and steepness map

SL is defined from flow accumulation, slope, and cell size. In this study case in Uong Bi, both of them are created from DEM using ArcGIS tools such as Flow Direction, Flow Accumulation (Spatial Analyst), and Slope (3D Analyst) with cell size 5m×5m. After that, SL surface built by Raster Calculator in ArcGIS Spatial Analyst tool based on the equation 6. The results show in Figure 4 and 5.

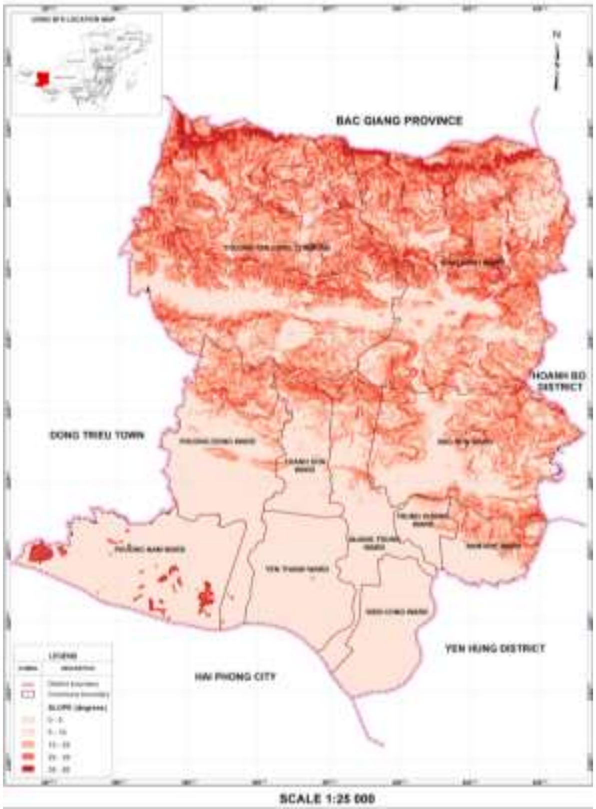

Figure 4. Uong Bi's slope map

Figure 5. Uong Bi's LS map

4.4. Cover management map

VNREDSAT-1 scenes are registered through ground control points then mosaic them to archive ortho image by PCI software. NDVI is generated from ortho image. After that Uong Bi's cover management map is created based on equation 2 using Raster Calculator tool of ArcGIS Spatial Analyst extension. Figure 6 shows the results of C factor maps.

4.5. Conservation practice map

Conservation practice mapping progress includes 2 phases: 1. Classify support practices, slope steepness; 2. Create the conservation practice map.

The support practices in Uong Bi are classified using eCognition's object-oriented method for VNREDSAT-1 ortho image. Firstly, the optimal empirical parameters set up for the segmentation process involve shape (0.2), compactness (0.5), scale (15). Afterwards, the support practice types are defined by combining classified land cover and image interpretation method. The main types of defined land cover include resident, paddy, perennial tree, forest, bare land, industrial and water areas. The interpreted support practices contain contouring, terracing cultivations, forest, and others. All of these are divided into the strip and none-strip cropping cultivations. When comparing the classification result with 21 field samples, the total accuracy (Kappa factor) is appropriate 82%. The land cover map presented in Figure 7. Slope steepness made from DEM reclassified to the range values accord to the appendix B of TCVN 5299:2009 (MOST, 2009).

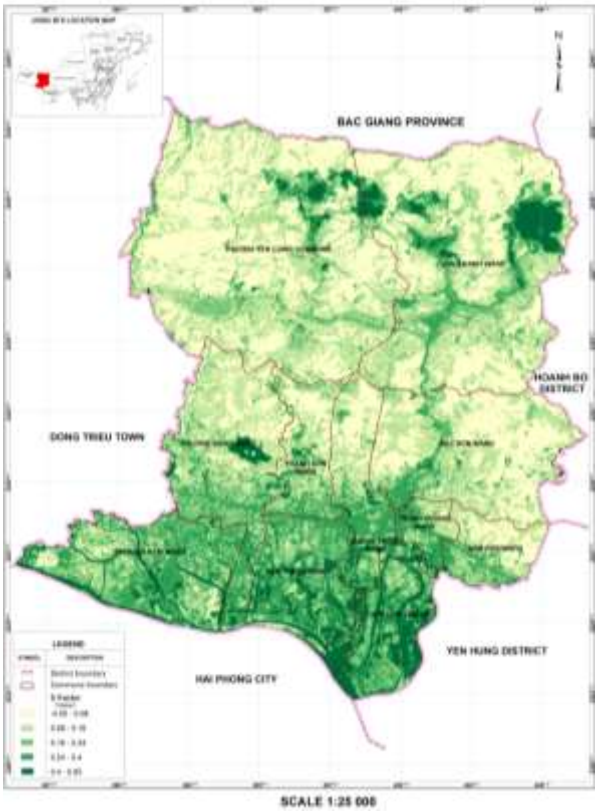

Figure 6. Uong Bi's cover management map

Overlaying support practice with a reclassified slope data to get conservation practices layer. Assigning referenced P values in Appendix B (MOST, 2009) for respective combinations. The Uong Bi's map of conservation practices shown in Figure 8.

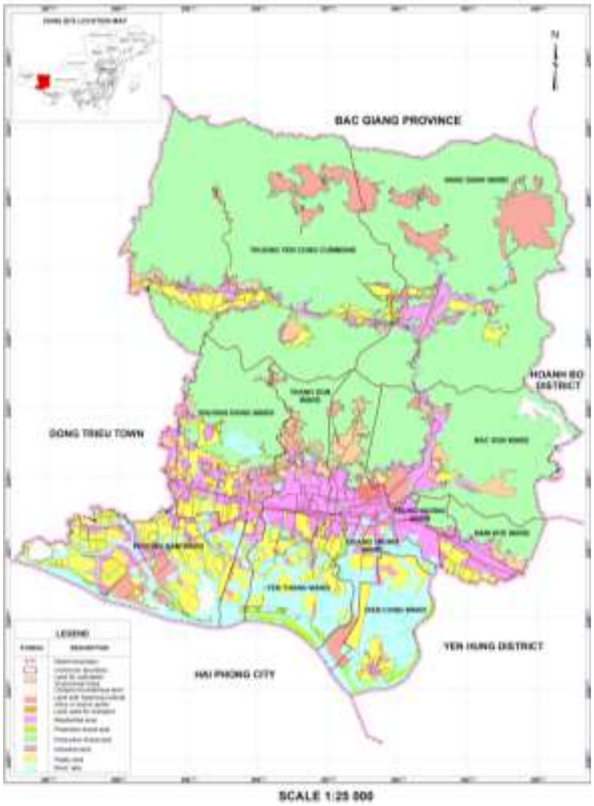

Figure 7. Uong Bi's land cover map

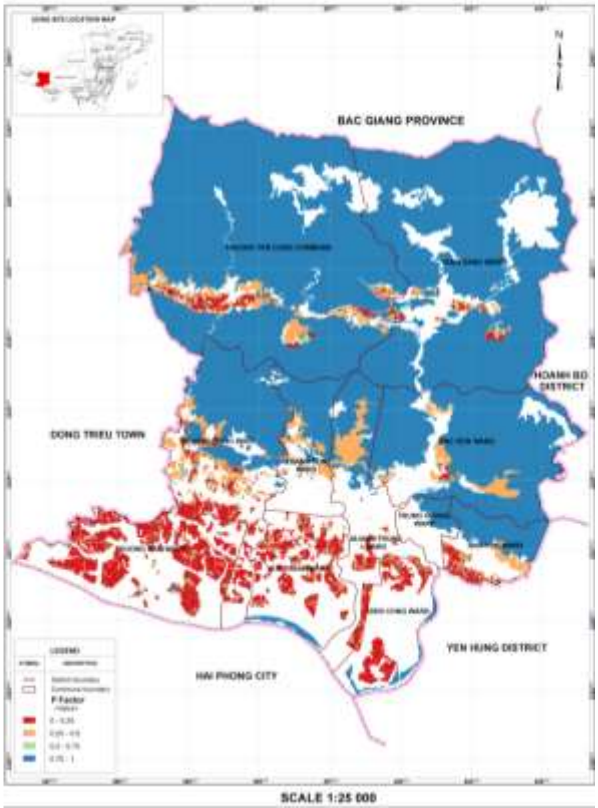

Figure 8. Uong Bi's conservation practice map

4.6. Establishing soil erosion map

Uong Bi's soil erosion map is created by integrating all maps of R, K, LS, C, P according to formula 1. The degree of soil erosion in the study area is divided into five ranges (MOST, 2009). Table 2 indicates the soil loss, the distribution of soil erosion in Uong Bi in 2013 shown in Figure 9.

Table 2. Statistic of Uong Bi' soil erosion in 2013

Soil erosion degree	**The loose soil (Ton/ha/year)**	**Description**	**Area (ha)**	**Percent (%)**
I	0-1	No erosion	7611.42	29.77
II	> 1-5	Moderate erosion	14557.38	56.94
III	> 5-10	Average erosion	805.55	3.15
IV	> 10-50	Strong erosion	358.56	1.4
V	>50	Extreme erosion	247.68	0.97
Total			**23580.58**	**92.24**

The results in Table 2 and Figure 9 show that:

- The areas of strong erosion and extreme erosion are mainly distributed in the high slope and elevation mountains (2.37% of total area);
- The average erosion areas in the relatively high hills occupy about 3.15% of total area;
- The moderate erosion areas distribute in the low hills and relatively flat terrain (56.94% of total area);
- The no erosion areas are in the delta, low landforms (29.77%).

The remaining percentage (7.76%) are non-argricultrural lands such as residential land; non-agricultural production, and business; and land for production of building materials, and pottery. These areas are not considered in this study.

5. DISCUSSION AND CONCLUSION

The study uses the RUSLE model, satellite images data, topographic data, and GIS to produce the component factor maps (R, K, LS, C, P) which are then integrated to map soil erosion in Uong Bi. C and P maps produced from VNREDSAT-1 satellite images, topographic data combine with the experimental standard (MOST, 2009) indicate the ability of remote sensing technology, especially using high-resolution and very high-resolution satellite imagery that could meet the requirements of soil erosion map for the large areas. The soil erosion map using remote sensing data for establishing is better in comparison with that produced by the traditional method.

The results of the project (coded BDKH.10/16-20) "Researching and applying modern technologies for building natural resource change management models, completing the management tools and improving the monitoring capacity in land use change" greatly contributing to the fact that the study on soil erosion using remote sensing technology and GIS is efficient and vital.

Figure 9. Uong Bi's soil erosion map

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CONTACTS

Dr. Son Nguyen Phi
Vietnam Institute of Geodesy and Cartography
Address: No 479, Hoang Quoc Viet street
City: Hanoi
COUNTRY: Vietnam
Tel: +84912308694
Email: sonnguyenphi@gmail.com
Website: www.vigac.vn