SOIL EROSION RISK MODELING WITHIN UPLAND LANDSCAPES USING REMOTELY SENSED DATA AND THE RUSLE MODEL

A case study in Huong Tra district, Thua Thie Hue province, Vietnam

Pham Huu Ty[1]

The aim of this research is to assess soil erosion risks for upland landscapes using the RUSLE model and remotely sensed data within a GIS and to propose several land use scenarios which are able to reduce soil losses. Each erosion factor of the RUSLE model was computed. The Tropical Rainfall Measurement Mission (TRMM) data, provided by point scale, was examined to calculate rainfall and runoff erosivity (R) factors. The monthly TRMM rainfall data and measured rainfall were significantly correlated with a regression correlation coefficient of approximately 0.9. Annual R values range from 960 to 1033 MJ mm ha^{-1} hr^{-1}, whereas the R values of the wet season are double that of the dry season. Additionally, the TRMM data describe the spatial variation of rainfall in the region better than measured rainfall at meteorological stations. The Digital Elevation Model (DEM) of Shuttle Radar Topographic Mission (STRM), NASA was validated with measured elevation values (720 points in official topographic maps) with the linear correlation coefficient of 0.96. Using this DEM, the topographic LS factors were computed from slope and flow accumulation algorithms. Flow accumulation illustrates the impact of upslope contributing areas to sediment detachment and transportation, so it better reflects the effects of concentrated flow on increased erosion on sloping areas. Landsat ETM+ images were used to calculate C factors by using the Linear Spectral Mixture Analysis (LSMA) model which determines the proportion of each land use type within each pixel. The comparison between bare soil and erosion resistant covers (vegetation cover and non-photosynthetic materials) resulted in C factors for pixels. Soil erodibility factors were computed from readily available soil maps by using a soil erodibilty nomograph. Lastly, soil loss rates were computed for pixels, and erosion risk classes were identified by reclassification. Erosion risks on rice cultivation land were moderate, whereas they were quite high on dry crop, protection forest, and unused land types. The most severe erosion rates occurred on production forest land which had poor vegetation cover. The RUSLE model was also used for developing forest land planning in which the balance between low erosion land area (protection forest) and severe erosion land area (production forest) was taken into account. Erosion risk and slope maps are useful to identify and delineate the spatial allocation of protection forest. In summary, the integration of the RUSLE model and remotely sensed data provides an effective tool for assessing soil erosion risks and selecting appropriate land use scenarios which can reduce soil losses in a large scale.

Key words: Remotely Sensed Data, GIS, RUSLE, Erosion modeling, Decision Support Systems (DSS)

1. RATIONALE

Soil erosion is one form of soil degradation that has been recognized as a serious hazard not only for agricultural lands, but also areas used for forestry, transport, and recreation. Soil erosion can result in both on-site and off-site impacts. On-site impacts are particularly important on agricultural land where the redistribution of soil within a field, the loss of topsoil from a field, the breakdown of soil structure and the decline in organic matter and nutrient levels result in reduction of cultivatable soil depth and a decline in soil fertility (Morgan, 2005).

Stream systems in Huong Tra district either flow into the Huong or the Bo River, and eventually transport sediments to low paddy field areas surrounding, and within Tam Giang Lagoon. Annual crops and forestry are the two main land use types, in which forest land accounts for 58 % of the total area. Additionally, unused land makes up 23 % of the total area. These types of land, forest and unused land, have been prone to water erosion due to poor vegetation cover and steep slopes. Ho Kiet (1999) measured soil losses on seven cropping systems from 1996 to 1998

[1] Pham Huu Ty, a lecturer of Faculty of Land Resources and Agricultural Environment, Hue University of Agriculture and Forestry, Vietnam

and indicated that annual soil loss rates varied from 18.28 t ha^{-1} (dry crops applying soil conservation practices) to 204.56 t ha^{-1} (agro-forestry systems) illustrating soil loss rates are very severe

Soil erosion risk modeling and identification of erosion risk levels will provide important information supporting for land managers and policy makers building appropriate decisions for land use planning and soil conservation planning in upland areas at large scales. The Revised Universal Soil Loss Equation (RUSLE) can be used for modeling soil erosion by water by incorporating five main factors: (i) rainfall and runoff, (ii) soil erodibility, (iii) topography, (iv) vegetation cover and crop management, and (v) soil conservation practices. In recent years, there have been many GIS and remote sensing software such as ArcGIS, IDRISI, and ENVI which facilitate the construction and use of RUSLE models in which erosion factors can be individually calculated and incorporated together to estimate soil loss rates at large spatial scale.

The aim of this research is to assess soil erosion risks for upland communes using the RUSLE model and remotely sensed data within GIS and image processing software, and to propose several land use scenarios which can reduce soil losses for the study area.

Objectives of this research include:

- *Integrating the Revised Universal Soil Loss Equation and remotely sensed data into a Geographic Information System (GIS) to simulate soil erosion risks by water*
- *Developing forest land planning in a commune by using erosion risk and slope limit maps for allocating protection forests*

2. METHODOLOGIES

2.1. The Revised Universal Soil Loss Equation (RUSLE)

The RUSLE model is generally expressed as follows (Renard et al., 1997):

$$A = R * K * LS * C * P \qquad [2.1]$$

where:

A = the annual average soil loss (t ha^{-1}),

R = the rainfall and runoff factor (MJ mm ha^{-1} hr^{-1}), which is is the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water where such runoff is significant,

K = the soil erodibility factor (t ha^{-1} per unit of R), which is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 72.6-ft (22.1 m) length of uniform 9 % slope continuously in clean-tilled fallow,

L = the slope length factor-the ratio of soil loss from the field slope length to soil loss from a 72.6-ft (22.1 m) length under identical conditions (dimensionless),

S = the slope steepness factor-the ratio of soil loss from the field slope gradient to soil loss from a 9 % slope under otherwise identical conditions (dimensionless),

C = the land cover and crop management factor (dimensionless), which is the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow,

P = the support practice factor (dimensionless), which is the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to soil loss with straight-row farming up and down the slope.

Risse et al., (1993) evaluated the USLE model and found that the correlation coefficient between measured soil loss and USLE-computed soil loss was 0.75 for annually average erosion. The high correlation coefficient illustrates the considerable efficiency of the USLE model, especially given that the same dataset showed an annual erosion variability of ± 35 % between replicated plots, which should have produced very similar erosion values. The RUSLE was developed from USLE, therefore it is expected to provide about the same degree of fit.

2.2. The study site

The Huong Tra district includes 7 communes: Hong Tien, Binh Dien, Huong Binh, Huong Ho, Huong Van, Huong, Huong Tho, and Binh Thanh. The area of upland region characterized by hilly and mountainous topography is approximately 408 square kilometers, which accounts for 78 % of the district area. The center of the region is located at $107^{o}27'59''$ E and $16^{o}22'46''$ N, about 15 kilometers Southwest from the center of Hue City. rainfall varies significantly in terms of time and slightly in terms of space. The majority of rainfall occurs between September and December, whereas the dry season lasts from February to May with rainfalls just less than 200 mm per month.

2.3. Methods of collecting data

Erosion factors within Equation [2.1] typically are determined by using remotely sensed data. The rainfall and run-off factors (R) are calculated by using monthly accumulated rainfall from the Tropical Rainfall Measurement Mission satellite and freely downloaded from the website: http://lake.nascom.nasa.gov. The topographic factors (LS) are estimated by using the Digital Elevation Model from the International Center for Tropical Agriculture (CIAT), a member of the Consultative Group for International Agricultural Research (CGIAR), who published a modified version of the Shutlle Radar Topography Mission satellite, in which all holes have been filled. Additionally, One free ortho-rectified Landsat ETM+ image (path 125, row 49) from June 2, 2001 was downloaded from the Tropical Rain Forest Information Center (TRFIC) via FTP. Also, another Landsat ETM+ image with the same path and row from March 31, 2007 was purchased from the Global Observatory for Ecosystem Services, TRFIC, Michigan State University.

All remotely sensed data sources were validated to assess their accuracies with ground-based measurement before using for calculating erosion factors. Monthly rainfall data was obtained from the Hue Centre for Meteorological Station to validate with SRTM rainfall. The Topography Map was collected at the Department of Science and Technology in Thua Thien Hue province to assess the accuracy of elevation values in SRTM – Digital Elevation Model. Furthermore, soil map and soil properties report were collected at the Department of Science and Technology in Thua Thien Hue province to estimate soil erodibility factors (C) in term of the soil-erodibility nomograph of Wischmeier and Smith (1978).

Field observations were conducted in Cham village, Huong Ho commune, Huong Tra district to determine land use and land cover patterns within the training site and to implement the analysis of linear spectral mixture model within pixels. Also, eroded areas and erosion issues were surveyed by interviewing local farmers and leaders at village. Land use map in Huong Tra district was obtained at the Centre for resources and environment in Thua Thien Hue province to determine erosion rates for individual land use types.

Soil erosin risk modeling is performed wihin pixel-by-pixel basic, so all data should be in raster format and the same resolution. Therefore, the original resolution of Landsat ETM+ is generally 30 m, and it was used to identify land cover patterns and to estimate the C factor. There are various land cover types recorded within a pixel because the size of pixel is typically insufficient to detect individual land cover types (.e.g. one pixel can contain w The original resolution of Landsat ETM+ is generally 30 m, and it was used to identify land cover patterns and to estimate the C factor. There are various land cover types recorded within a pixel because the size of pixel is typically insufficient to detect individual land cover types (.e.g. one pixel can contain water, trees, and road). Therefore, the finer resolution the image has the better the land cove type is detected. The SRTM DEM and TRMM data were originally processed at 90 m and 27 km resolutions respectively and eventually were reduced to the 30 m resolution. More importantly, USLE-measured soil losses were conducted on a standard plot of 22.1 m in length, therefore 30 m resolution will provide a similarity between the RUSLE model and remotely sensed data. All raster layers were managed in World Geodesy System 84 datum, and projected in Universal Transverse Mercator (UTM) 48 N projection. However, Landsat images were geometrically corrected due to the horizontal distortion of the Landsat images compared with the topographic map within IDRISI 14.02 software.

2.4. Methods of calculating erosion factors

2.4.1. Calculating rainfall and run-off factor (R)

The rainfall subsets of the study region were obtained from 1998 to 2006 in ASCII format which contains longitude, latitude, and accumulated rainfall. Then, ASCII files were imported into an Excel table and saved as an Excel DBF extension file which can be added and exported as a DBF shapefile in ArcMap to create point features. Before using for computing R factors, they were validated with monthly measured raindfall in 1998, 2000, 2004, and 2006. The TRMM accumulated and measured rainfalls are significantly correlated with high linear regression correlation coefficients ranging from 0,88 to 0,97. Rainfalls of TRMM from 1998 to 2006 were imported in ArcGIS 9.2 and interpolated into raster layers by Kiring method. The rainfall and run-off factors (R) was computed from Equation [2.2]. This is an imperical equation of Ho Kiet (1999) who implemented erosion measurement in sereral cropping systems within the same study area.

$$R_i = - 25,319 + 0,49917 * P_i \qquad (r^2 = 0.989) \qquad [2.2]$$

Where:

R_i = monthly rainfall and run-off factor (MJ mm ha^{-1} hr^{-1})

P_i = Monthly mean rainfall (mm)

2.4.2. Simulating topography factors (LS)

The hole-filled SRTM DEM, version 3 – a STRM 58(09) piece, was downloaded from the CGIAR Consortium for Spatial Information (CGIAR-CSI) at the website: http://srtm.csi.cgiar.org/ in zipped Arc-ASCII format. Therefore, it was converted into raster and projected to Universal Transverse Mercator (UTM) projection, zone 48 north.

A validation of SRTM data using an official topographic map collected from the Department of Science and Technology in Thua Thien Hue province was conducted. There are 720 available elevation points in the topographic map which were used as a mask to extract the elevation points from the SRTM DEM. The 720 extracted elevation values from SRTM were validated with 720 available elevation values in the topographic map by using linear regression equation in Minitab 14. The goodness of fit, with a regression correlation coefficient of 0.96, was the reason for utilizing SRTM data to compute LS factors.

The calculation of LS factors was integrated in the RUSLE model:

- Modeling slope using the SRTM - Digital Elevation Model within the Spatial Analyst extension of ArcGIS 9.2.
- Simulating accumulated flows for individual pixels using flow accumulation algorithm in Raster Calculator within ArcGIS 9.2.
- LS factors are computed by Equation [2.3] of Mitasova et al. (1996) as follows:

$$LS = (t+1)\left(\frac{A}{L_o}\right)^{t} * \left(\frac{\sin\beta}{b_o}\right)^{n} \qquad [2.3]$$

where:

A = the upslope contributing area per unit of width (m^2), which is calculated by multiplying cell size with accumulated pixel numbers that are fallen into the processing pixel,
β = the land surface slope (degree),
b_o = the standard slope of the plot in RUSLE (9 % or 5.16 degrees)
n = the constant, n varies between 1.0 and 1.4
t = the constant depending on slope

The Equation [2.3] was converted into Raster Caculator of ArcGIS 9.2.

2.4.3. Method of computing vegetation cover and crop management factors (C)

Alejandro (2007) made use of the fractional abundance of bare soil, vegetation cover, and non-photosynthetic material to define the C factor on a pixel-by-pixel basis as follows:

$$C = \frac{F_{bs}}{1 + F_{veg} + F_{NPM}} \qquad [2.4]$$

where:

F_{br} = the fractions of bare soil,
F_{veg} = the fraction of vegetation,
F_{NPM} = the fractions of non-photosynthetic materials.

Spectral Mixture Analysis (SMA) has been applied to address the problem of mixed pixels. Alejandro (2007) estimated the vegetation cover factors for modeling soil erosion using a linear spectral mixture analysis (LSMA) model of Landsat ETM and obtained a high correlation coefficient of 0.94, whereas that of the Normalized Difference Vegetation Index (NDVI)-derived C factor was only 0.64. The research was conducted in the Philippines which is situated from 14.70^{o} to 14.77^{o} North latitude, and from 120.98^{o} to 121.12^{o} East longitude. The climatic and vegetative condition of the Philippines is similar to Vietnam. The climate is dominated by distinct rainy and dry seasons with a mean annual precipitation of just over 2069 mm. This indicates the possibility of applying the LSMA model for the circumstance of Vietnam to estimate C factors.

The LSMA model was performed in the interface of IDRISI, a program which supports the processing of images. To conduct the analysis of the LSMA model, a 4 km training site was established in the Huong Ho commune. It was selected because of sufficiently representative land cover patterns for the whole area. The training site is a high spatial resolution image obtained from Google Earth. More details were added from field visits to confirm the current pattern of land covers. Additionally, it was digitized by using the on-screen digitizing tools and saved as a vector layer. There are four selected end-members: bare soil, vegetation, non-photosynthetic material (NPM), and water body.

The signature of each class within the training site was statistically calculated from six bands (band 1, 2, 3, 4, 5, and 7) of Landsat ETM+. The MAKESIG tool of IDRISI extracts the pixels over six bands for each information class and computes the signature statistics such as minimum, maximum, mean, variance, and covariance. The signature group of MAKESIG output was employed in the UNMIX module (the linear spectral unmixing or linear mixture modeling). The output of the UNMIX module consists of an image for each class indicating the percentage of that cover in each pixel and a residual image specifying how well the actual pixel values match the simulated values.

2.4.4. Method of deriving soil erodibility factors (K)

Soil erodibility values are computed from the soil erodibility nomograph (Wischmeier and Smith, 1978) for representative soil types in the region. Also, K values are assigned to similar soil types to make the final soil erodibility map

3. RESULTS AND DISCUSSIONS

3.1. Erosion factors in the RUSLE model

Annual R values range from 967 to 1033 MJ mm ha^{-1} hr^{-1}, whereas the R values of the wet season were double those of the dry season. Calculated R values were compared to literature reviewed values and show that they are noticeably close to those of Ho Kiet (1999) who found values of 1130 MJ mm ha^{-1} hr^{-1} in Thua Thien Hue province and 963 MJ mm ha^{-1} hr^{-1} in the north of Vietnam for Thai Phien (1999). Additionally, R values were well differentiated in the region in terms of space and time. The distinct variation of R values respects the nature of spatially and temporally uneven rainfall distribution and provides unbiased values while modeling soil erosion in the RUSLE model.

LS values mainly range from 0 to 50. However, there are significant areas where LS values exceed 50. Those values are typically distributed on steeply sloped mountains or hills, especially on over 16^{o} slope areas which account for over 28 % of the total area. High LS values illustrate the high potential of soil erosion in this area

The fraction of each cover class, including bare soil, non-photosynthetic materials (such as concrete roads or roofs of houses), and vegetation cover, was incorporated into Equation [2.4] to derive C factors and to create C factor map (Figure 3.1).

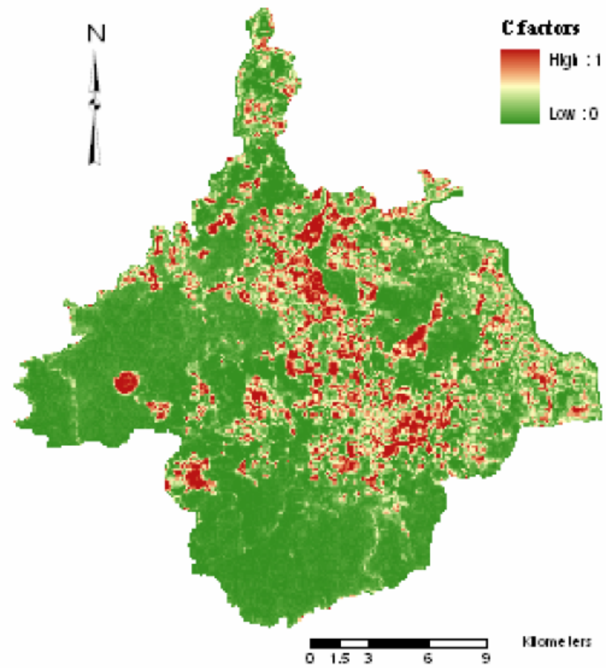

Figure 3.1. Vegetation cover and management (C) factor map for the study area

It appears that the higher the percentage of bare soil, the higher the C value. It is clear that LSMA-derived C factors represent better the influence of vegetation cover in terms of space than that of literature-reviewed factors because LSMA-derived C factors calculate a value for individual pixels, whereas literature reviewed factors assign one value to a large area for a land use type. The limitation is that the C factor of a pure pixel, which is fully enveloped by canopy or ground cover, equates to zero which rarely occurs in practice. In fact, erosion might occur even when the ground surface is fully covered by canopy cover or ground cover. Nonetheless, the rate of erosion is very low in this circumstance, so it can be reasonable when identifying erosion risk areas for the strategy of soil conservation.

The conservation practice factors (P) were not calculated because of time limitation and limited conservation practices applied in the study area. Therefore, P factor was assigned to 1 for all region.

4. EROSION RISK MAPPING

All erosion factors of RUSLE were aggregated and computed in ArcGIS 9.2 to derive annual erosion risk map (Figure 3.2). The large area of zero erosion corresponds to the dense forest land and rice fields, whereas severe erosion risks are mainly found on very steeply sloped areas and bare land within dry crop land. Additionally, the most severe erosion risk typically occurred on critical regions such as ridges and passes where forest trees were not taken into account by villagers due to the difficulties of terrain. Generally, over 75 % of the area was identified as insignificant erosion risks, the rest was very vulnerable to erosion, which is approximately 97 km^2 accounting for 24 % of the total area. Land use maps in 2006 were also digitized to identify seven main land use types in this region (Table 3.1). The total area and total soil loss of each were calculated to compute annual mean soil loss rates for each land use pattern.

Table 3.1 Annual mean soil losses for individual land use types

Land use type	Erosion risk area (km^2)								Total area (km^2)	Annually average soil losses ($t\ ha^{-1}$)
	Nil	Very slight	Slight	Moderate	High	Severe	Very severe	Catastrophic		
Rice cultivation land	6.4	0.3	0.3	0.3	0.6	0.1	0.1	0.0	8.2	9.5
Dry crop land	16.7	1.0	1.0	1.0	3.2	1.2	1.5	0.3	26.1	28.4
Protection forest	60.9	1.5	1.8	2.2	7.4	3.2	4.7	1.2	82.8	35.0
Unused land	53.0	2.2	2.3	2.9	9.4	3.9	5.4	1.3	80.5	40.5
Security land	8.9	0.4	0.4	0.4	1.4	0.5	0.7	0.3	12.9	46.7
Natural production forest	69.5	1.8	2.0	2.5	9.2	4.7	8.7	3.4	101.7	66.1
Planted production forest	9.4	0.3	0.4	0.4	1.7	0.8	1.5	0.7	15.2	81.5

The Table [3.1] illustrates that erosion rates on rice cultivation were moderate because Landsat images were taken at the period of the non-cultivation season of rice. They are typically not significant because rice fields are distributed on fluvial areas with very low slope and subdivided into very small plots which are surrounded by stable banks.

Annual soil losses on dry crop, protection forest, unused, and security land are fairly high ranging from 28 to 46 $t\ ha^{-1}$. Traditionally, maize, peanut, bean, sweet potato, cassava, and flowers are solely grown, alternated, or interplanted on dry land, so their cover changes successively from one growing stage to another. While protection forest land has one of the densest vegetation covers, soil loss rates are high because it is scattered on steeply sloped mountains or hills. In addition, illegal wood logging has resulted in the degradation of the protection forest. Security land is allocated to the military and is used for different purposes such as farming, building, and military practices. The erosion rate is high because its vegetation cover is low. Unused land accommodates several land cover patterns such as forest, shrub, and bare land, so its plant cover is variable. Shrub cover is typically the greatest proportion of vegetation cover on unused land and frequently maintained on the ground, but forest cover has been degrading due to over-exploitation by villagers. That is why the erosion rate of unused land is high.

Production forest consists of two main types: (i) natural forest and (ii) planted forest. They are commercial forests, timber production, or non-timber forests and assigned to individuals, households, or economic organizations. The vegetation cover of production forest is poor, therefore its erosion rate is severe. The erosion rate of planted production forest is the highest with

81.5 t ha^{-1} annually. Planted forest is one of the most important programs in which forest land and sloping unused land are allocated to individuals, households or forest groups to recover or replant forest for the sake of villagers' income, so forest land cover has moderately increased.

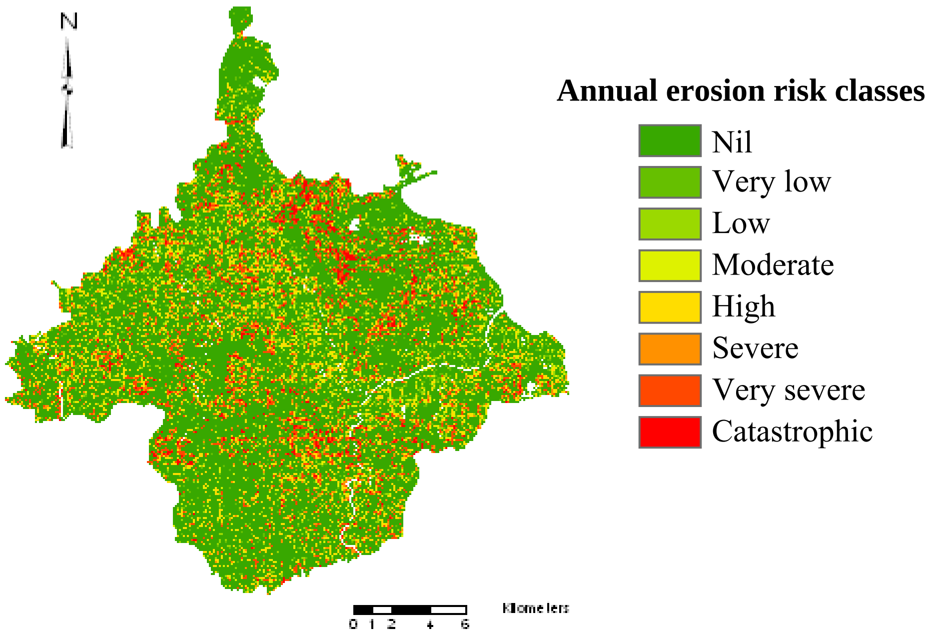

Figure 3.2 Annual erosion risk map for the study area

However, there are several reasons resulting in severe erosion in those areas. First of all, the clearance of shrubs causes the reduction of vegetation cover. Moreover, forest land holders are allowed to log trees for commercial means and therefore they usually harvest earlier than the fixed production cycle during high timber price periods.

In summary, high rainfall, steep slope, and poor plant cover are the most important factors that contribute to high and severe soil erosion risk in the study area. The vegetation cover of forest land impacts greatly on the total erosion losses of the region because forest land represents the greatest area and possesses the most vulnerable areas to erosion by water due to high potential runoff and steep slope. Therefore appropriate forest development and protection planning, in which soil erosion conservation practices are taken into account, is very necessary for the study area.

The literature-reviewed comparisons were examined. Ho Kiet (1999) conducted soil loss measurements on several farming systems in the same study area: (i) traditionally planted forest (model 1), (ii) mixed forest (model 2), and (iii) dry crops (model 3). All models were measured on different slopes ranging from 5^{o} to 12^{o}. Model 1 was grown with *Acacia Auriculiformis* and soil losses were monitored at the third year growth stage. Model 2 was similar to model 1, but it was interplanted with a variety of indigenous trees, for instance *Manglietia conifera Dandy, Litsea glutinosa (Lour.) C.B.Roxb, and Michelia mediocris Dandy.* Model 3 was mixed with peanut and green bean. To compare soil losses on those models, three similar farming systems were identified in the field and delineated on a high resolution Google image. The soil loss of each model was extracted from the simulated erosion map to compute its annual mean soil loss. Simulated and measured soil losses are reasonably similar, but simulated soil losses are typically greater than measured soil loss (Figure 3.3).

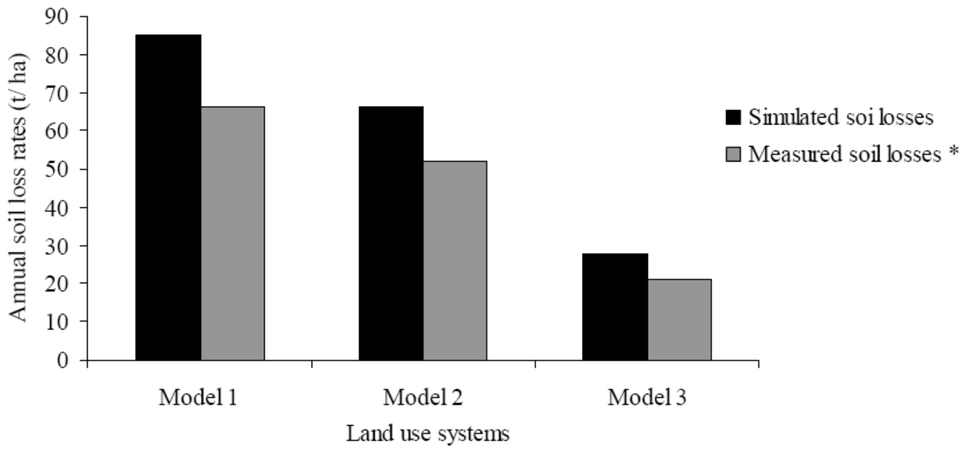

Figure 3.3. Comparisons between annually simulated and measured soil loss rates
** Annual soil losses of three models were conducted by Ho Kiet (1999)*

4.1. Decision Support Model (DSM) for forest land use planning

Recently, forest conservation and development planning has been implenmented in Thau Thien Hue province at communal level. The most important requirement is to determine the location, boundary, and purposes of three type of forests: protection forest, production forest, and special-use forest. Protection forest plays an environmentally important role in flood mitigation, erosion protection, and environmental improvement. Therefore, the appropriate identification of protection forest will be extremely necessary.

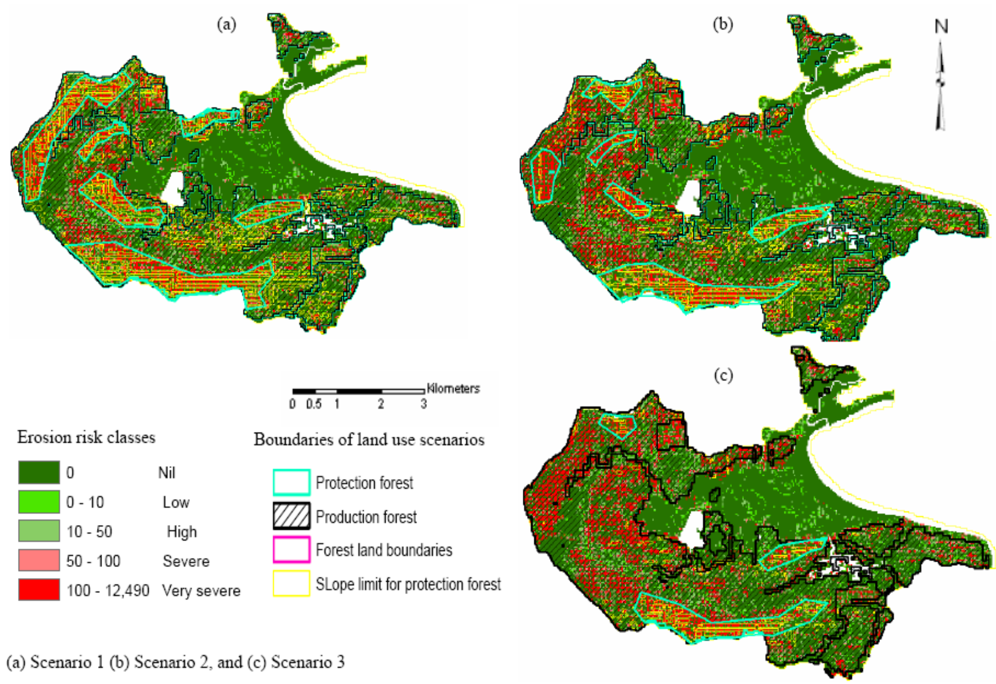

Figure 3.4 Forest land use scenarios in Huong Ho commune

However, it is challenging for planners to locate protection forest in the field due to difficult terrain, limitation of local awareness of protecting forest, and lack of supporting database. Soil erosion is one consequence of low forest cover. According to simulated models, erosion rates on protection forests are much lower than thos of production forests because of better protecting forest cover. Therefore, protection forest should be appropriately planned for reducing soil erosion by water and increasing the ability of improving environment. Two main criteria, erosion risk level and slope, were selected to identify protection forest location and boundary. Protection forests should be allocated in severely actual erosion risk areas and high potential erosion areas, which is steep slope areas (Figure 3.4). There are three scenarios simulated as follows (Table 3.2):

Table 3.2 Summary of scenarios for forest land planning

Forest land scenarios	Description	Production forest		Protection forest	
		Area (ha)	%	Area (ha)	%
Scenario 1	Protection forests are located on severe erosion risk areas and slope limit greater than 30 %	1553	71	611	29
Scenario 2	Protection forests are located on severe erosion risk areas and slope limit greater than 40 %	1777	82	387	18
Scenario 3	Protection forests are located on severe erosion risk areas and slope limit greater than 50 %	1927	89	237	11

5. CONCLUSION

Integration of the RUSLE model and Remotely Sensed Data (such as TRMM, SRTM, and Landsat images) into GIS platforms (ArcGIS 9.2, IDRISI 14.02) provides a useful tool for soil erosion modeling in a large scale. Accuracies of Remotely Sensed Data (such as TRMM, SRTM, and Landsat images) were validated and provided good confidences in simulating and calculating erosion factors by water. However, there are significant limitations of remotely sensed data due to coarse resolution and geometric distortions that constrains the accuracy of erosion modeling. Although, soil erosion risk modeling accommodates several weaknesses, erosion risk maps will help environmental and natural resources management agencies monitor the status of erosion and affected factors to soil erosion, such as land cover, land use, and topographic features. Overlaying erosion risk maps and slope limit maps enable land managers and policy makers to initially identify locations and areas of protection forests which can help reduce soil erosion and improve environment quality. Additionally, it is possible to integrate remotely sensed data and the RUSLE within GIS platforms as a screening tool when making decisions on selecting appropriate land use scenarios. However, simulated erosion risks should be surveyed and validated with actual data. Land managers and policy makers should conduct soil erosion risk assessment for upland areas in the land use planning. Incorporating more supporting data, such as local knowledge, economic conditions of local households, policy, and others, to build a multi-criteria or multi-agents model -based forest land planning

6. REFERENCES

Alejandro, M.de Asis, Kenji Amasa. (2007). Estimation of vegetation parameter for soil erosion using linear Spectral Mixture Analysis of Landsat ETM data. Photogrammetry and Remote Sensing Journal, 62, 309-324.

Department of Science and Technology. (2004). *Characteristics of climatic and hydrological conditions in Thua Thien Hue province*. [Vietnamese version]. Hue city, Vietnam: Thuan Hoa Publisher. Ho kiet (1999). Soil erosion and deposition assessment on cropping systems in Huong River basin, Thua Thien Hue province, Vietnam. (Doctoral Dissertation, Ha Noi University of Agriculture)

Mitasova, H., Hofierka, J., Zlocha, M., Iverson, L.R., 1996. Modelling topographic potential for erosion and deposition using GIS. Int. J. Geogr. Inform. Syst. 10, 629–641.

Morgan R.P.C. (2005). Soil Erosion and Conservation. The United Kingdom: Blackwell

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C. (1997). *Predicting Soil Erosion by Water:* A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA-Agriculture Handbook No. 703.

Risse, L.M., Nearing, M.A., Nicks, A.D., Laflen, J.M. (1993). Error assessment in the universal soil loss equation. Soil Science Society of America Journal 57, 825– 833.

Thai Phien and Nguyen Tu Siem. (1999). Upland soil in Vietnam : Degradation and Restoration. Ha Noi, Vietnam : Agricultural Publisher.

Wischmeier, W.H., Smith, D.D. (1978). Predicting Rainfall Erosion Losses — A Guide to Conservation Planning. USDA-Agriculture Handbook No. 537. Washington: U.S. Government Printing Office.