Available online at www.humg.edu.vn

ESASGD 2016

GIS-IDEAS (2016)

Conference Title: International Conference on GeoInformatics for Spatial-Infrastructure Development in Earth & Allied Sciences (GIS-IDEAS)

Usage of LUCIA model in assessing the effects of climate change to main crops at slope areas: A case study at Phong Xuan commune, Phong Dien district, ThuaThien Hue province, Vietnam

Nguyen Hoang Khanh Linh[a]*, Nguyen Thi My Quynh[b], Nguyen Bich Ngoc[a]

[a]*Hue University of Agriculture and Forestry*
[b] *Centre for Planning and Design on Agriculture and Forestry, Thua Thien Hue Province*

Abstract

The objective of this study is to evaluate the application of LUCIA model (Land Use Change Impact Assessment) in assessing the effects of climate change on main crops under differential scenarios in mountainous areas at Phong Xuan commune, Phong Dien district, Thua Thien Hue province. Various data (weather, rainfall, inflow, outflow, digital elevation model, soil, land cover) were collected and analyzed by LUCIA and GIS. Based on land use orientation to 2020, three land use scenarios were created and surveyed in field samples. The results showed that the estimated soil loss due to erosion of cassava was larger than acacia and rice plant. The integration of LUCIA model and GIS tool in this study allows simulation of soil loss and their distribution in space of an effective and fast way. Besides, it could help in simulating the change of nutrition inside the plant as the impact of climate change. Based on the assessment, the study also aims to select an effective arable land for assisting policy-makers in the management and protection land resources under climate change.

Keywords: *erosion, GIS, LUCIA, mountain, nutrition, plant, simulation*

1. Main text

Due to climate change on a global scale, the disasters in Vietnam are increasing in number, intensity and level of impact, which effect significantly on production activities, economic development, and social aspect. According to the World Bank, Vietnam is among five countries that could be the most severely affected by climate change. The Vietnamese Ministry of Natural Resources and Environment announced (2009) that the average annual temperature has increased by about 0.5°C and sea level has risen about 20cm during the last 50 years. Accordingly, the average temperature in Vietnam could rise 3°C and the sea level could rise one meter in 2100 under climate change scenarios. It estimates that about 2 million hectares of paddy land of more than 4 million hectares at present could be lost, which seriously threats to national food security and affects ten of millions of people (Dao Xuan Hoc, 2009).

In Vietnam, sloping areas occupy about 74% of natural ground. There is around 9.4 million hectares of agricultural land. In which, 4.06 million hectares is paddy land and more than 5 million hectares of land is mostly in sloping land. Since most of the low land has been exploited, so the mountainous areas are the only place where the potential arable land could expand. In addition, the slopes are strongly varied. Therefore, the use of land for agricultural production in occupied mountain cab be seen as important strategy for developing economy (Le Trong Cuc, Chu Huu Quy, 2002). However, the usage of land in sloping areas still contains various problems and shortcomings. According to statistics, the total area at risk of erosion in Vietnam is 13 million hectares, accounting for 40% of total natural area (Nguyen Anh Hoanh, 2010). Average arable land in

* Corresponding author. Tel.: +84 01634647777;
E-mail address: nguyenhoangkhanhlinh@huaf.edu.vn

the country is decreasing every year, from 0.101 ha to 0.036 ha per capita. The fragmentation of agricultural land in combination with inappropriate farming leads to lower crop yield and poverty, especially in the hills (Le Van Du, 2011). Therefore, the use of sloping land resources should be seen as a strategy based on efficient use and sustainable development to avoid damages due to lack of awareness and voluntarism (Ho Thi Hong Hanh, 2010). In this case, the subject of research is to simulate the risk of soil erosion and degradation in plant nutrition under the impact of climate change in the slope areas at Phong Dien District, Thua Thien Hue Province using GIS and LUCIA toolkit. Based on that assessment, the research results will assist policy-makers in the management and protection of land resources in mountainous areas.

2. Study area

Phong Xuan commune has a quite large area of agricultural land, which occupies mostly in slope areas. Therefore Phong Xuan commune was chosen as to evaluate the risk of soil erosion. Phong Xuan, a mountainous commune, locates in southwest of Phong Dien district centre around 9km and covers an area of 15667.31 hectares naturally, distributed over 15 villages. The hilly terrain at Phong Xuan district occupies an area of about 13,000 hectares (nearly 83% of natural land). Accordingly, agricultural land still plays a dominant role in economic structure and life of people at Phong Xuan commune.

3. Data and methods

3.1. Select research sites

Field samples of research site were selected based on their characteristics of the slope, rainfall, crops and methods of cultivation. Based on the coverage percentage of each type of land use, number of site plots was determined appropriately. In which, each type of land use has at least three site plots at study area. The sampling sites have at least one differential characteristic of the slope, crop, rainfall or soil conservation measures in comparison with the remaining positions.

3.2. Methods of data collection, data processing

- Collect secondary information: Collect documents and data such as natural conditions, socio-economic situation of land use, maps of land use, elevation diagrams and maps point at Phong Xuan commune.
- Investigation and field survey methods:
• Survey, cross-check, supply and revise the geographical elements on maps.
• Field surveys to ensure the accurate of documentation and collected data.
- Expert advice method: learn more about the economic efficiency of agricultural production.

3.3. Simulation the change of plant growth in LUCIA

After providing input data including digital elevation map, soil map, land use/cover map, the direction of flow, hydrology map and sample plot map of the survey, the software analyze the changes and productivity of plant biomass under the impact of climate change scenarios.

3.4. Simulation the erosion in LUCIA

LUCIA is used to simulate erosion based on RUSLE (Revised Universal Soil Loss Equation). The model is designed to evaluate, calculate the volume of soil loss caused by rain and runoff surfaces. RUSLE formula is expressed in Renard et al (1997), (Pham Huu Ty, 2008) as follows:

$A = R * K * LS * C * P$

Inside:

A: The average amount of soil loss per unit area in the year; R: coefficient of rainfall-runoff; K: Coefficient of soil erodibility; LS: Coefficient of slope length; S: Coefficient of slope steepness; C: Coefficient of cover-management; P: support practice factor.

3.5. Method map

- Using GPS devices and land use map to locate the position of study sites in the communes.
- Using specialized software such as Microstation SE, MapInfo and ArcGIS 10.2 software to generate input data for LUCIA model.

4. Result and discussion

4.1. Main crops in Phong Xuan commune

Phong Xuan commune is a highland area, where topography is mostly in hilly form. Therefore, cultivation land, especially food crops, is rather less, just about 1000 hectares (accounting for 7% of agricultural land at commune). Major crop likes paddy rice covered an area of 846.6ha, concentrated mainly in the villages such as Vinh Ngan, Dien Loc, Hien An. The average yield is 54.7tons/ha, total production reaches at 4630 tons, of which: winter-spring crop: 414.6ha, average yield 54.2tons/ha, total production 2247 tons; summer-autumn crop: 432 hectares, average yield 55.2tons/ha, total production 2384 tons. Corn is planted mainly in winter season, which is intercropped with early crops such as peanut and cassava. Cassava is planted in area of 262.5 ha, the average yield is 250tons/ha, total production reaches at 6562 tons. Peanut is planted in area of 272.64 ha, the average yield is20 tons/ha; total production reaches at 545.2 tons. Bean is normally intercropped with main crops such as potatoes and cassava, which are mainly local varieties (green, red, black bean). The area of other cultivation crops is 129,8ha; including: vegetable 82ha, other beans 10ha, pepper: 9.3 ha, other fruit trees 26,5ha.In addition, the commune has nearly 13500ha of forest land. In which, 3000ha of procedure forest was covered by acacia with average yield of 50 tons/ha, which was considered as the main contributing to poverty alleviation in the villages.

4.2. Preparing input data for LUCIA model

Terrain data used in the model is DEM was interpolated from elevation map by Kriging method in ArcGIS 10.2 with the cell size of 25 meters (Figure 1a). Based on digital elevation map, it shows that the terrain in Phong Xuan commune is very complex, with high ascending direction towards northeast - southwest. Only in the range of 15000 hectares, the altitude changes from 1.41m to 1662.66m. It means that the topography of the commune is prone to soil erosion.

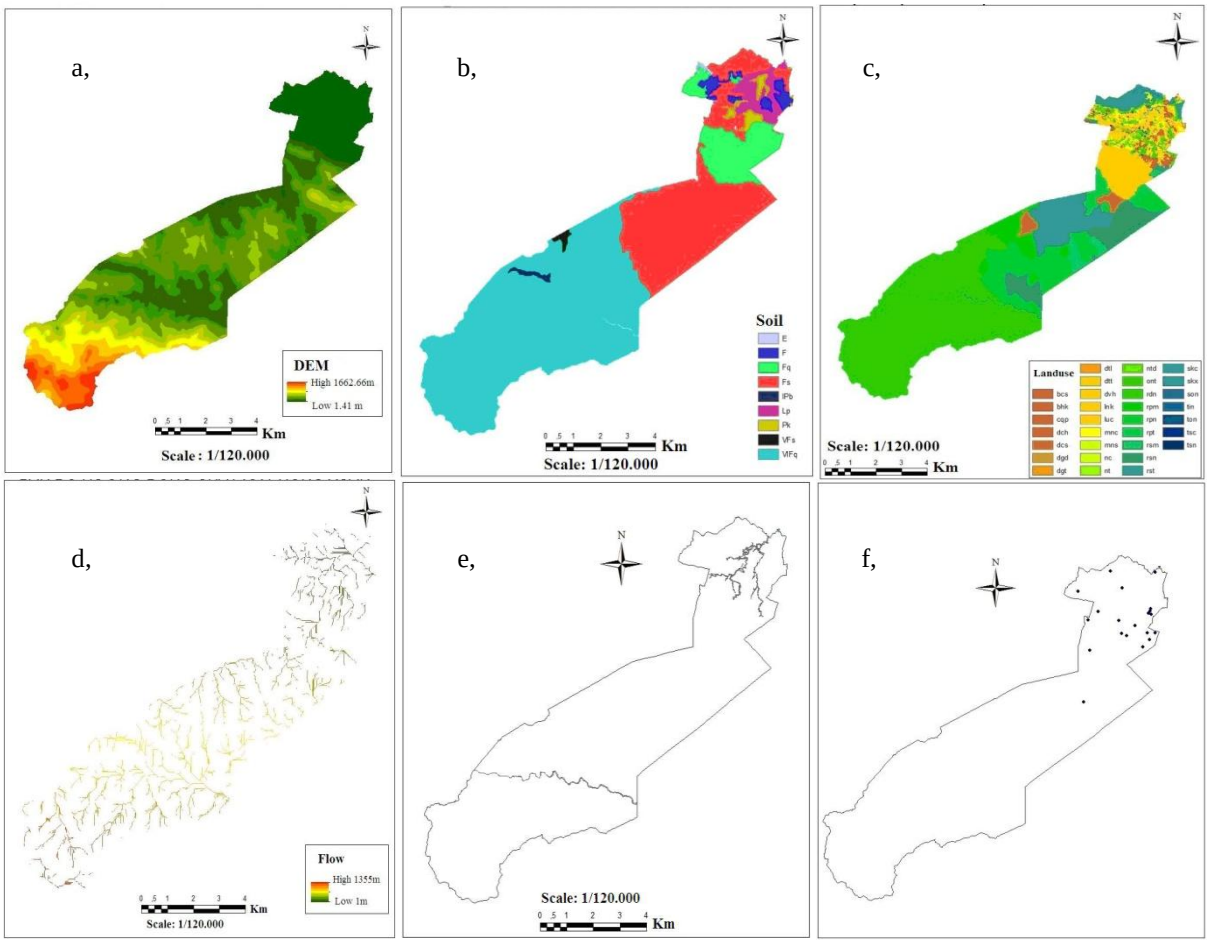

Figure 1.a, Digital elevation map; b, Soil map; c, Lan use/cover map; d, Inflow and outflow map; e, Hydrology map; f, Field sample points in Phong Xuan commune

The soil map in Phong Xuan was extracted from soil map of Thua Thien Hue province within boundary region of commune by ArcGIS with Clip command in Analysis Tools toolbar. Then soil map was transferred to raster format by the command Polygon to Raster Conversion Tool toolbar with the cell size of 25 meters (Figure 1b).

As analytical results, the soils in Phong Xuan commune includes mostly yellowish soil on sandstone (Fq), red soil (F), barren soil on shale (Fs), very shallow soil over hard rock Leptosols (Lp), gravel and stones (E) and some other soils. The soils, occupied in large areas, are mainly distributed in the southwest of the commune and covered by forest. In the northeast of the commune, the soil types are occupied in small areas and belong to clay sand. Based on soil map and land use/cover map, three kind of land soils were selected as soil erosion factors, including: pale yellow soil on sandstone (Fq), barren soil on shale (Fs) and the very shallow soil over hard rock Leptosols (Lp).

Similarly, land use/cover map, collected from Natural Resources and Environment Department of Phong Dien district, was switched from Microstation format to ArcGIS format. And then the data was converted to raster by Conversion Tools raster type with cell size of 25 meters (Figure 1c). The results show that agricultural areas concentrate mainly in the northeast of commune, where paddy rice and other annual plants are cultivated. Conversely, perennial plantations and production forest are mostly in southwest of commune. Based on research objectives, three kinds of agricultural crops in the commune were selected, including paddy rice, cassava in group of annual crops, and acacia tree in group of perennial trees.

The direction of flow within Phong Xuan commune was created from DEM map by using the commands in Spatial Analyst ArcGIS software (Figure 1d). The result shows that flows across the entire commune under uncertain directions because of the complicated terrain. Generally, inflow and outflow mainly run along the steep mountain ravines, forming small flowsin upstream area.

The hydrological map was constructed by filtering from status land use map. And then it was converted to raster format by command Polygon to Raster Conversion Tools toolbar in ArcGIS, with a cell size of 25 meters (Figure 1e). Hydrology system in commune are mainly small, short and deep rivers flowing under the base of the mountains, which causes soil prone to erosion and landslides.

The sampling sites in this study were selected based on soil map and land use map. Various types of land use including paddy land (LUC), land with annual crops (BHK), production forest land (RST) in land use map were overlayed to soil map including soil on sandstone yellow (Fq), barren soil on shale (Fs) and the very shallow soil over hard rock Leptosols (Lp). Based on overlayed map, sampling points had been selected from field surveys (Figure 1f). Garmin eTrex 10 device was used to locate the coordinates of sampling points in the field in order to compare and cross-check to choose the right kind of soil and plants for study.

4.3. Assessing the erosion of changing the crops

Based on the current status of land use and land use orientation of Phong Xuan commune to 2020, three land use scenarios were created and 20 sample pointswere surveyed. After running the model, three field sample points were selected to perform resultsofsoilerosion, namely 1, 3 and 10.

Point 1 locates in coordination 754,027.59; 1,829,237.11, where slope ranges from 3 to 8 degree with soil type Lp (heading Leptopsoil). Twoscenarioswith different landusetypeswere designed for the next ten years (Table 1). Based on input data, the LUCIA model processed and gave results expressed in Figure 2.

Table 1. *Land use scenarios at point 1*

Title	Year				
	Year 1-2	Year 3-4	Year 5-6	Year 7-8	Year 9-10
Scenario 1	Acacia	Acacia	Acacia	Acacia	Acacia
Scenario2	Cassava	Cassava	Cassava	Cassava	Cassava
Scenario3	Acacia	Acacia	Cassava	Cassava	Cassava

Figure 2.*The amount of soil loss in point 1*

It shows that planting Acacia could preserve land from soilerosion better than planting cassava. The average amount of soil loss by planting Acacia is 1.45Mg/ha/day, while the average amount of soil loss by planting cassava is approximately 240Mg/ha/day. The modeling in scenario 3 indicates that if crop change from acaciato cassava, the amount of soil loss increase rapidly, which is equivalent in comparison to scenario 2 for ten years.

Point 3 locates in coordination 749,441.04; 1821007.1, which is covered by light yellow soil on sand stone and its slope is less 3 degree. The change of land use types is presented in Table 2. Based on input data, the LUCIA model processed and gave results expressed in Figure 3. Even though Point 3 has the same land use scenarios as Point 1, but the amount of soil loss due to erosion is totally different (Figure 3). The analytical results demonstrate that the average amount soil loss by planting Acacia is about 0.906 Mg/ha/day, while the average amount soil loss by

planting cassava is approximately113 Mg/ha/day. It shows that the average amount of soil loss at Point 3 decreases about50% in comparison to Point 1. Accordingly, soil erosion occurs not only by land use types, but also by type of soils and slope in farming areas.

Table2. *Land use scenarios at point 3*

	Year				
	Year 1-2	Year 3-4	Year 5-6	Year 7-8	Year 9-10
Scenario 1	Acacia	Acacia	Acacia	Acacia	Acacia
Scenario2	Cassava	Cassava	Cassava	Cassava	Cassava
Scenario3	Acacia	Acacia	Cassava	Cassava	Cassava

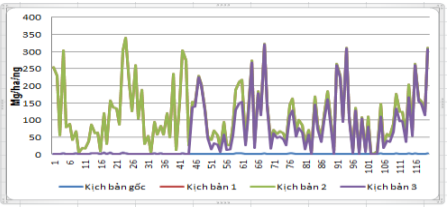

Figure 3. *The amount of soil loss in point 3*

Point 10 locates in coordination 749,084.84; 182,8031.62, which is covered by light yellow soil on sand stone and its slope is less than 3 degree. The change of land use types at point 10 is presented in Table 3. After processing input data, the LUCIA model gave results expressed in Figure 4.

Table 3. *Land use scenarios at point 10*

	Year				
	Year 1-2	Year 3-4	Year 5-6	Year 7-8	Year 9-10
Scenario 1	Paddy	Paddy	Paddy	Paddy	Paddy
Scenario 2	Cassava	Cassava	Cassava	Cassava	Cassava
Scenario3	Paddy	Paddy	Paddy	Cassava	Cassava

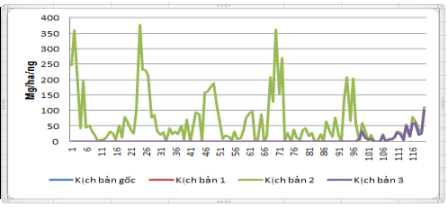

Figure 4. *The amount of soil loss in point 10*

Result in Figure 4 shows that the average amount of soil loss by planting paddy rice just around 0.005 Mg/ha/day, while the average amount of soil loss by planting cassava is approximately 63.92 Mg/ha/day. Accordingly, planting cassava could cause soil erosion bigger than other plants. As can be seen from the graph of scenario 3, the amount of soil loss increase visibly when the land use changes from paddy to cassava.

4.4. Simulation change of major crops under the climate change scenarios

Based on climate change in Vietnam, three scenarios (A2, A1B and B1) have been selected as the trend of climate change for the next decades. Accordingly, scenario A1: annual temperature rises 0.04 degree/year, annual rainfall reduces 0.2 mm/year; A1B: annual temperatures increases 0.5 degree/year, annual precipitation has not changed; B1: temperature increases 0.3 degree/year, annual precipitation has not changed.

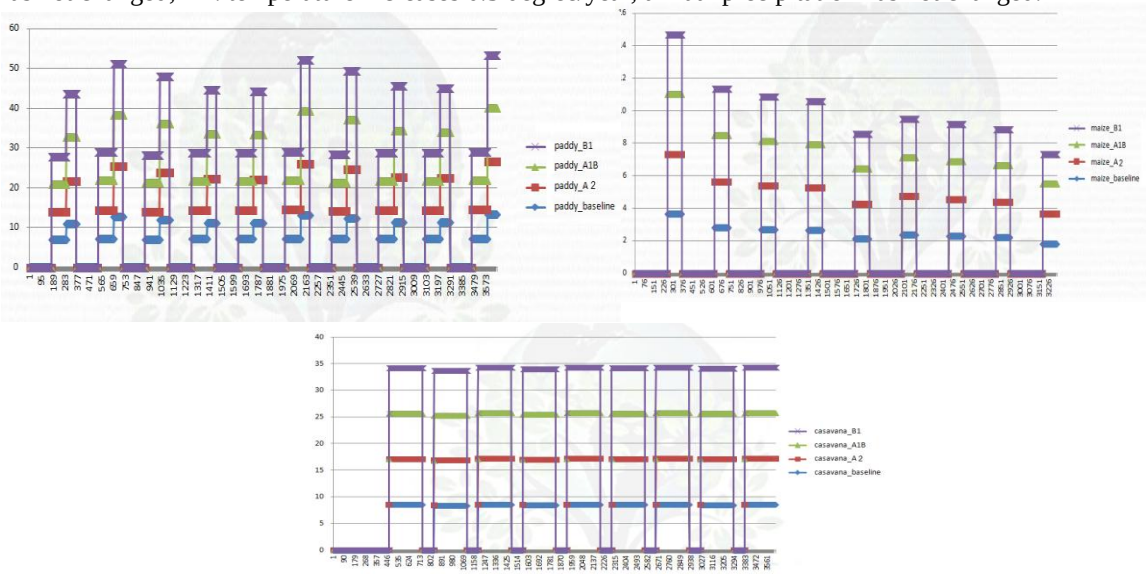

Figure 5.*Productivity of paddy rice, maize, cassava*

After changing the parameters and running LUCIA model, the yield and biomass of paddy rice, maize and cassava were identified and figured out as Figure 5 and Figure 6. As can be seen the results shown in the chart above, the productivity and biomass of crops under climate change scenarios are totally different. Accordingly, the change of biomass depends on type of crop, whereas the change of productivity depends on temperature. Figure 5 indicates that the productivity of paddy rice has the biggest changes, following maize and cassava.

Consequently, productivity can be seen as the most sensitive parameter. Based on LUCIA model, the analytical results show that:

- Scenario B1 has the good result in getting biomass and productivity in comparison with other scenarios.

- The light increase of temperature does not affect the productivity of the crop. In this case, the increase in temperature in the next 30 years is still in the allowed threshold.

- The climate will affect productivity of paddy rice, cassava and maize. In particular, it is one of reasons that reduce rice production; meanwhile, productivity of cassava and maize will increase, which leads the growth of biomass.

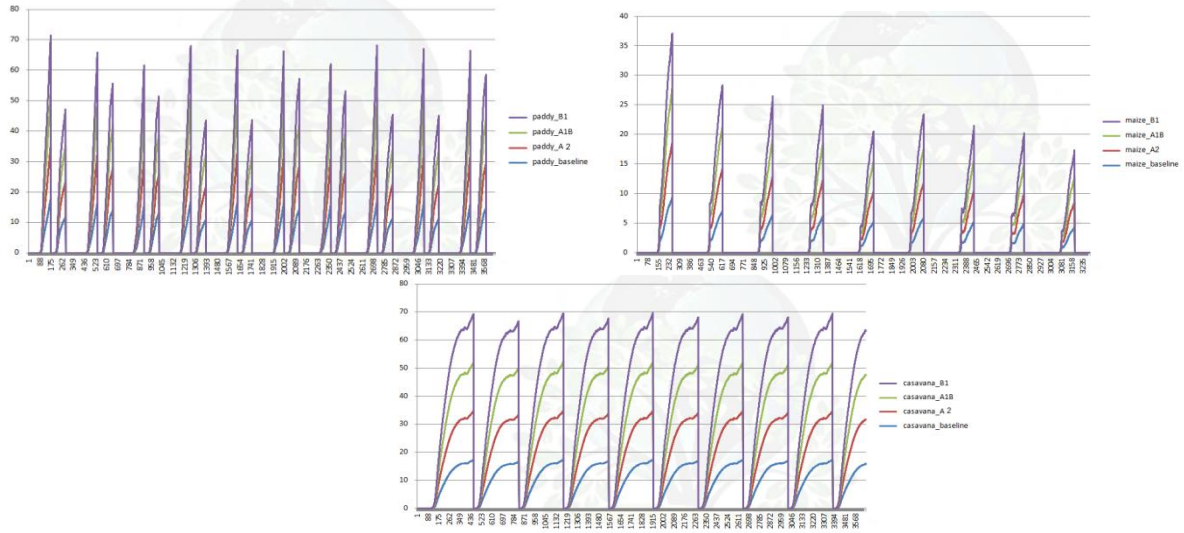

Figure 6. *Biomass of paddy rice, maize, cassava*

5. Conclusions

Application LUCIA model showed that rainfall, slope, soil type and vegetation cover are the direct factors affecting soil erosion and the growth of crops. The amount of soil loss of cassava is bigger than acacia, whereas paddy rice crop has the negligible effect to erosion. Recently, the deforestation to plant annual crop has caused accelerated erosion. Cassava has largest effect to erosion than any main agricultural crops in the area. In this case, cassava land should be reduced in size to avoid erosion in an uncontrolled manner. Besides, the climate will also affect productivity of paddy rice, cassava and maize. In particular, rice production decreases promptly; meanwhile, production of cassava and maize increase lightly, which leads the growth of biomass.

Through the analysis it found that LUCIA is an effective model, which uses to calculate the distribution of sediment flow and assess the impact of climate change on soil erosion in slope area. It requires a huge and available database in such region or country. The results of modeling help to raise the awareness of people in protecting environment and minimizing the degradation of land resources.

References

1. The Ministry of Natural Resources and Environment, (2009), Climate Change Scenario Vietnam, Hanoi
2. Le Trong Cuc, Chu Huu Quy et al, (2002). Sustainable development of mountainous Vietnam 10 years to look back and the posed problems.
3. Le Quoc Doanh, Ha Dinh Tuan, Andre Chabanne (2005) . Sustainable upland farming. Agriculture Publisher.
4. Le Van Du (2011). Farming practices and soil quality. International workshop on Cashew-cocoa vegetable agroforestryand systems in Vietnam. Ho Chi Minh City, Vietnam. WASWAC. 6a: 63-70.
5. Ho Thi Hong Hanh (2010), Assessing the effectiveness of use of agricultural land on the slopes in Nghia Dan - Nghe An, Thesis, University of Agriculture I.
6. Nguyen Anh Hoanh (2010). Integrated study geography and land degradation arising purposes rational use of land resources and regional disaster prevention Binh - Tri - Thien. Dissertation, Hanoi.
7. Dao Xuan Hoc, Planning adapt to climate change in agriculture and rural development, Vietnam Workshop adapt to climate change, Hoi An - Quang Nam, 7/2009
8.Pham Huu Ty (2008), Simulation erosion risk hilly landscape on the basis of using remote sensing data and the universal soil loss model calibration (RUSLE). Journal of Science, Hue University of 48.2008.
9. Uplands program (2012), The Uplands - Research Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia, Vietnam.