Spatial Modeling for Soil Erosion in Chay Basin, in Vietnam

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Key words: Soil erosion, Universal Soil Loss Equation (USLE) model, GIS

SUMMARY

For the some past of decades, encroachment of agricultural activities and forest reserves have become an actuate problem in Vietnam. They are impulse cause of the soil erosion and degradation in this country, special in the sloped areas. The Chay Basin has total of 409,813 ha. Its topological are include mountain, hill, narrow lowland near and river-valley, with a diversity of land use patterns. Their soil types are very sensitive with erosion, because the topological, rainfall and flow conditions, in particular deforested and non-suitable cultivated activities that are cause of the soil erosion and degradation in this area.
The article described the method to apply the Universal Soil Loss Equation (USLE) model in Geographical Information System (GIS) to predict the erosion risk area. The factors in the USLE were encoded in a GIS to create the thematic layers. Then they were integrated as the USLE model to create soil erosion risk in raster data. The study area was divided into 5 classes of soil erosion (weak, medium, strong, very strong and dangerous). The weak class was kept 49.47% of the total area; the medium class was holed 22.88% of the total area; the strong class was occupied 16.83% of the total area; and the dangerous class was 4.79% of the total area.
The result of this research is also showed the ability of the GIS on assessment soil erosion.

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1. INTRODUCTION

Soil erosion is one of the top caused of the soil degradation in the sloped area. Vietnam has 3/4 of the area is upland, so soil loss by erosion is a serious problem in this country. Together with erosion, the human activities are also a main cause of the soil degradation, event they are increase the rate of soil loss by the wrong cultivate methods in the sloped areas and destroy the watershed forests.

Chay basin is total of 408,729.6 ha. IT is lie down in upland area, and belongs to Hagiang, Laocai, Yenbai and Phutho provinces. It stretch out from the high mountain and plateau areas to the low hill land in the Northern of Vietnam. The topographical, geological, geomorphologic, hydrological, climate etc. conditions are diversified and complex. These conditions created complex for studying on the soil erosion in this area.
For a long time ago, the shifting cultivation of wandering hill-tribes and burn off to clear land exited. These activities were bringing soil erosion and degradation in this area. Up to day, beside the cultivated terraced fields, the wrong cultivate are still exited by the ethnic minority people in many places. Addition, deforest are increasing in watershed forests. So that, not only, soil infertile and degradation because soil loss humus and fertility, are increasing quickly, but also natural risks were frequently happened, such as, flash food, mud and stone food, landslide. Especially, one of the big risk is the bottom of the Hydroelectric Thacba Lake is higher because the sediment from the up-streams. Therefore, this study area has to find the reasons of the soil erosion for finding the solutions to control risks, improve soil quality and proposal suitable use of soil resource in this area.

This article concentrated on the assessment of the soil erosion by applying the catchment's approach and using the Universal Soil Loss Equation (USLE) model, with spatial analysis tool in GIS to quality the soil loss in Chay basin. Moreover, the soil erosion coefficients were defined and establish coefficient maps by using GIS tools. The output of the soil potential erosion map is one of the based information for proposing sustainable land use in Chay basin.

2. METHOLOGY AND METHODS

2.1 Catchment's approach

Soil and water resources are clearly crucial for productive and sustainable economies and environments. Both soil and water resources were threatened by soil erosion and sediment redistribution. This problem is big in the tropical area, especially in the upland areas.
The catchments can divide into sub-catchments that are difference on runoff and hydrological conditions. Additions, the physical conditions (slop, length slop, geological, land-cover, soil

characteristics, etc.) are also differences. The catchments approach tries to find out the relationships between soil loss with hydrological system and other conditions in the catchments. The proposals based on these relationships to control the soil loss and protected water resource, particular to control impact of the sediment in the upland sub-catchments to the hydroelectric lake, as in the study area.

2.2 Universal Soil Loss Equation apply for Chay Basin

2.2.1 The Universal Soil Loss Equation

The USLE was established by Wischmeier W.H and Smith D.D since 1978, it is applied in many areas in the world. It is described by coefficient and factors, they are following:

$$A = R.K.L.S.C.P \qquad (1)$$

A represents the potential long term average annual soil loss in tons per acre per year. This is the amount, which is compared to the "tolerable soil loss" limits.
R is the rainfall and runoff factor by geographic location
K is the soil erodibility factor
LS is the slope length-gradient factor; L is the length of the slope steepness, its unit is m; and S is slop angle, its unit is radian
C is the crop/vegetation and management factor
P is the support practice factor

2.2.2 The coefficient of the factors for assessing soil erosion in Chay basin in the USLE model

This research was assessing and predicting the potential of the soil erosion in the catchments, so only three of the coefficients of the USLE that are R, LS and K factors were examine.

R factor is the rainfall and runoff factor by geographic location as given from 9 weather stations in the Chay Basin and its vicinity. The coefficient of the R factor was gived by Ha N.Tr (1996) as following:

$$R = 0{,}548257P - 59{,}9 \qquad (2)$$

In which,
R is the coefficient of the average erosion by rain (J/m^2)
P is the average rainfall year (mm/year)

K factor is the soil erodibility factor. It is the average soil loss in tons/acre per unit area for a particular soil in cultivated. K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Texture is the principal factor affecting K, but structure, organic matter and permeability also contribute. Wischmeier gave the equation for caculate K factor as following:

$$100K = 2{,}1.10^{-4}M^{1,14}(12-OS) + 3{,}25(A-2) + 2{,}5(D-3) \qquad (3)$$

In which,

K is the soil erodibility factor. Its unit is ton/acre.1000.foot.tonf.inch.acre^{-1}.h^{-1}

M is weight of size of the grain (according to 2R of the grain).
(%) M = (%limon + % smooth sand)*(100% - %clay)

OS is the content of the organic master in soil, its units is %

D coefficient of the permeability of the soil

A coefficient of the soil structure (shape, arrange and kind of composition or structure)

LS is the slope length-gradient factor.

The LS factor represents a ratio of soil loss under given conditions to that at a site with the slope steepness of below 21% then

$SL = L/72{,}6.(65{,}4.\ Sin^2\ (S) + 4{,}56\ .\ Sin\ (S) + 0{,}056;$ (4)

If the steeper and longer the slope, the higher is the risk for erosion, then

$LS = (L/22{,}1)^{0,7}(6{,}432\sin(S^{0,79})\cos(S).$ (5)

The relationship between slope steepness and the slope length is described by equation

$L = 0.4S + 40$ (Thai Phien, 2001) (6)

LS factors are presented for topographical condition relates to soil loss, so they can be calculated by the topographical data, such as DEM and its derivation. These tools can be formed quickly and exactly in GIS software (such as, ArcGIS).

2.3 Application GIS tools

2.3.1 Establishing GIS database

The database of the soil erosion assessment are include data types, they are following

- Topological data
- Hydrological system
- Rainfall
- Soil map
- Auxiliary data: They are land-use/cover; administrative and catchments boundary, etc.

2.3.2 Spatial analysis tools and running USLE model in GIS software

The USLE can carry out in GIG. The coefficients of the module and their maps can be achieved by using GIS tools and input data from the database. Figure 1 showed the main steps from input data (include average rainfall, DEM, Soil type and land-cover, etc) to calculate R, LS, K, C and P coefficients, to created the outputs that are soil erosion potential and current soil erosion.

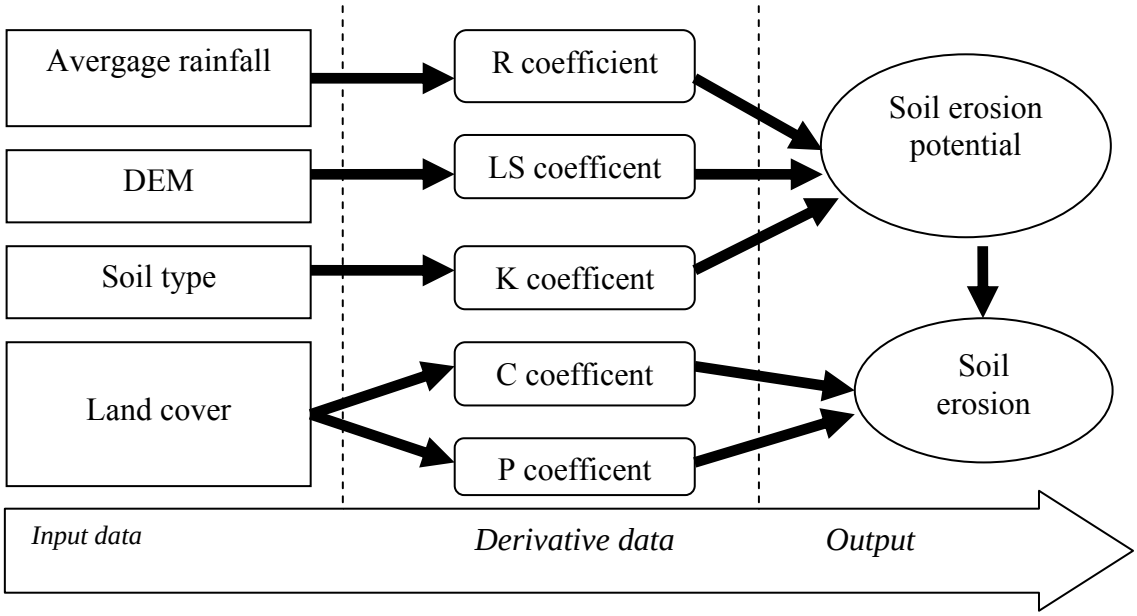


Figure 1: Processing carrying out of USLE module in GIS

3. SOIL EROSION POTENTIAL AND DISCUSSION

3.1 The coefficient of R factor of the soil erosion by rain

The rainfall and runoff factors are the main affected to the coefficient of R factor in USLE module. The study area is the tropical monsoon climate. In the summer, the high humid air runs over the mountains to bring the heavy rain for mountainsides. The greater the intensity and duration of the rainstorm, can create higher the erosion potential. The average rainfall factor is used to calculate the R coefficient in the study area. The rainfall of Catchments Chay River is range from 1700mm/year to 4800mm/year (table 1). In the upstream valley, the average rainfall can be reach 1944mm/year (such as, Muong-khuong). However, the rainfalls in the hidden or deep hollows are lower. The total of rain days is about 150-163 days/year and concentrated in the summer in the study area.

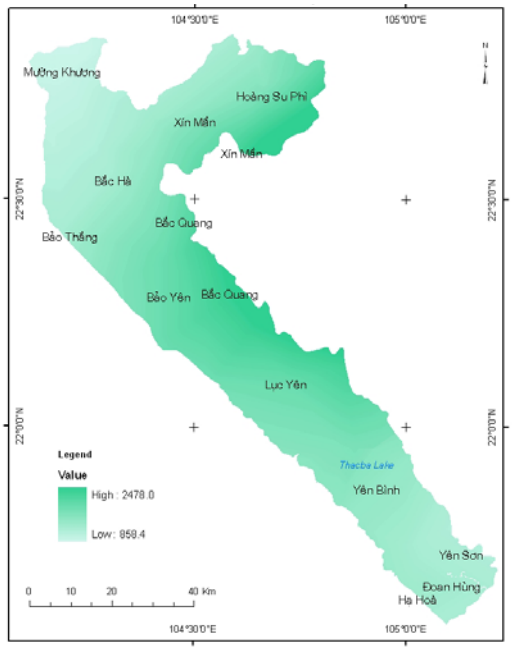
The second of factor is high affect to R coefficient that is runoff. Runoff is belonging to high or low rainfall, the time of the rain, topographical, morphologic and hydrological conditions. The topographical and morphologic conditions can be obtaining from DEM (digital elevation model). The runoff can be created from these data. The geological and morphologic conditions are complex. They are cause of the separate Catchments Chay into many partitions with very difference on the runoff condition.

The different of the average rainfall and runoffs created the difference of the coefficient of R factor in each point of Catchments Chay, they are calculate by the equation (1). The output of this calculation is showed in the table 1.

Table 1. The coefficient of R factor in the Catchment's Chay

Weather stations	Average rainfall (mm/year)	R ceofficient
Hà Giang	2430.1	1224.4
Hoàng Su Phì	1814.4	899.0
Bắc Hà	1737.5	858.4
Lào Cai	1764.4	872.6
Bắc Quang	4802.1	2478.0
Yên Bái	2106.9	1053.6
Phú Hộ	1850.0	917.8
Lục Yên	2076.5	1037.5
Tuyên Quang	1641.4	807.6

Figure 2. Map of the coefficient of R factor



The R coefficient is ranging from about 800 to 2500, the highest of R is in Bac Quang (its reach 2478), and the lowest is 807.6 in Tuyen Quang. Figure 2 is clearly described the coefficient in the geographical position. The deep color as high R is concentrated in the Northeastern. The value is decreasing in the surrounding areas.

3.2 The coefficient of K factor of the soil erodibility

K factor and its coefficient are high affect to the soil erosion in the Catchments Chay. This factor is belong to the kind of the soil, including soil type, quality, structure, organic matter and permeability also contribute, and it is also high depended on the slop steep and the length of slope steepness.

In the Catchments Chay has 7 groups of the soil types as according to FAO-UNESCO classification, that are Fluvisols ; Gleysols ; Luvisols ; Acrisols ; Ferralsols ; Alisols ; and Leptosols. They have 16 kinds of soil. Each kind of soil has difference of the soil quality, organic matter and permeability, etc. In addition, each kind of soil is lie down in the difference of the steep slop. All of these difference conditions are showed in the soil map and its database. Therefore, the soil map and its database calculated K coefficent. The output of this classify is showed in the table 2. The output is described in figure 3.

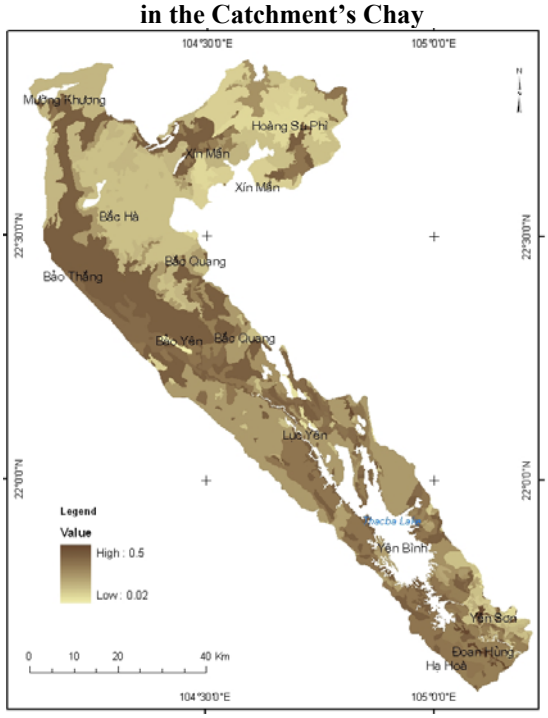
Table 2: The coefficient of the K factor in the Catchments Chay

No	Soil type (Vietnamese)	Soil Symbol	Soil type FAO-UNESCO	Ký hiệu	Coefficent of K factor	Area (ha)	% total area
I	**Nhóm đất phù sa**	**P**	**Fluvisols**	**FL**		**1936,2**	**0,41**
1	Đất phù sa không được bồi	P	Eutric Fluvisols	FLe	0.30	585,9	0,12
2	Đất phù sa chua	Pc	Dystric Fluvisols	FLd	0.23	1350,3	0,29
II	**Đất glây**	**GL**	**Gleysols**	**GL**		**3354,5**	**0,71**
3	Đất glây	GL	Eutric Gleysols	GLe	0.38	2068,8	0,44
4	Đất glây chua	GLc	Dystric Gleysols	GLd	0.50	1285,7	0,27
III	**Đất đen**	**R**	**Luvisols**	**LV**		**1617,2**	**0,34**
5	Đất đen glây	Rg	Gleyic Luvisols	LVg	0.12	916,1	0,19
6	Đất đen cacbonnat	Rv	Calcic Luvisols	LVk	0.03	701,1	0,15
IV	**Đất xám**	**X**	**Acrisols**	**AC**		**339701,5**	**72,30**
7	Đất xám cơ giới nhẹ	Xa	Areni Acrisols	Aca	0.39	1000,5	0,21
8	Đất xám feralit	Xf	Ferralic Acrisols	ACf	0.28	277601,5	59,09
9	Đất xám glây	Xg	Gleyic Acrisols	ACg	0.19	1248,1	0,27
10	Đất xám điển hình	Xh	Haplic Acrisols	ACh	0.14	14985,8	3,19
11	Đất xám mùn trên núi	Xu	Humic Acrisols	ACu	0.19	44865,7	9,55
V	**Đất đỏ vàng**	**F**	**Ferralsols**	**FR**		**83894,5**	**17,86**
12	Đất nâu đỏ	Fd	Rhodic Ferralsols	FRr	0.28	341,1	0,07
13	Đất nâu vàng	Fx	Xanthic Ferralsols	FRx	0.38	2178,5	0,46
14	Đất mùn vàng đỏ trên núi	Fh	Humic Ferralsols	FRu	0.20	81374,9	17,32
VI	**Đất mùn Alit núi cao**	**A**	**Alisols**	**AL**		**1654,2**	**0,35**
15	Đất mùn Alit núi cao	Ah	Humic Alisols	ALh	0.37	1654,2	0,35
VII	**Đất xói mòn trơ sỏi đá**	**E**	**Leptosols**	**LP**		**524,7**	**0,11**
16	Đất xói mòn trơ sỏi đá	Ec	Lithic Leptosols	LPq	0	524,7	0,11
	Tổng đất					***432682,8***	***92,10***
	Núi đá					17084,7	3,64
	Sông suối					20054,0	4,26

The K coefficients are ranging from zero – 0.50. The highest of K is appeared in the group Gleysols, which is Dystric Gleysols (0.5), after that, K are a rounded 0.3 in the Fluvisols, Gleysols, Acrisols, Ferralsols and Alisols, that are Humic Alisols; Xanthic Ferralsols; Areni Acrisols; Eutric Gleysols; and Eutric Fluvisols. Then K below 0.3 appeared in almost groups, particular in the Humic Ferralsols; Rhodic Ferralsols; and types of the Acrisols, Luvisols; and Dystric Fluvisols. The lowest (K equal 0) is appeared in the Lithic Leptosols.

The K coefficients are showed in the figure 3. The high K coefficients are concentrative in the Central of North (belong to Baothang and Bacquang), then they are decreased to the south, and the lower of the K coefficients are rise in the North (belong to Bacha, Ximan and Hoangsuphi).

Fig 3. The coefficient of the K in the Catchment's Chay



Comparing the distribution of the K with the R coefficients, showed rather opposite distribute between them. The places of higher K coefficient are the lower R coefficients. So that, when they are integrated in the USLE module, they will be eliminating each other.

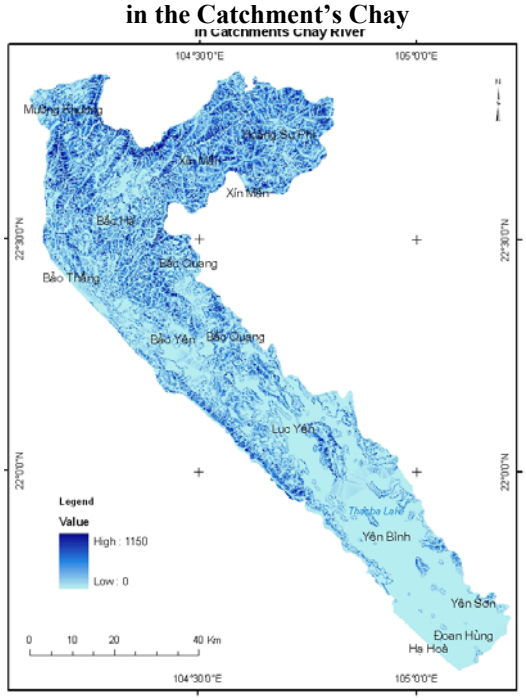
3.3 The coefficient of slope length-gradient factor (LS)

Slope length-gradient factor is one of the main required in the USLE. Based on the topographical and morphologic conditions in the study area, the LS can be calculated. The LS of this area can be divided into 8 levels, they are showed in table 3, and figure 4 is described the distribution of the LS in the Catchment's Chay.

Table 3. The coefficient of LS factor in Catchment's Chay

No.	LS	Area (ha)	% total area
1	0-5	260,571	55,46%
2	5-10	47,026	10,01%
3	10-20	84,756	18,04%
4	20-30	42,057	8,95%
5	30-40	17,311	3,68%
6	40-100	15,974	3,40%
7	100-500	2,068	0,44%
8	500-1150	59	0,01%
	Total	**469821,5**	**100.00**

Figure 4. Map of the LS in the Catchment's Chay



The highest level of the LS coefficient (level 8) is occupied only 0.01% of the total area (59 ha). The largest area of the LS coefficient is belonging to level 1 (LS ranging from 0-5), it is appropriated 55.46% of the total area (260,571 ha). Right after that is the level 3, it holds 18.04% of the total area (84,756 ha). These numbers are described in the figure 4. The higher LS are concentrated in the North, then they are decrease to the center and the south (from Yenbinh to the south). The LS coefficients are lowest appear close to Thacba Lake.

3.4 Prediction of the soil erosion in the Catchments Chay river

Because of this assessment only for prediction of the soil erosion potential, so the calculation took 3 kinds of main factors (R, K and LS) which are sustainable factors in the process. So the map of the prediction of the soil erosion potential in the Catchment's Chay River (P) is established by following equation (7).

$$P = R.K.LS \qquad (7)$$

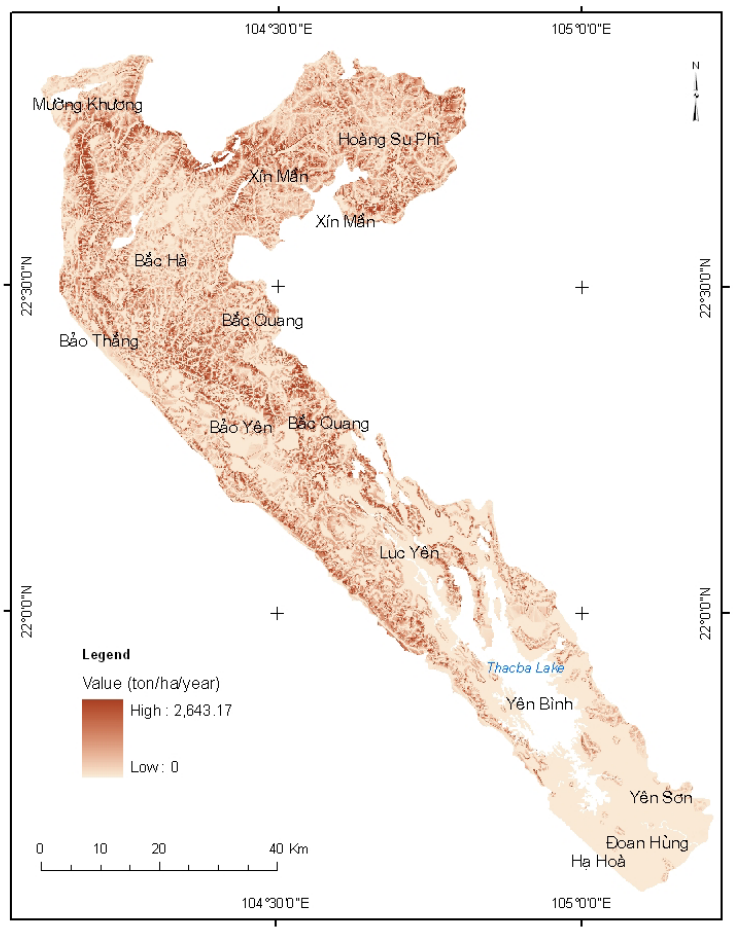
GIS tools were integrate 3 factors and their coefficients to calculate the soil erosion potential in the Catchments Chay River. The statistic tool given the amount of the soil loss potential in table 4, it is also classify the level of the soil loss potential in the study area.

The figure 5 showed overview of the soil loss potential in the Catchments Chay River. The higher soil loss potential concentrated in the North and the lowest is close to the Thacba Lake. Not many difference between soil loss potential with LS maps. Therefore, the LS factors are the main affected to the soil loss. However, soil types are not main affected factor of the soil loss in this area. Moreover, the highest affected factor to the soil loss is the rainfall and runoff factors, they are presented by the R factor and its coefficient. With the higher rainfall in the Xi-Man, Hoang Su Phi districts (from 1,100 – 1,400 mm/year) than the South of Thac Ba Lake and Doan Hung district, so the their R coefficients and soil loss potential is also higher.

Table 4. The degree of the soil loss potential in Catchments Chay River

Degree of the soil loss potential	Amount of the soil loss potential (ton/ha/year)	The average of the amount of the soil loss potential (ton/ha/year)	Area (ha)	% total area
Weak	< 100	4.16	214,038	49,47%
Medium	100 – 500	303.86	98,998	22,88%
Strong	500 – 1000	708.60	72,839	16,83%
Very strong	1000 – 1500	1,208.47	26,103	6,03%
Dangerous	> 1500	2,643.17	20,705	4,79%

Figure 5. Soil erosion potential in Catchments Chay



Therefore, the rainfall and topographical conditions are highest affected factors to the overview picture of the soil loss potential in the Catchments Chay River. This conclusion has significance importance for Vietnam, because 3.4 of Vietnam is sloped area and it is lie down in the tropical climate with the high rainfall.

4. CONCLUSIONS AND RECOMMENDATIONS

The catchments approach is suitable way for assessing the soil loss in the upland, as the study area. The inter-relationship of the affected factors and soil loss can be easily established in the catchments. The data of integrated process as in the Universal Soil Loss Equation (USLE) model can be performed in GIS software.

Application the Universal Soil Loss Equation (USLE) model in the GIS can be easily and quickly to obtain quality of the soil loss in each of the point in the study area. These assesse processes is bring more advantage than other methods. The outputs of these analyses are the raster data or cell. However, this module is requiring the right particular coefficients for each study area. This mean, the USLE module is need the users who have experience on the soil science and soil loss and deep understand in the conditions in the study area.

The map of the soil loss potential in the Catchments Chay River can be achieved by integrating the erosion factors (R, K and LS). The partitions of the soil loss are created by the difference of the rainfall, runoff and topological conditions. The degree of the strong and dangerous of the soil loss is appearing in the upstream. These levels of soil loss are appropriate about 28% of the total area. The levels of the weak and medium of the soil loss is concentrated in the lower section of the river, and they are hold about 72% of the total area.

To control the soil loss, this catchments need the strategies for land use suitability, especially application the suitable cultural method in the sloped areas, apply the technical methods for improve soil quality, and must be protected the upstream watershed forests. Addition, improve knowledge on the protected soil and forest for local people is required immediately. Training of suitable cultural methods is need together.

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