THE SOIL EROSION AND NUTRIENT LOSSES IN HILLY AREA IN CENTRAL VIETNAM

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Abstract

The study was conducted in Asap river basin, A Luoi district, Thua Thien Hue Province, Vietnam, using the Universal Soil Loss Equation (USLE) to determine the soil erosion status by water and nutrient contents in the soil that are lost by soil erosion. The results show strong effect of the heavy rainfall and high slope on the erosion level in the research area. More than 31% of land area lost over 10 tons/ha/year. The natural forest land lost the most, while the agricultural land showed less. The annual loss of organic matter is mainly less than 50 kg/ha/year and may reach to 300kg/ha/year due to specific terrain as well as land use type. The nitrogen and phosphorus lost less than 5kg/ha/year. Potassium erodes 30kg/ha/year in about 50% of total area.

Keywords*: Soil erosion, loss of nutrients in soil, USLE, Vietnam,*

Introduction

Soil erosion by water is one of most serious problems that happen on a global scale *(S.D.Angima et al, 2003)* and is also one reason that leads to a reduction in arable land *(Grandomkar et al, 2008)*. Especially for the upland area, the erosion risk is higher than for others *(George Ashiagbor et al, 2013;Nguyen Manh Ha, 2009).* Moreover, soil erosion is the reason for agricultural yield reductions *(M.M. Bakker et al, 2005;Ikponmwosa D. Ighodaro et al, 2013;M. Littleboy et al, 1992)* and has negative impact on water availability, nutrient contents in soil, biomass as well as biodiversity and other environmental problems *(David Pimentel et al, 2013;David Pimental, 2006).*

Wind and water are key reasons that lead to soil erosion problems and among them water is more extensive than wind erosion *(H.E. Dregne, 1987)*. For Vietnam, in the upland catchments, the erosion is mainly caused by rainfall *(Trinh Cong Tu, 2008)*. In Central Vietnam, especially in Thua Thien Hue province *(Ho Kiet, 1999)*, the measured annual soil loss rates on seven cropping systems during the period from1996 to 1998 varied from 18.28 tons/ha to 204.56 tons/ha, *(Pham Huu Ty, 2008)* calculated around from 9.5 tons/ha to 81.5 tons/ha under comparable natural conditions but different rainfall amounts. However, their researches have skipped the influence of the land use factor on soil erosion. So far, there exists no research on soil erosion for the highest area of this province that focuses on various soil erosion factors such as land use type.

In recent years, many researchers have focused on estimating soil erosion through different models. Among them, The Universal Soil Loss Equation (USLE) is widely used for the study of soil erosion by water, despite of many inconveniences due to its extensive requirement for input data *(A. Lufafa et al, 2003).* The USLE method - developed by Wischmeier W.H and Smith D.D (1978)- predicts the long-term average annual rate of erosion on a field based on rainfall pattern, soil type, topography, crop system and management practices.

The aim of this study is to estimate the soil erosion for a basin in upland area of the Thua Thien Hue province, by using the USLE model to calculate organic matter, nitrogen, phosphorus and potassium losses in soil.

The study area

A Luoi district (16°30’N, 107°0’E and 16°0’N, 107°30’E) is at the western of Thua Thien Hue province, central of Vietnam with main terrain is hilly area and high mountain. In this district, there are a lot small rivers; however, the most important among them is Asap River with basin area is 33,150 hectares in total. The watershed of Asap River covered at least a quarter natural area of A Luoi district.

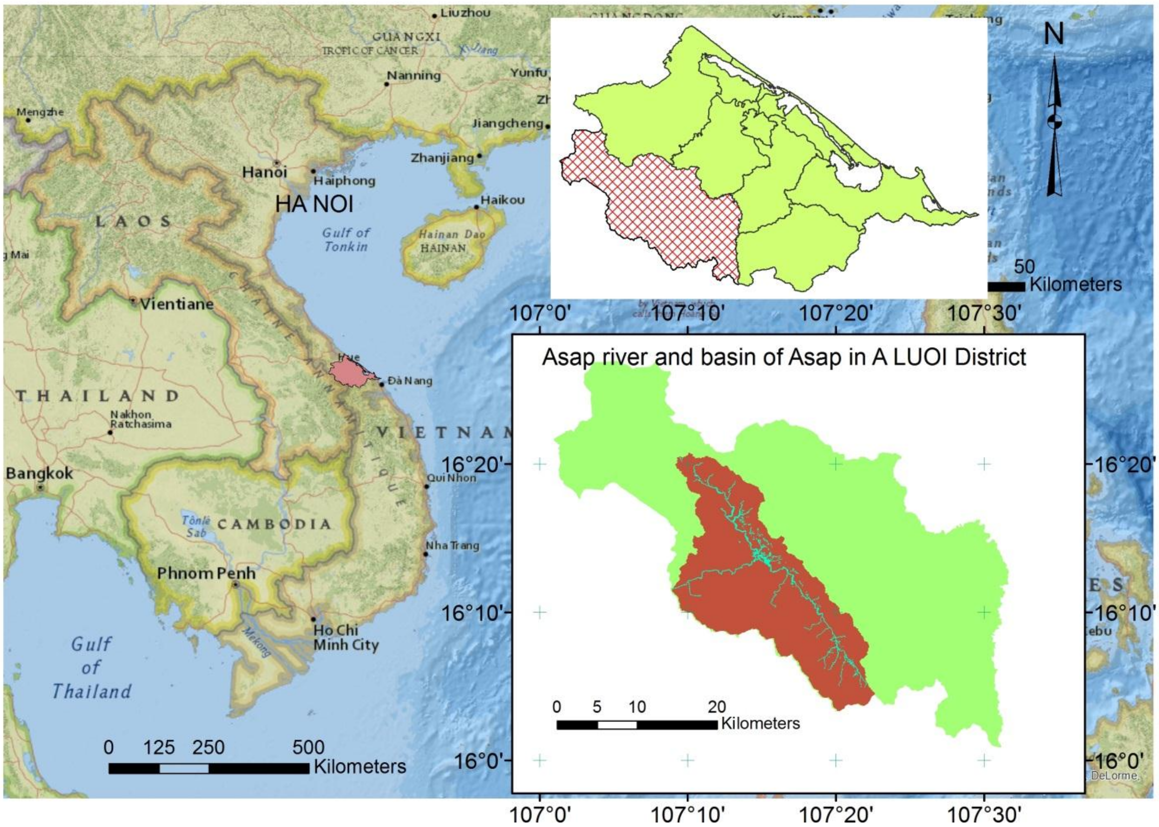

Fig 1: Location of Asap basin in A Luoi district

The A Sap basin has 33150 hectares. The climate at the research site shows tropical monsoon characteristics with an annual rainy season from September to March. The annual precipitation is 3900 mm (averaged for period from 2001 to 2014). The average temperature reaches the highest in May and the lowest in January, 25 °C and 17°C degree respectively. The elevation of the basin fluctuates from 504m to 1770m above sea level and decreases from west to east. Some exceptional high places are Dong Ngai mountain (1774m) and A So mountain (1528m). The slope of the terrain is steep (with an average of 60%) and complex. There are 7 land use types in the basin area, among them protection forest and production forest (e.g. Acacia spp. plantations) are the predominant land use types.

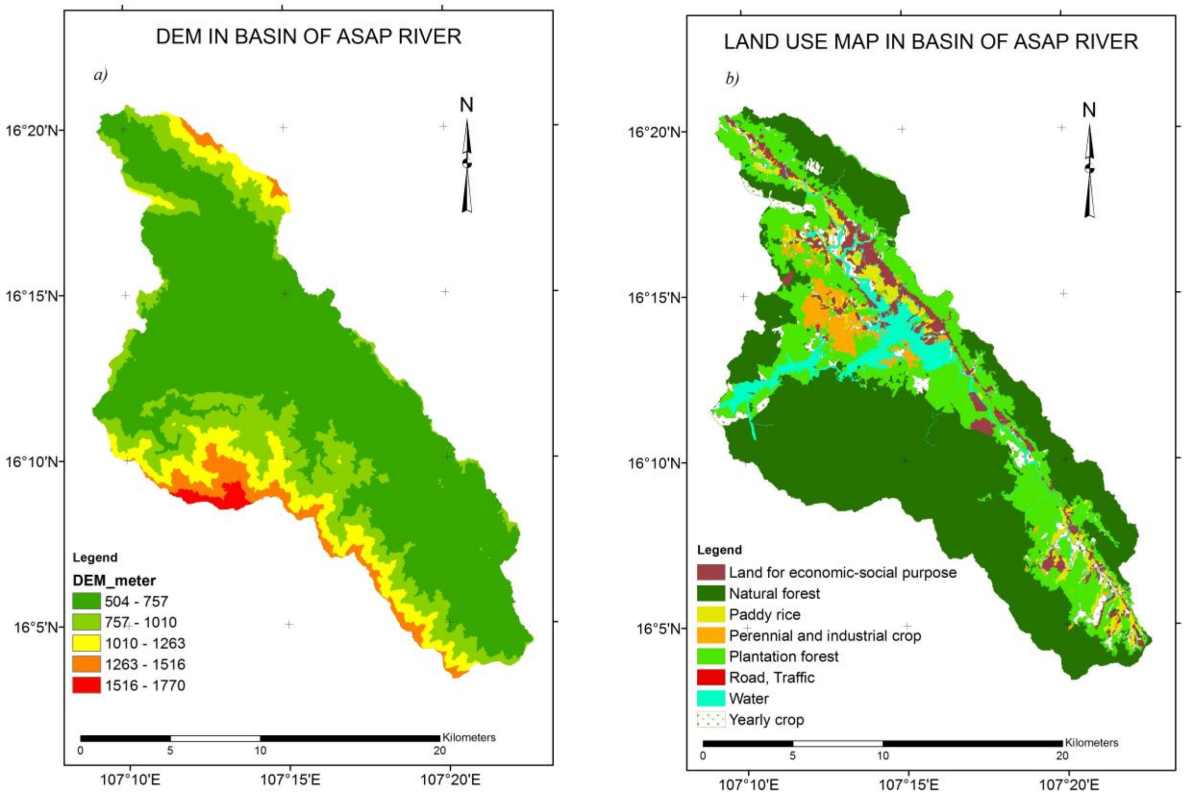

Fig1 (a) is DEM and Fig 1 (b) is land use map in year 2015

Methodologies

The Universal Soil Loss Equation

The USLE was proposed Wischmeier W.H and Smith D.D in 1978 and is applied in many areas in the world. It is described by the following coefficients and factors as equation 1:

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

Where:

A Average annual soil loss (t/ha/year)

R The rainfall and runoff factors by geographic locations (MJ*mm/ha*hour*year)

K The soil erodibility factor (t/ha/R unit)

LS The topographic factor (dimensionless); L is the length of the slope steepness, (in m); and S is slop angle (in radian)

C The crop/vegetation and management factors (dimensionless)

P The support practice factor (dimensionless)

The correlation between USLE model and observed field is 75% *(Risse et al, 1993)* and the amount of soil loss in the simulations are always higher than in the real environment *(Pham Huu Ty, 2008;Tran Quoc Vinh et al, 2011)*

Level of soil erosion risk in Vietnam will follow the Vietnamese government standard document *(TCVN 5299, 2009)*, which is based on long lasting research on soil erosion in Vietnam to match Vietnamese natural conditions. The paper divides soil erosion into 5 levels depending on the volume of soil loss per hectare per year, namely, less than 1/ton/ha/year is no erosion, from 1 to 5 is low level, from 5 to 10 is medium level, from 10 to 50 is high level and higher than 50 is very high.

R factor

Rainfall erosivity is the kinetic energy of raindrop and rate of runoff *(Wischmeier and Smith, 1978)* and it is one of the main drivers of soil erosion *(Panos Panagos et al, 2015).* There are a lot of methods that can be used to calculate the annual rainfall erosivity factor, such as Renard and Freimund (1994), Singh, Chandra and Babu (1981), *(Yu et al, 1996), (Reshma Parveen et al, 2012), or (Ioannis Z. Gitas et al, 2009) who* even define single equation for each month for certain areas. For Vietnamese conditions, *Nguyen Trong Ha(1996)* suggested the equation (2) which we applied in this study.

$$\mathbf{R = 0.548257*P-59.9 \ (2)}$$

Where: **R** is the rainfall erosivity factor and **P** is the yearly precipitation (mm)

K factor

The soil-erodibility factor (K) represents the effect of soil properties and soil profile characteristics on soil loss. K is strongly related to the physical properties of the soil and plays an important role in soil conservation strategies *(Farzin Shabani, 2014).* The K factor can be calculate by Wischmeier and Smith (1978) (eq. 3)) and is applicable for cases where the silt fraction does not exceed 70% or Williams et al (1984) *(Trust Manyiwa et al, 2013).*

$$\mathbf{K= 2.73*10^{-6}M^{1.14}(12-OM) + 3.25*10^{-2}(A-2) + 2,5*10^{-2}(B-3) \ (3)}$$

Where K is the soil erodibility factor and **M** is the texture from the first 15 cm of soil profile and is calculated using Equation (4), based on soil primary particles percentage. **OM** is the percentage of organic matter content that could be determined in laboratory, **A** is soil structure code and **B** is soil permeability class. All of these values come from USDA (Unites State Department of Agriculture) and they have been widely accepted all over the world *(R. Wawer et al, 2005).*

$$\mathbf{M = (100-C)*(D+E) \ (4)}$$

Where C, D and E are the percentage of clay, silt and very fine sand, accordingly.

All of the equations to measure the K factor is related to the soil texture and organic carbon matter and percentage of sand, silt and clay in the soil. Therefore, soil erodibility is one of the trickiest erosion factors and takes a lot of time while being costly because researchers must do a lot of experiments inside laboratory as well as spend too many resources for field survey *(H.A.Bahrami, 2005).* Some researchers such as Thai Phien et al (1999), Schwab et al (1981) and Parveen et al (2012) have found a relationship between soil organic matter content, soil texture and K factor. In this study we used the K factor for soils in Vietnam as recommended by Thai Phien (1999).

LS factor

LS is the slope length-gradient factor, of which the L-factor represents the impact of slope length while the S-factor accounts for slope steepness *(Panos Panagos, 2015)*. Almost all research uses Digital Elevation Models (DEM) and Geographic Information System (GIS) tools to measure LS in soil erosion studies *(Panos Panagos, 2015; Van Remortel, 2001)*. In this study, an approach developed by Moore and Burch (1985) (eq. 5) is used to compute the LS factor.

$$\mathbf{LS=(FA*cell\ size/22{,}13)^{0.5}*((sin(slope)/0{,}01745)/0{,}09)^{1{,}3}\ (5)}$$

Where: **FA** is flow accumulation, **cell size** is 30m and Slope angle is in degree

C factor

The C factor reflects the effect of cropping and management practices on the soil erosion rate and has an important role in soil erosion *(Biesemans.J et al, 2000), (De Jong, 1994), (R. J. Patil et al, 2013)*. Generally the C-factor will range between 1 and almost 0. If C is 1 no cover is present and the surface is treated as barren land, while 0 means a very strong cover effect and soil erosion does not occur.

Normally, the C factor will be assigned the default value based on a land use or land cover map, however, because of all pixel in one class have the same value, those pixels cannot represent the variation of vegetation *(Wang et al., 2002)*. Since remote sensing technology can provide a lot of information about the land surface through Normalized Difference Vegetation Index (NDVI), the C factor was calculated by many researchers with different equations *(Ahmet Karaburun, 2010), (De Jong et al, 1998), (Van der Knijff et al, 2000), (V. L. Durigon et al, 2014)*. In this study, we applied the equation (6) from Durigon et al (2014).

$$\mathbf{C = (-NDVI +1)/2\ (6)}$$
$$\mathbf{NDVI = (NIR - RED)/\ (RED+NIR)\ (7)}$$

Where **NIR** is the surface spectral reflectance in the near-infrared band and **RED** surface spectral reflectance in the red band.

P factor

P factor is defined as the impact of land use or farming system on the soil erosion. The P factor adjusts the potential erosion by water runoff through implementing the effects of contouring, strip cropping, and terraced contour farming *(Wischmeier et al,1978), (Kim et al, 2006)*. In fact, there are a lot of difficulties in estimating the P factor and some researchers suggested the P value is rather dependent on the slope inclination *(Wischmeier et al,1978), (Wenner, 1981), (Shin, 1999)*; while others use farming practices to calculate P value *(Stone, 2000)*. In this study, we use the land use map and slope map to identify values for the P factor. Natural forest and barren land have a P value of 1 because there are not any cultivated activities here to limit the soil erosion, for the remaining land use types, plantation forest belongs to "contouring"* and agriculture belongs to "strip cropping"** groups

Table 1: *Determine P value*

Slope (%) / Land use type	0-7	7-12	12-17	17-27	>27
Natural Forest	1.00	1.00	1.00	1.00	1.00
Plantation Forest (Acacia)*	0.55	0.60	0.80	0.90	1.00
Paddy field (Rice)**	0.27	0.30	0.40	0.45	0.50
Yearly crop (Cassava, Soybean, corn)**	0.27	0.30	0.40	0.45	0. 50
Bared land	1.00	1.00	1.00	1.00	1.00

(Modified from Shin, 1999)

Analysis for nutrient in soil

Soil sampling

Totally, 60 soil samples were taken in the research area for soil analysis. Each soil sample was the result of a combination from 5 sub-samples inside a circle with a radius of 5 meters around the center of the respective land use unit.

Soil analysis

Table 2 presents the method that has been used for soil analysis in the soil laboratory at the Hue University of Agriculture and Forestry (Vietnam).

Table 2: *Method for soil analysis*

Criteria	Method	References
Organic Matter (OM)	Walker-Black (1934)	*(SFRI, 1998)*
Total Nitrogen (N)	Kjeldahl	*(SFRI, 1998)*
Total Phosphorus (P)	Color Spectrophotometer	*(SFRI, 1998)*
Total Potassium (K)	Flame photometer	*(SFRI, 1998)*

Amount of nutrient in soil losses was calculate as equation (8)

$$F = H*A*1000 \quad (8)$$

Where **F** is nutrient in soil loss (kg/ha), **H** is nutrient content in soil (%) and **A** is average annual soil loss (t/ha)

Result

1. Soil erosion

Fig 2a shows the R factor in this area is very heavy in comparison with other places in the same province. Annual precipitation at the research site fluctuates from 3090 mm to 3270 mm per year leading to R factor values from 1634 to 1732; the magnitude of R is one of the main causes to the influences on soil erosion intensity.

Fig 2b indicates the K factor at the research site. It fluctuates from 0.31 to 0.46 and among them, *Ferralic Humic Acrisols* have the highest value and *Umbric Hyperdystric Acrisols* have the lowest value. In Asap catchment, the lowest K values are distributed in the low land and the highest K values are concentrated in the area with high elevation.

Fig 2c shows the LS factor at the research site changes from 0 to 30, as computed by equation (5) and DEM data with a resolution of 30m. The topography must be considered extreme and steep, with some places as steep as 45 degrees or above, while slope lengths are short. This leads to a very powerful rain flow rate, making the erosion situation more serious.

There is a negative correlation between the C factor and NDVI value, which means that an area with high NDVI values (i.e. areas with large forest cover) shows low C coefficients (i.e. erosion will be reduced). The results from equation (6) indicate that the C factor fluctuates from 0.19 to 0.59 as depicted in Fig 2d.

Based on the land use and slope map, we measured that the P value at the research site fluctuates from 0.27 to 1.00, with the lowest value in paddy fields and yearly crops cultivation in flat areas (slope < 7%). On the other hand, if the land use is natural forest, barren land or water in places where slope >30%, the P value is 1.00. Fig 2e shows that in the central of basin, the P value is lower than at any other places.

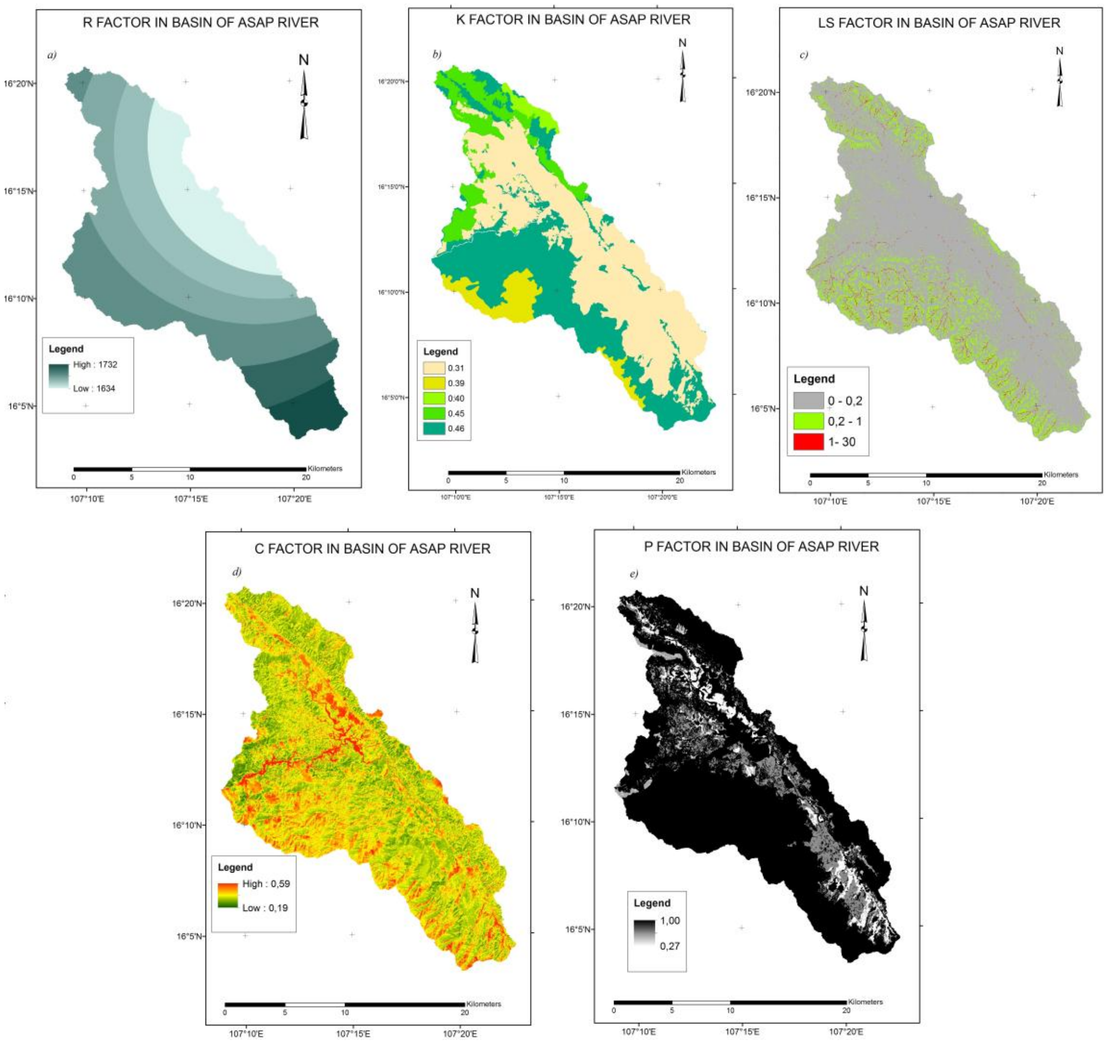

Fig 2a,b,c,d,e are R,K,LS,C and P factor respectively

The USLE model results under the use of the Vietnamese standards document, are depicted in Fig 3 for the soil erosion situation in the Asap River basin in A Luoi .

Table 3: *Soil erosion in Asap basin*

Level	Soil losses (t/ha/year)	Percent of area
No erosion	0 – 1	44.67
Low	1 – 5	7.71
Medium	5 – 10	6.14
High	10 – 50	27.72
Very high	> 50	13.76

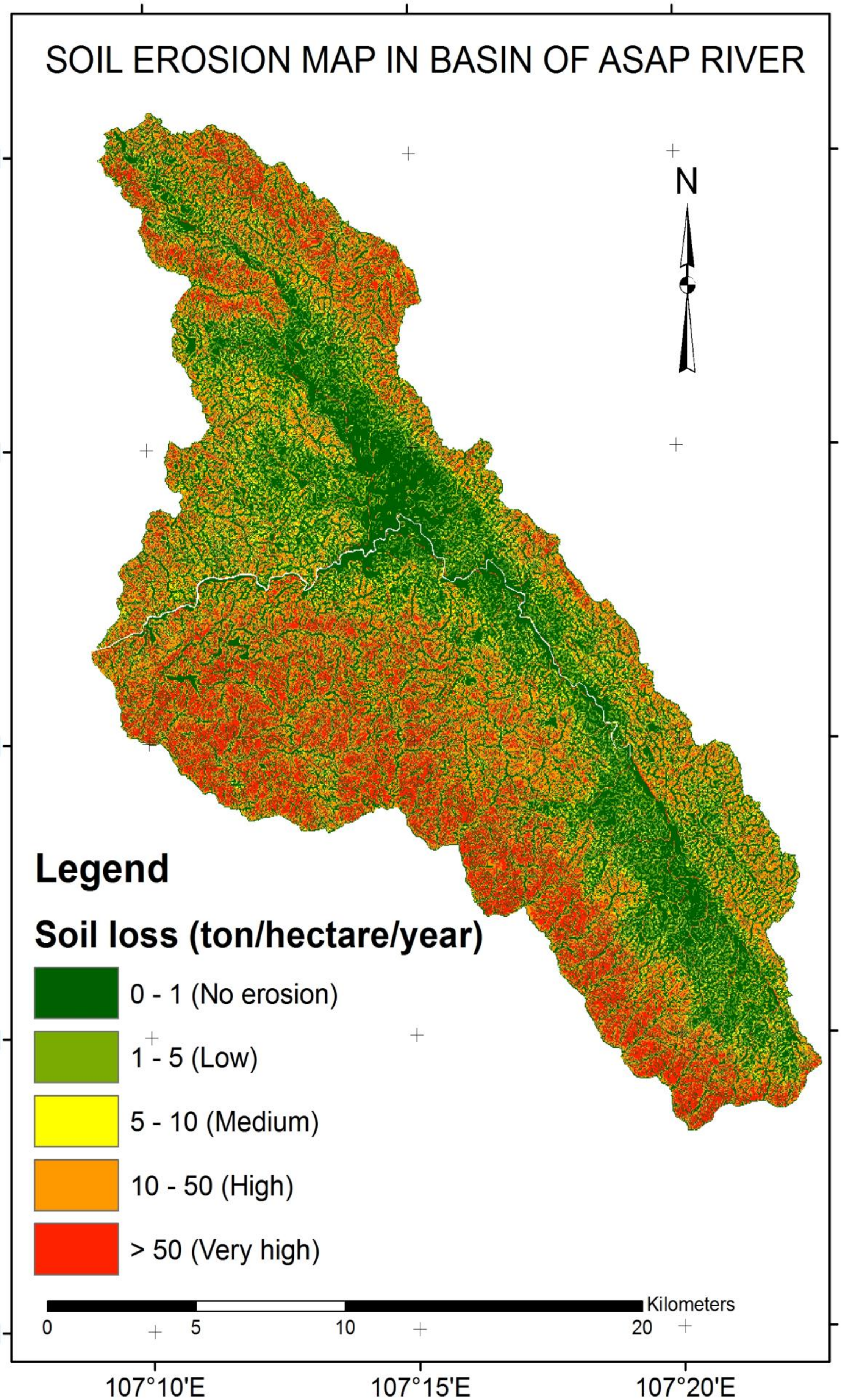
SOIL EROSION MAP IN BASIN OF ASAP RIVER
N
16°20'N
16°15'N
16°10'N
16°5'N
16°0'N
107°10'E
107°15'E
107°20'E
Legend
Soil loss (ton/hectare/year)
0 - 1 (No erosion)
1 - 5 (Low)
5 - 10 (Medium)
10 - 50 (High)
> 50 (Very high)
Kilometers
0
5
10
20

Fig 3: Soil erosion map in Asap catchment

2. Soil quality

After using IDW algorithm for interpolation, the concentrations of organic matter (OM), Total Nitrogen (N), Total Phosphorus (P) and Total Potassium (K) are presented in Fig 4a,4b,4c,4d respectively.

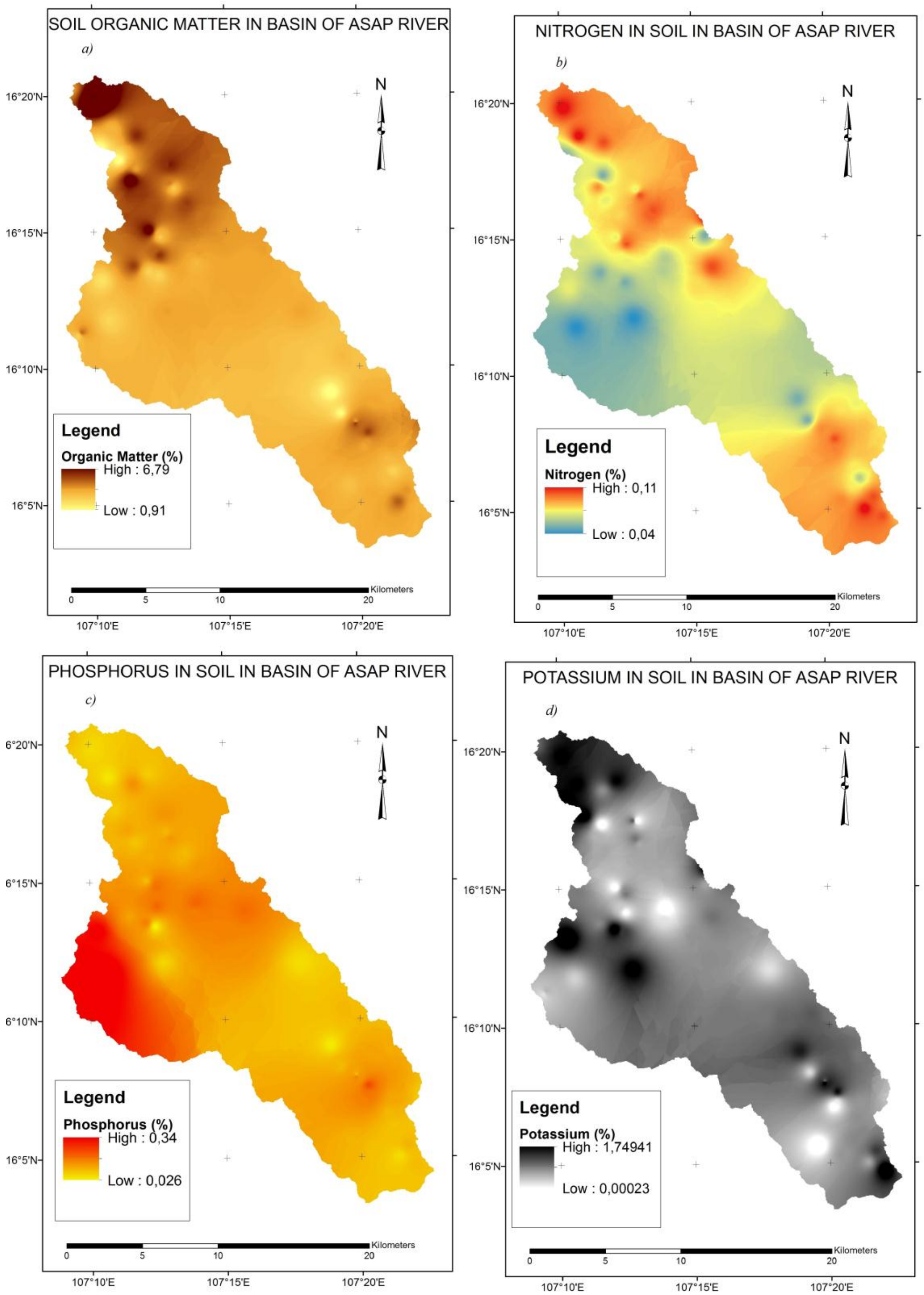

Fig 4a,4b,4c,4d: The nutrients content in soil

Except for P, the remaining criteria are highly concentrated in the northern region and lowest in the Western region, with many high mountains and mostly natural forest. Variations in the level of nutrients in the soil are quite large, depending on the soil type and other factors such as level of vegetation cover and land use types. The variation of the content of nutrients in soil among the positions is very different, in which potassium has the highest disparity.

Table 4 shows the nutrient contents in soils of each land use type. Land use for agricultural purposes has nutrient content higher than other lands because farmers add fertilizer during cultivation process.

Table 4: *Nutrients in soil by land use types*

Land use type	OM (%)	N (%)	P (%)	K (%)
Natural forest	2.17	0.07	0.09	0.80
Plantation forest	2.41	0.07	0.08	0.76
Paddy rice	2.63	0.09	0.08	0.75
Yearly crop	3.69	0.08	0.09	0.78
Water (Area for hydropower station)	2.26	0.07	0.10	0.68
Perennial and industrial crop	2.54	0.07	0.10	0.54
Other	2.53	0.08	0.08	0.69

OM is Organic matter, N is Nitrogen, P is Phosphorus and K is potassium

3. Nutrients in soil loss

The map of nutrient loss shown by Fig 6a, 6b, 6c and 6d.

Table 5: *Situation of nutrients in soil losses*

Nutrients loss level (kg/ha/year)*	OM (ha)	N (ha)	P (ha)	K (ha)
0 - 5	15713.82	18109.26	17907.39	14481.09
5 - 10	1247.04	2767.68	2425.05	721.17
10 - 15	997.11	2362.41	2045.34	564.93
15 - 20	878.13	1857.15	1636.02	460.62
20 - 25	846.72	1435.05	1305.36	406.17
25 - 30	817.83	1112.04	1032.3	358.11
> 30	12503.88	5312.34	6604.38	15963.84

** The unit for OM loss is 10 * kg*

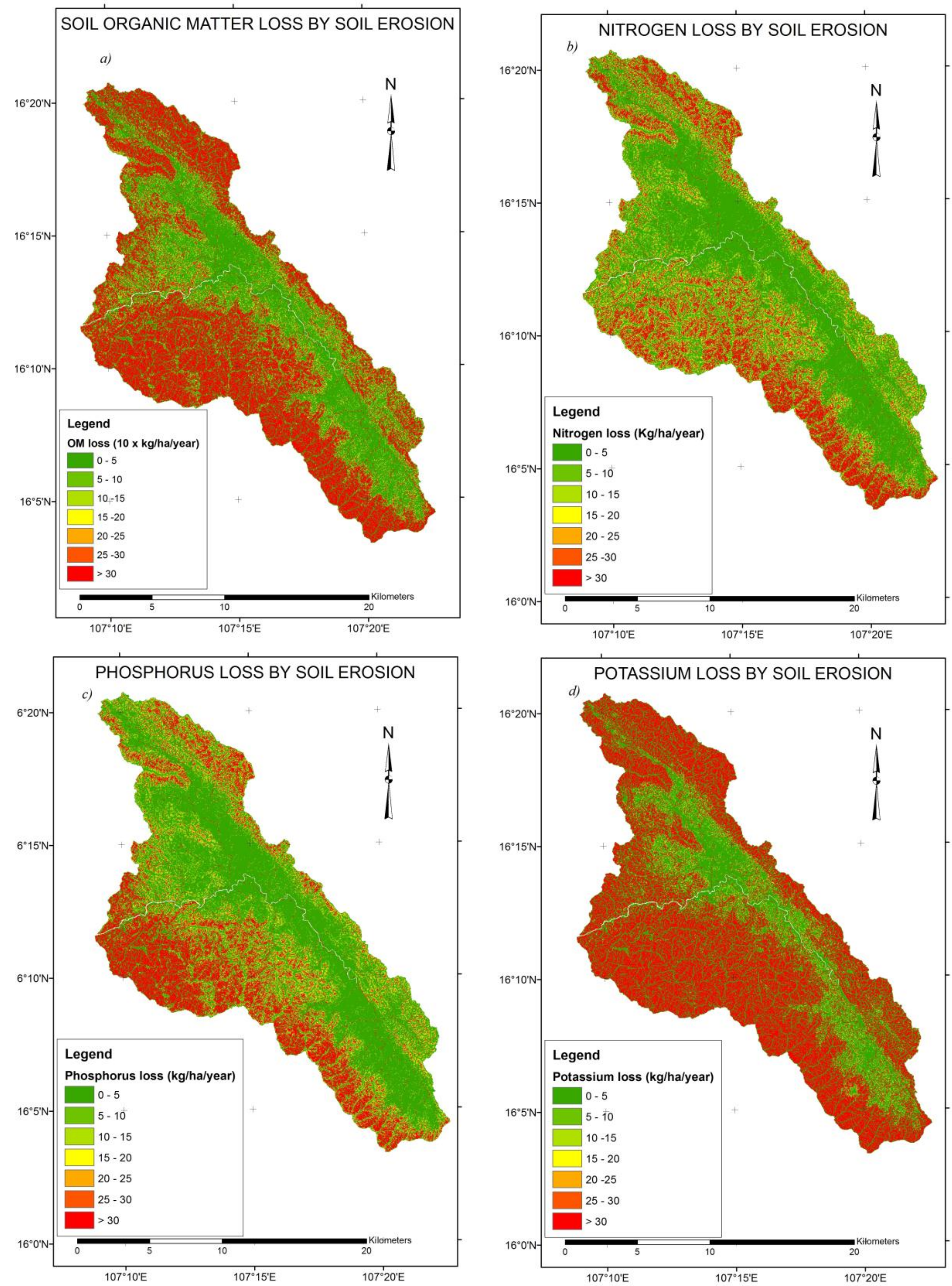

Fig 6a, 6b, 6c, 6d are OM, N, P, K loss in Asap Basin respectively

Table 5 indicates that the absolute numbers soil organic matter and potassium are being washed away the most by the process of soil erosion. Especially soil organic matter loses more than 300kg/hectare/year on nearly 40% of the land area, which mainly concentrated in the southwest region (where it has low organic content but having high erosion levels), making the soil quality in this region declines rapidly. The similar situation also occurs for potassium in soil, but smaller than organic carbon , only 10% in comparison with total area.

Discussion

Soil quality in Asap Basin

Nutrients content in soil in Asap basin is 0.72 kg of nitrogen, 0.9 kg of phosphorus, 9.7 kg of potassium and 2.26% of organic matter of soil weight, meanwhile *(David Pimentel et al, 2013)* commented that a ton of fertile topsoil averages 1 to 6 kg of nitrogen, 1 to 3 kg of phosphorus, 2 to 30 kg of potassium and 4% to 5% organic matter of total top soil weight. This means that soil quality in research area is poor. Soil organic matter content in each soil in Asap basin is lower than other places in Vietnam. Other nutrients such as nitrogen, phosphorus and potassium are the same organic carbon situation.

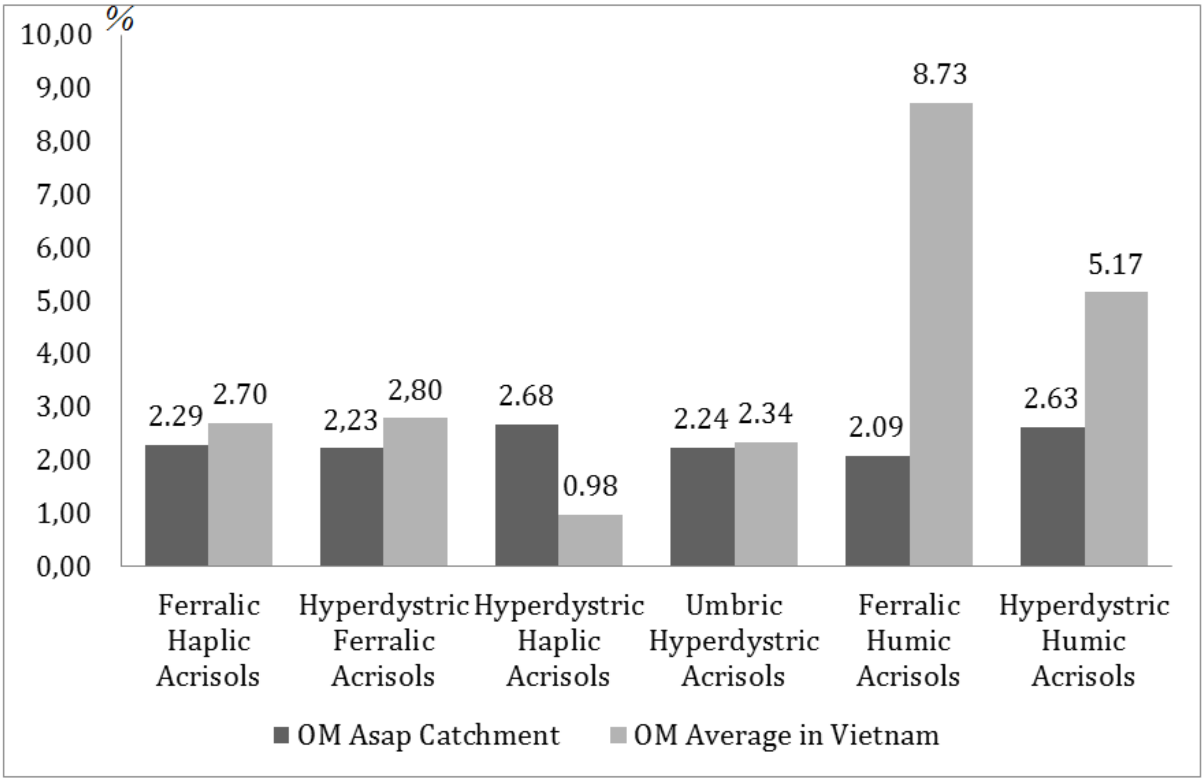

Fig 7 is value OM of each soil type in Asap basin in comparison with average value of Vietnam

Land use type and soil erosion

Land soil erosion caused by rain is very strong and quite complex in the study area. In particular, very high levels of soil erosion occurred on 13.77% of the total natural area while the area with no erosion comprises 44.67%. This can be explained by the very steep terrain, high altitude and mostl-y natural forests and a lack of solutions to prevent soil erosion.

Our result has a significant difference from others *(Pham Huu Ty, 2008)*, *(Ho Kiet, 1999)*, *(Nguyen Duy Liem et al, 2011)* who conducted researches in another districts with the same natural conditions, especially, amount of soil loss in Asap basin is lower. The main reason leading to this difference is the use of the inputs for the model USLE. Previous studies usually ignore the influence of the element P and give it a value of 1, which means they ignore the ability to reduce soil erosion by the agricultural solutions. However, comparison between some places of Vietnam and the Southeast Asia showed that soil erosion in watersheds of Asap is more serious. For example, for the type of land use of annual crops, in

Vietnam the average loss of about 4.3 tons/ha/year, while in Thailand eroded soil around 1.6 tons/ha/year. Worldwide, soil erosion rates range from 1 to 5 ton/ha/year in mountainous regions *(David Pimentel et al, 2013);* however, in Asap catchment eroded soil in average is 25ton/ha/year.

Table 5: *Soil loss by land use in comparison with other studies (t/ha/year)*

Land use type	Pham Gia Tung et al (2016)	Ho Kiet (1999)	Pham Huu Ty (2008)
Natural Forest	38.40	N/A	66.10
Plantation Forest	10.95	34.59	81.50
Paddy Rice	2.79	0.41	9.50
Yearly Crops	7.58	9.47	28.40

Moreover, results show that natural forest lands a have the highest annual erosion rate. Similarly *(Pham Huu Ty, 2008)* argued that the plantation forest has the highest erosion while *(Liu Gangcai et al, 2004)* confirmed that the most serious erosion is agricultural land. The reason might be due to the natural forests in watersheds of Asap is very poor. Most of the area are shrubs, grassland, which lead to think surface and is more difficult to keep soil. There are many small flows and steep terrain also makes the situation of soil erosion of this land use type is increasingly aggravated. Therefore, the intercropping of trees in natural forests, restoring and protecting native plants to prevent erosion is a necessary activity.

Land use type and Nutrient loss

Table 4: *Nutrient in soil loss by land use type*

Land use type	Nutrient in soil loss (kg/ha/year)			
	OM	N	P	K
Yearly crop	1169.00	5.14	9.66	60.34
Paddy rice	80.00	2.50	2.02	24.10
Plantation forest	2860.00	8.47	9.36	88.36
Natural forest	8320.00	26.12	37.75	302.57
Water (Area for hydropower station)	4820.00	13.43	35.99	170.01
Perennial and industrial crop	1040.00	3.04	3.70	22.05
Other	1920.00	6.01	5.30	58.11

Natural forests have poor soil quality; however, this area is where the process of nutrient erosion is the strongest. One of the most important reasons is the area’s steep terrain and its lack of serious anti-erosion measures. Because there are not any research on loss of nutrient in soil at the research site or any related places, we do not have previous data to compare. By reference with other studies conducted in Vietnam with the same natural conditions such as land use types, slope degrees we found that nitrogen in the soil in the study area is lower leaching than other regions. For yearly crop, the loss of 5.14kg/ha/year are high compared with losses from hill country cassava cultivation, which was reported in northern Vietnam of 33 to 88kg/ha/year *(Tran et al, 2004)* and 179kg/ha/year *(Nguyen Van De et al, 2007)* and 37kg/ha/year *(Reinhardt H. Howeler, 2001)*). This contrast compared to the elements phosphorus and potassium. The main reason leading to this situation is caused by nitrogen in the soil is too low compared with other regions.

Conclusion

First, the soil erosion due to rainfall and runoff in Asap catchment is very high (> 30% of natural area inside the catchment lost > 10 t / ha/ year). Second, the soil erosion is the main cause of the loss of nutrient content in the soil; especially potassium and organic matter are the most affected

Third, although the area is natural forest but it was significantly devastated. Besides, with high slope and lack of erosion restrictive measure are main reasons lead to a lot of land area and nutrient in the soil are lost. Clearly, there is a close relationship between soil erosion and loss of nutrients in the soil. In most of types of land use, especially natural forests, the higher erosion level, the larger nutrient content in the soil are lost.

Last, we see that the prediction result about the soil lost of USLE is always higher than the experimental results. Besides, we had to calculate and apply correctly the parameters in the equation, avoid ignoring the impact of the P coefficient to get the most accurate model result.

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