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EFFECT OF RESERVOIRS ON SEDIMENT LOAD IN THE LO RIVER BASIN (CHINA-VIETNAM)

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1 INTRODUCTION

The Lo river is a left side main branch of the Red river, located on its eastern side. The river sources start from Ping Yuan of Yuanshan, in the Yunnan Province (China). The location of the river source is 105°37' E longitude, 23°35' N latitude, at an altitude of 1100 m above the sea level. The location of the river mouth is 105°27' E longitude, 21°18' N latitude and at the Viet Tri gauge the catchment area is 38165 km^2 of which 22600 km^2 are in Vietnam. The length of the Lo River is 470 km, 275 km being in Vietnam. It flows through the Cao Bang, Tuyen Quang and Yen Bai provinces in Vietnam and joins the Thao river at Viet Tri, Phu Tho province, where the main stream takes the name of Red River (Song Hong). The average basin altitude is 884 m and the basin area above the altitude of 250 m covers more than 80% of the total basin area. The average slope of the Lo basin area is 19.7%. The maximum elevation decreases from 2000 m altitude in China to 1000÷1500 m altitude in Vietnam. The mountain topography is separated by four main rivers. The Thao and Chay rivers are separated by the Con Voi mountain range and Bac Ha plateau. The Khanh mountain ridge, reaching an altitude of 2427 m asl divides the Chay and the Lo rivers.

There are some major hydrometric stations in the Lo river, with runoff and suspended sediment load data records longer that 30 years, such as the Ha Giang station gauging a basin of 8300 km^2 drainage area, Ham Yen (11900 km^2), Chiem Hoa (16500 km^2), Tuyen Quang (29600 km^2) and Vu Quang station with a basin 37000 km^2 in size (see Figure 1). In this paper the effect of the two major reservoirs, the Thac Ba and the Tuyen Quang reservoirs, on suspended sediment load downstream is presented based on the analysis of long term data series. A suspended sediment load modeling approach based on a RUSLE soil erosion model and a distributed routing on a monthly scale basis is presented with simulations compared with observations over a 39 years period.

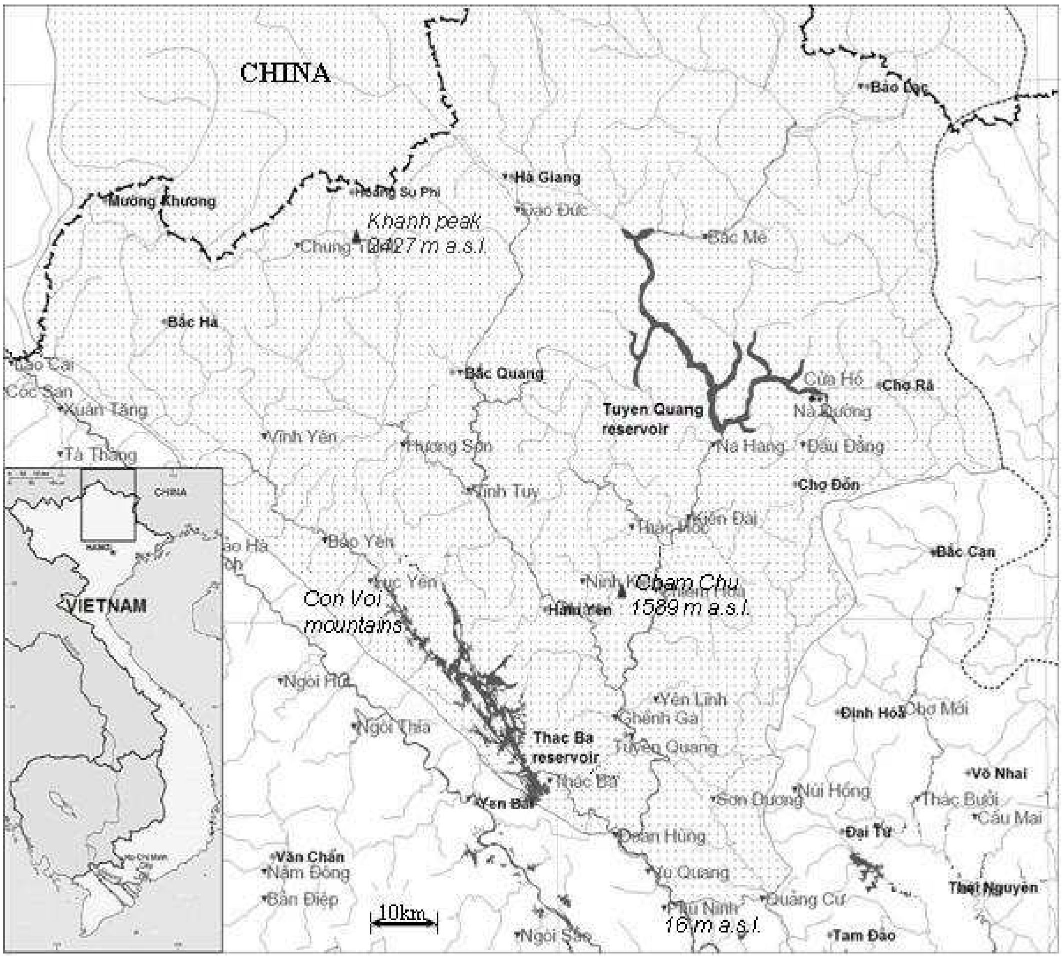

Figure 1 - The Lo river basin with the hydrometric and the suspended sediment load measurement stations in Vietnam. The basin's sources are in China.

2 PRECIPITATION, RUNOFF AND SEDIMENTATION DATA

2.1. RAINFALL REGIME

Rainfall in the Lo basin is relevant but is highly variable on space and time (Table 1), depending on local terrain conditions and monsoon circulation in

Northern Vietnam. The Ha Giang province is more rainy, reaching an annual rainfall depth of 4815 mm measured, on average, in Bac Quang from 1961 to 2007 (Table 1 and Figure 2). Similar to other areas in the North, the climatic regime is divided into 2 seasons: the rainy season and dry season. The rainy season begins from May - the start of the hydrological year to October; the dry season is from November to April of the following year.

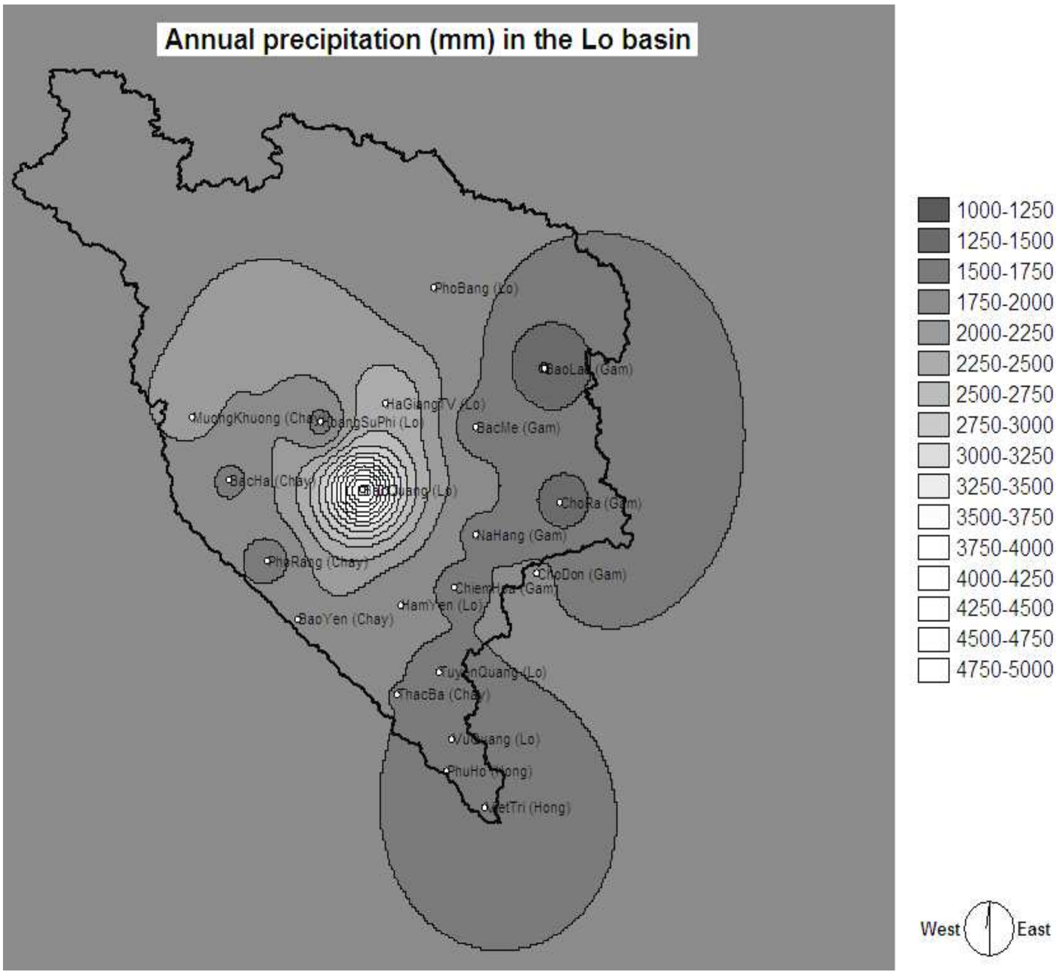

Figure 2
Annual precipitation in the Lo basin (1959-2007)

Average annual rainfall on a climatic basis in the Tuyen Quang province fluctuates in the 1500÷1800 mm range. The annual average rainy days are 150. The rainy season coincides with summer with total seasonal rainfall ranging, at different stations, around 1310÷2131 mm, comprising 85.3÷94.1% of total annual rainfall; the dry season coincides with winter with total seasonal rainfall at 134÷225 mm, only comprising 5.9÷24.7% of the total annual rainfall.

Months with higher average rainfall are July, August and September with rainfall of 250÷320 mm/month, and up to 950 mm/month (September 2000 in Tuyen Quang). Months with lowest average rainfall are January and December with rainfall reaching only 16÷25 mm/month. The fluctuations of monthly average rainfall (1959-2007) in some stations of the Lo basin are shown in Table 1.

Table 1
Average monthly Rainfall regime in the Lo basin (1959-2007), (mm)

Month	Dao Duc	Bac Quang	Ham Yen	Bao Lac	Na Hang	Cho Ra	Chiem Hoa	Pho Rang	Luc Yen	Thac Ba
1	39.0	72.0	27.3	22.2	21.2	19.0	26.0	27.4	32.5	21.9
2	43.7	73.5	39.5	25.9	29.5	22.4	32.8	34.8	41.9	30.2
3	67.6	90.3	56.2	44.9	56.7	45.0	52.9	59.6	71.7	54.6
4	108.6	246.3	126.4	76.1	107.5	92.8	122.9	135.3	136.4	112.7
5	305.0	761.9	232.1	165.1	251.9	176.0	234.4	183.6	209.0	212.4
6	450.8	983.7	281.6	212.7	322.4	238.7	280.4	213.8	283.5	255.1
7	545.8	919.4	321.6	241.6	336.0	254.0	283.9	251.1	328.0	331.8
8	415.2	625.1	318.3	217.3	278.4	239.7	295.3	333.0	396.6	332.2
9	234.5	406.5	184.7	98.2	135.3	125.1	166.9	203.8	255.1	198.4
10	165.9	391.6	120.8	76.3	90.2	86.2	106.9	112.9	144.4	126.7
11	83.8	166.1	44.7	41.5	43.4	40.8	45.3	44.8	59.7	50.8
12	34.5	78.3	22.2	21.5	22.7	19.2	22.0	17.4	27.6	20.5
Year	2494.4	4814.8	1775.4	1243.4	1695.2	1358.9	1669.7	1617.2	1986.3	1747.3
Month	Ghenh Ga	Vu Quang	Viet Tri	Bac Ha	Bac Me	Cho Don	H.Su Phi	Muong Khuog	Pho Bang	Phu Ho
1	23.1	31.9	26.4	24.1	26.0	17.4	17.8	41.7	20.2	33.7
2	29.5	38.8	30.9	31.8	27.6	27.2	21.6	46.1	19.9	37.1
3	52.4	57.8	46.2	57.1	51.1	46.5	44.7	50.2	38.0	55.0
4	112.8	111.3	102.3	124.8	90.1	112.6	88.4	115.6	94.7	112.1
5	222.6	209.9	187.2	194.9	244.3	203.5	196.0	204.5	181.0	215.2
6	270.8	243.7	260.6	237.5	287.7	320.9	294.2	327.2	313.1	247.9
7	289.6	281.4	269.4	276.2	329.2	345.8	338.5	405.2	367.1	279.3
8	298.4	275.1	272.2	332.2	267.0	340.9	319.9	363.0	323.6	286.7
9	172.6	195.1	183.0	211.1	132.6	162.8	165.2	207.5	180.7	202.5
10	124.3	136.7	142.0	124.8	91.6	119.3	105.0	159.5	123.4	151.3
11	45.6	48.0	51.8	64.1	46.6	44.8	52.4	81.5	66.6	60.4
12	17.3	24.0	20.2	22.3	21.6	20.6	21.1	35.4	26.5	24.0
Year	1659.0	1653.6	1592.3	1700.8	1615.4	1762.4	1664.6	2037.4	1754.7	1705.3

2.2. RUNOFF AND SUSPENDED SEDIMENT DATA

In the following Table 2 and Table 3 the mean annual runoff and suspended sediment discharge measured at the stations over a 39 years period is reported, derived from daily runoff and sedimentation measurements at 8 stations in the Lo river basin, indicated in Figure 1.

In Figure 3, the effect of the Thac Ba reservoir on suspended sediment impounds can be observed. The reservoir was in operation starting with 1971 when a dramatic drop on suspended sediment concentration is observed. The average sediment concentration over the 1971-1975 period had fallen to 0.026 kg/m^3 from the 0.529 kg/m^3 average over the 1959-1963 and 1966-1970 period, prior to the reservoir construction with a resulting suspended sediment trap efficiency of 95%.

Table 2
Annual total runoff (10^6 m^3/year) in the Lo river basin

Station	Bao Yen (5000 km^2)	Thac Ba (6170 km^2)	Ha Giang (8300 km^2)	Ham Yen (11900 km^2)	Bao Lac (4060 km^2)	Chiem Hoa (16500 km^2)	Tuyen Quang (29600 km^2)	Vu Quang (37000 km^2)
1959		5 790.64		11 318.49				32 400.95
1960		5 995.96		11 403.37			22 593.60	28 980.98
1961		6 929.48		12 915.23			25 294.81	33 709.13
1962		5 993.27		11 005.70			20 937.57	27 952.04
1963		5 787.85		10 311.01			17 459.02	24 143.88
1964		7 092.46		14 121.56	2 125.44		26 713.24	33 368.03
1965		5 373.91		10 702.57	1 846.23	9 947.91	21 835.87	27 407.29
1966		6 649.08		11 294.13	2 536.67	11 952.39	23 212.92	32 508.43
1967		4 707.32		9 268.93	1 418.72	8 040.95	17 578.25	23 510.22
1968		6 166.59		13 425.35	3 116.07	15 607.48	29 403.39	38 041.49
1969		5 831.52		11 761.62	1 973.35	11 092.32	23 999.16	31 695.24
1970		7 091.82		12 903.92	2 320.14	11 874.51	25 699.94	33 779.89
1971		9 243.31		16 621.46	2 901.86	16 023.43	33 806.59	46 074.44
1972		5 405.54		10 485.58	1 317.41	11 959.87	20 414.76	26 315.02
1973		7 489.37		14 255.98	2 839.62	9 947.91	30 213.56	40 444.70
1974		5 222.46	5 164.69	11 197.66	1 820.29	11 025.69	22 878.98	30 219.26
1975		6 192.12	5 149.20	11 659.31	2 062.63	11 927.24	24 593.85	33 484.06
1976			3 662.06	9 963.23	1 912.01	10 135.14	18 708.71	27 880.16
1977			3 665.80	9 291.63		7 998.64	17 147.29	23 608.63
1978			6 808.78	13 477.50		14 034.99	28 911.69	37 506.15
1979			7 015.84	14 775.77		14 627.93	30 044.65	40 406.86
1980			3 795.25	9 812.64		9 556.30	21 869.65	30 343.42
1981			5 965.86	12 812.41		14 133.89	27 865.99	39 836.02
1982			5 153.26	11 242.90		11 971.16	23 891.41	36 013.85
1983	4 413.92		5 327.30	12 013.81		12 799.99	25 152.85	35 729.68
1984	5 152.09		5 334.05	14 430.48		11 871.17	27 890.87	38 194.16
1985	4 361.53		5 718.06	11 348.61		12 597.64	23 679.65	33 503.07
1986	5 617.18		7 948.26	14 874.95		16 228.11	30 990.04	42 954.80
1987	3 548.80		4 866.68	10 763.69		9 210.21	19 775.58	27 460.77
1988	3 450.62		4 310.21	10 847.62		10 958.92	23 117.79	29 703.97
1989	4 448.44		5 105.72	10 925.17		9 649.17	23 085.65	28 427.41
1990	5 267.00		5 811.07	13 758.08		15 255.04	32 975.51	44 932.32
1991	3 550.29		4 814.11	11 672.80		10 217.23	22 775.21	31 729.10
1992	3 821.03		4 386.39	9 748.29		10 385.19	21 191.59	28 181.35
1993	3 347.53		4 484.36	9 733.61		12 615.69	25 059.46	30 856.46
1994	4 303.20		5 382.54	11 732.03		13 288.61	27 347.59	35 950.18
1995	5 150.68		5 789.53	13 817.74		12 447.99	29 469.74	36 858.76
1996	5 441.30		5 530.95	12 712.12		13 728.11	28 855.18	38 305.35
1997	4 972.87		4 920.82	12 373.17		14 523.04	28 670.98	37 279.35
1998	3 732.88		4 467.18	10 631.71		12 172.52	23 742.20	31 387.56
1999	4 053.91		4 574.23	11 676.17		12 170.86	24 774.85	30 735.07
2000	4 299.63		4 430.54	10 714.89		9 860.15	21 268.40	27 990.84
2001	4 401.86		4 633.13	10 405.71		13 090.78	24 703.83	33 729.52
2002	4 953.46		4 885.27	12 718.47		15 282.36	29 428.62	39 096.43
2003	4 344.72		4 182.85	10 829.51		10 638.34	22 362.65	27 597.89
2004	4 412.81		4 309.80	9 709.73		10 785.32	21 133.44	24 110.61
2005	4 642.50		4 032.95	10 325.53		9 953.03	19 841.41	20 070.12
2006	3 391.20		3 330.04	8 181.68		8 964.31	17 460.32	18 157.47
2007	3 856.03		4 094.27	10 021.42		12 119.09	21 397.82	26 194.39

Table 3

Annual total sedimentation (10^6 tons/year) in the Lo river basin

Station	Bao Yen (5000 km²)	Thac Ba (6170 km²)	Ha Giang (8300 km²)	Ham Yen (11900 km²)	Bao Lac (4060 km²)	Chiem Hoa (16500 km²)	Tuyen Quang (29600 km²)	Vu Quang (37000 km²)
1959		2.53		3.12				9.61
1960		2.72		1.99			5.35	6.73
1961		3.23		3.58			9.10	9.82
1962		2.41		4.23			6.80	8.56
1963		3.28		1.80			4.84	4.69
1964				4.68	0.51		11.22	13.09
1965				2.75	0.39	2.21	7.44	7.90
1966		4.90		2.19	2.33	6.84	10.16	12.12
1967		2.71		2.52	0.66	2.43	5.33	7.22
1968		3.99		4.24	2.68	9.09	12.51	13.96
1969		2.99		4.40	1.36	4.08	9.38	10.13
1970		3.45		4.10	0.81	4.16	10.26	10.36
1971		0.48		6.78	2.26	7.61	16.55	15.60
1972		0.19		3.35	0.38	3.91	6.90	7.26
1973		0.09		5.74	0.98	2.98	10.88	9.25
1974		0.12	3.64	4.58	1.05	4.33	8.81	7.68
1975		0.05	4.15	4.67	1.16	5.14	8.59	10.79
1976			2.35	3.45	0.80	3.67	6.08	6.85
1977			2.02	2.77		2.23	3.86	4.91
1978			5.86	5.85		11.05	14.27	18.48
1979			9.71	12.47		9.26	17.77	15.97
1980			1.77	2.94		3.23	7.24	8.11
1981			3.72	3.67		4.94	10.10	8.92
1982			2.17	2.04		3.42	8.21	6.16
1983	3.51		2.04	2.83		3.38	5.96	3.69
1984	5.58		3.93	5.07		4.31	8.39	7.66
1985	3.36		4.95	5.01		5.28	9.16	8.64
1986	8.98		12.95	6.90		11.86	22.31	18.29
1987	3.29			5.33		2.87	8.64	8.80
1988	3.31		3.06			5.30	9.58	14.47
1989	3.58		3.09	13.09		4.28	9.77	12.05
1990	6.65		2.94	6.17		12.22	18.37	21.86
1991	5.38		3.68	4.93		4.11	9.98	12.88
1992	4.95		2.52	3.30		4.55	10.61	9.28
1993	3.20		3.31	2.34		7.43	12.70	8.59
1994	3.08		3.60	4.87		4.65	11.56	14.38
1995	6.75		3.69	9.35		4.41	11.88	22.42
1996	5.38		3.88	4.77		4.27	12.12	12.54
1997	3.95		3.43	4.00		5.79	12.75	11.55
1998	3.38		3.79	5.54		5.93	12.40	15.27
1999	3.18		3.04	4.62		4.59	9.58	11.82
2000	4.18		2.75	4.33		2.74	6.59	10.13
2001	5.00		3.06	3.91		6.61	10.65	12.57
2002	6.41		4.48	5.84		7.71	16.64	17.33
2003	4.21		2.90	3.37		3.17	9.06	8.03
2004	4.28		3.52	3.80		10.45	10.04	9.57
2005	3.39		1.52	2.54		3.13	5.87	5.45
2006	1.74		0.90	1.71		1.12	2.84	3.45
2007	2.58		1.33	1.18		1.35	3.04	3.66

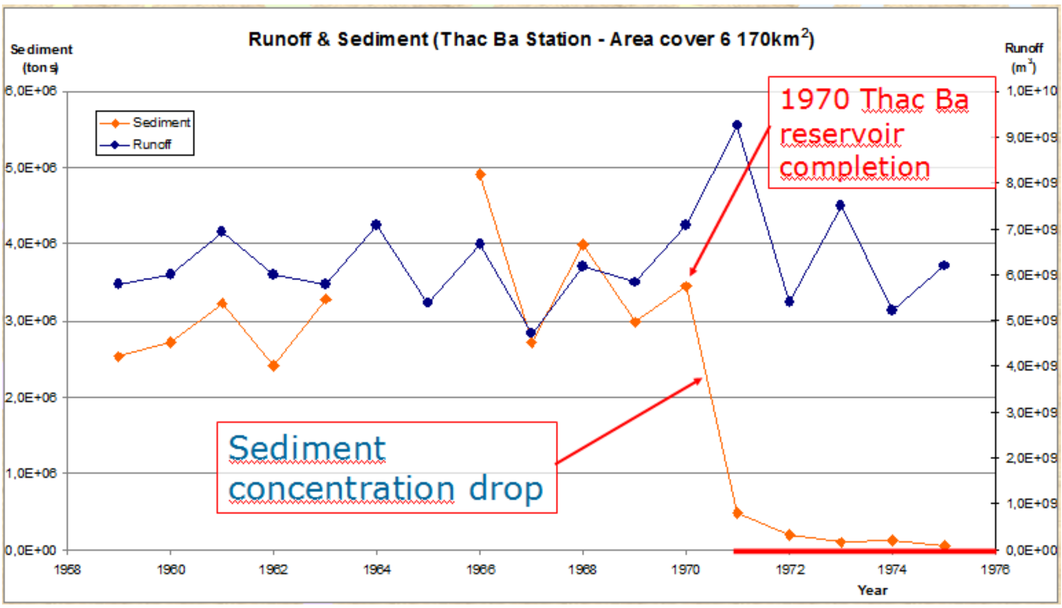

Figure 3
Effect of Thac Ba reservoir on suspended sediment load

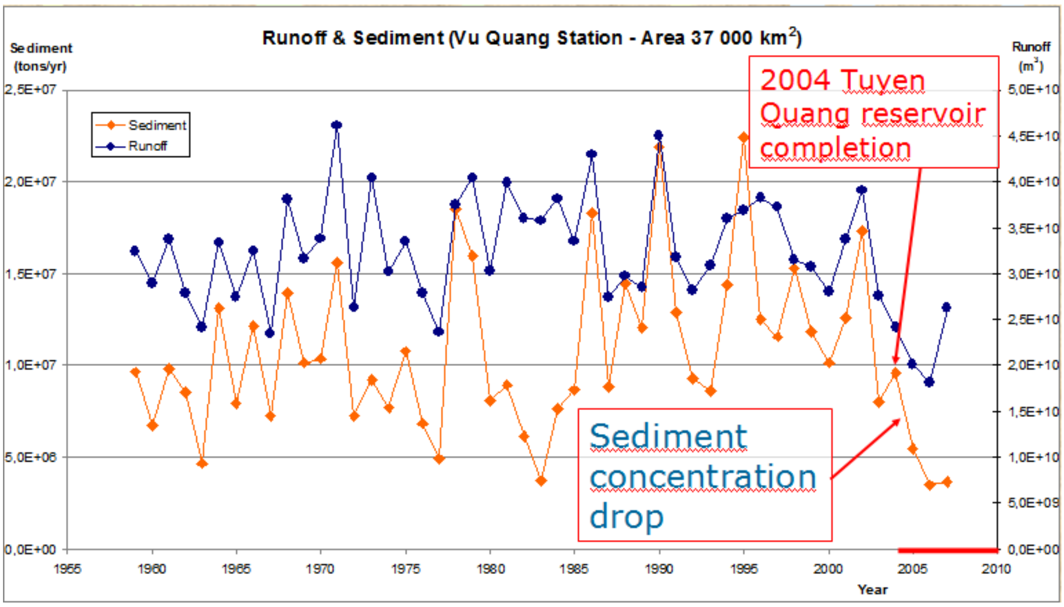

Figure 4
Effect of Tuyen Quang reservoir on suspended sediment load

Figure 4 illustrates the effect on suspended sediment load of the Tuyen Quang reservoir which was in operation starting with December 2004. The average sediment concentration measured in the downstream Chiem Hoa (16 500 km^2) over the 2005-2007 period was 0.184 kg/m^3 and over the 1965-2004 was 0.436 kg/m^3 with a resulting suspended sediment trap efficiency of 71% of the Tuyen Quang reservoir, draining an area of 13 454 km^2 computed from the 1 km resolution digital river network. These data are consistent with those by Nguyen et al., (2003) who reported that the suspended sediment load at the Son

Tay station (138960 km^2) decreased from $114 \cdot 10^6$ t/yr in the period 1958-1985 to $73 \cdot 10^6$ t/yr in the period 1986-1997, after the Hoa Binh reservoir, draining an area of 51800 km^2 on the Da river has come into operation. Estimates of specific sediment load in the Da river at Hoa Binh are 1.200 kg/m^3 for the 1958-1985 period and 0.300 kg/m^3 for the 1986-1997 period, corresponding to a trap efficiency of 75%, as reported by Le et al., (2007).

3 RUSLE AND ROUTING MODELLING

3.1. THE RUSLE MODELING

In order to assess the effect of rainfall, topography and land use on soil erosion and suspended sediment load an approach based on the RUSLE formulation of soil erosion was attempted. Soil erosion prediction and assessment have been challenging to researchers and several models have been developed. These models are categorized as empirical and physical process-based such as USLE, MUSLE, RUSLE, EUROSEM, WEPP,… The USLE and RUSLE are the most widely applied models. The use of Geographic Information Systems (GIS) makes the estimation of soil erosion in space and time feasible with reasonable cost and better accuracy in larger area. In this research RUSLE was assumed as an index of soil erosion, without taking into account detailed effects of landslides and riverbank erosion as sources of sediment. RUSLE was not originally intended to be valid for large study area. However, satisfactory results on large-scale watersheds were also reported by many researchers and for this reason we tested it on the large Lo basin.

The Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1958, 1962, 1978), and the revised version of it (RUSLE, Renard et al., 1994, 1997), were developed to predict the long term average annual erosion (A) from field sized areas from six factors: R the rainfall-runoff (erosivity) factor, K the soil (erodibility) factor, L the slope length factor, S the slope gradient factor, C the crop and management factor and P the conservation support practice factor. The USLE/RUSLE model is often represented by the equation:

$$A = R \cdot K \cdot LS \cdot C \cdot P \qquad [1]$$

where:

- A is average soil loss per unit of area during a unit period of time, usually year (tons/ha/year).

- R is average rainfall and runoff factor, erosion potential of rainstorm expected for given locality ((MJ/ha)·(mm/h)).

For this study, the equation of Loureiro and Coutinho (2001) is used:

$$R = \frac{1}{N} \sum_{m=12}^{1} \left(7{,}05 \cdot rain_{10} - 88{,}92 \cdot days_{10}\right) \qquad [2]$$

where:
N is the year period,
$rain_{10}$ is monthly rainfall ≥ 10 mm,
day_{10} is monthly number of days with rainfall ≥ 10 mm.

Using the above equation the monthly R factor value for rain gauges of the Lo river basin was computed. The average monthly R factor (1959-2007) is shown in Figure 5.

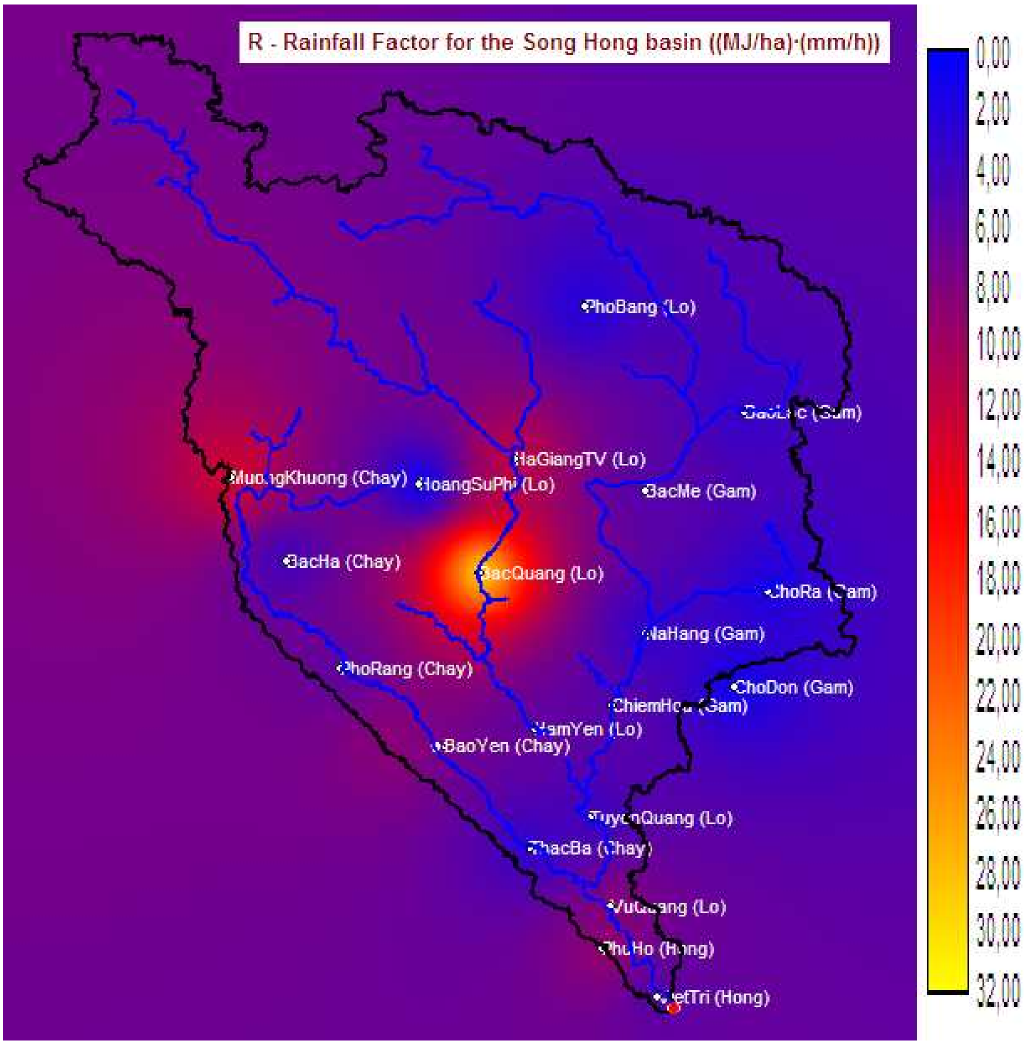

Figure 5
The monthly R factor (MJ/ha)·(mm/h) - Rainfall runoff erosivity

- K is the average soil erodibility factor ((ton/MJ)·(h/mm)).

Some soil types are naturally more prone to soil erosion due to their physical structure. Erodibility is function of soil texture, organic matter content and permeability.

Table 4
K factor (ton/MJ)·(h/mm) - Soil erodibility, Vezina et al., (2006)

Soil type	K factor
Fluvisols	0.055
Regosols	0.025
Leptosols	0.028
Cambisols	0.050
Alisols	0.045
Phaozems	0.065

In this study, without a detailed map of soil types, an average K factor is assumed 0,022 after literature data for watershed units in Vietnam’ s northern highlands, Vezina et al., (2006); Pham, (2007). Such a value is in agreement also with literature data about China, Zhang et al., (2008), which report a mean value of 0.038 in a (0.004÷0.091) range and 0.0144 in a (0.0016÷0.0381) range.

Table 5
K factor (ton/MJ)·(h/mm) - Soil erodibility, Pham, (2007)

Soil type	*D (mm)*	*K factor*
Feralit humus from lime stone	0.082557	0.033
Feralit yellow-red from lime stone	0.180637	0.021
Feralit humus from acid stone	0.097749	0.030
Feralit humus yellow-red from granit stone	0.113501	0.028
Feralit yellow-red from maxma acid stone	0.122138	0.027
Silt	0.14555	0.024
Feralit red- brown from gabrostone	0.117648	0.027
Feralit from typical limestone	0.130215	0.026

- LS is the slope length and the slope gradient factor.

Slope has a major effect on the rates of soil erosion. As slope increases, the velocity of overland flow increase, increasing the shear stresses on the soil particles. As slope length increase, the overland flow and flow velocity also steadily increase, leading to greater erosion forces applied to the soil surface.

In this study, the equation of Moore and Burch (1986) was used:

$$LS = \left(\frac{A_s}{22,1}\right)^{m'} \cdot \left(\frac{\sin\beta}{0,0896}\right)^{n'} \quad [3]$$

where:

A_s is the area of plot per unit width. Considering that crops are divided in small parcels in mountain basins of Vietnam, a reference value of 22.1 was assumed.

m’ , n’ are coefficients equal to 0.6 and 1.3 respectively.

β is slope angle.

- C is the cropping, vegetation and management factor. It used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss (C ≤ 1; without crop, vegetation and management C = 1).

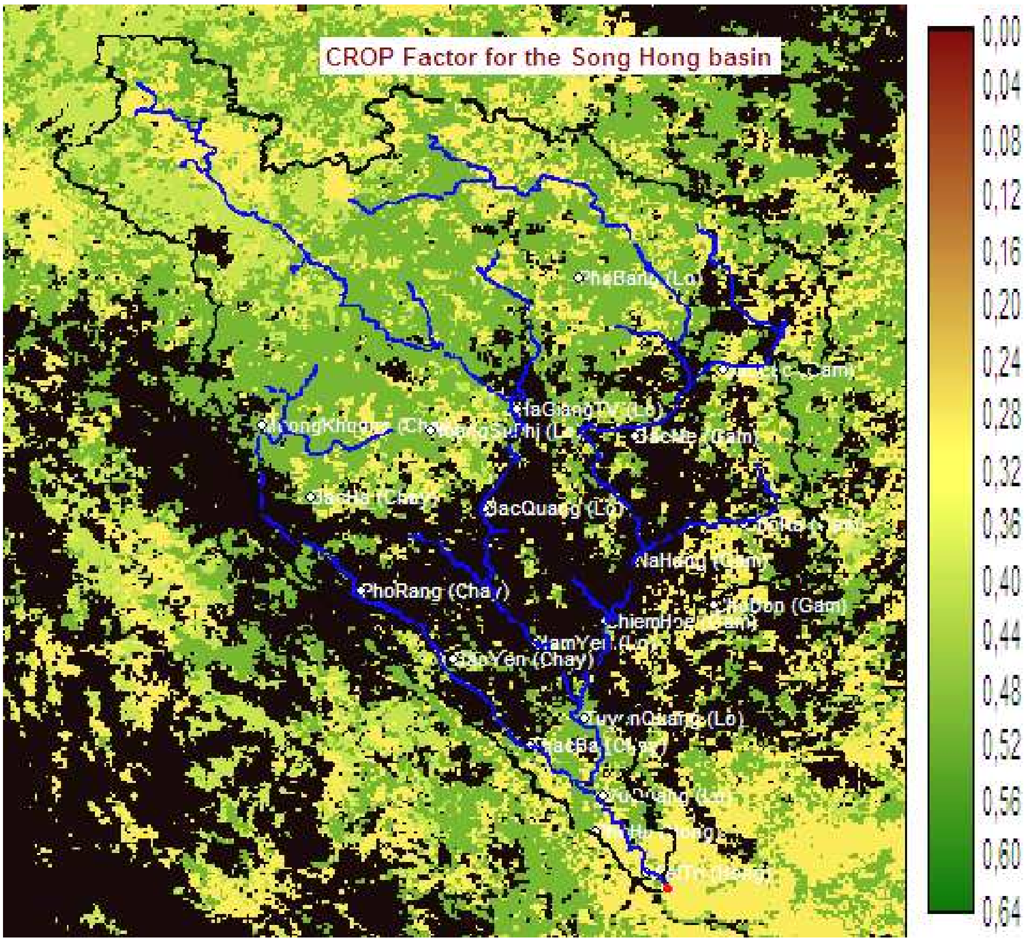

Figure 6
C factor - Cropping, vegetation and management

The C factor plays a critical role in determining the rate of erosion. The leaves of plants protect the soil from raindrop impact and the roots hold the soil together. Plants also tend to increase infiltration of water, thus reducing the volume of overland flow running down the slope. The C factors of the Lo basin for individual crops in addition to mixed farming systems as shown in Table 6, and Table 7 derived from literature data.

Table 6
Cropping factor, Pham, (2007)

Cropping system	C factor
Paddy rice and vegetable	0.60
Bush, shrub, grassland	0.18
Natural forest	0.003
Fallow, waste land	1.00

Table 7
Cropping factor, Vezina et al., (2006)

Cropping system	C factor
Paddy rice (2 cycles)	0.55
Paddy rice (1 cycle)	0.40
Paddy rice (1 cycle) with corn	0.55
Cassava	0.22
Corn	0.12
Soya	0.28

- P is a supporting practice factor. It reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduces the amount of erosion ($P \leq 1$; no supporting practice $P = 1$).

The support practice factor express the effect of support practices such as contour cultivation, strip cropping around contours, arable land terrace and bench terrace; it can not be reflected from land use map. The value of the P factor of the Lo basin for the support practice is reported in Table 8 after the International Soil Science Association data and in Table 9 also following literature data reported by Ferro (2006). In this study the P factor is assumed 0.2 because of the soil conservation practices in the basin, with extensive use of terraced crops and small crop parcels.

Table 8
P factor - Support practice, Pham, (2007)

Slope (%)	Plant under the contour line and Plants with the bench	Plant under the furrow
1÷2	0.3	0.12
3÷8	0.25	0.1
9÷12	0.3	0.12
13÷16	0.35	0.14
17÷20	0.4	0.16
21÷25	0.45	0.18

Table 9
P factor - Support practice, Vezina et al., (2006)

Cropping system	P factor
Paddy rice (2 cycles)	0.10
Paddy rice (1 cycle)	0.20
Paddy rice (1 cycle) with corn	0.10
Cassava	0.90
Corn	0.80
Soya	0.90

3.2. THE DIMOSHONG ROUTING MODELLING

DIMOSHONG is a river network routing scheme based on an 8 directions flow algorithm used for flood propagation in Europe (Ranzi et al., 2002) and

Vietnam, already applied for flood forecasting the Red River basin (Ranzi et al., 2007). No sedimentation is assumed along the river reach , with the exception of the reservoirs where an average trap efficiency derived from measurements is assumed. This hypothesis affects the value of the parameters assumed for the K factor parameter we assumed, which was slightly lower than literature data for the type of soils in the region.

4 RESULTS AND DISCUSSION

4.1. THE RESULT OF SOIL EROSION

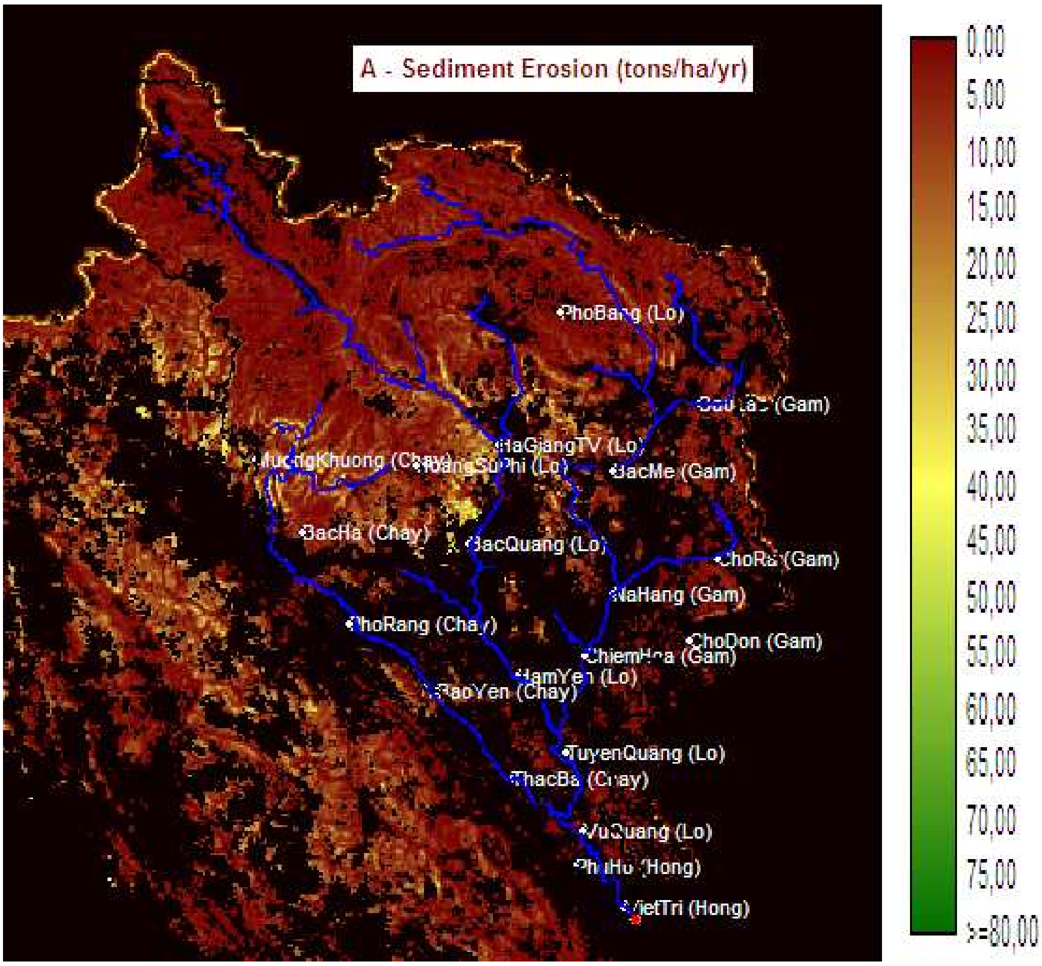

Figure 7
Average soil loss (tons/ha/year) in the Lo river basin

The RUSLE model was applied to the Lo river basin by using rainfall data coming from 20 rain gauges located in the basin and the parameters listed before. The results are shown in Figure 7. It reports the study period averaged soil loss in the Lo river basin. Using the soil erosion in each grid, the average annual soil loss of the basin can be estimated. The average annual soil loss thickness simulated over the 1959-2007 period at eight stations measuring discharge and sediment load in the Lo river basin results to be: at Bao Yen station 0.27 mm/yr, at Thac Ba station 0.34 mm/yr, at Ha Giang station 0.25 mm/yr, at Ham Yen station 0.32 mm/yr, at Bao Lac station 0.34 mm/yr, at Chiem Hoa station 0.17 mm/yr, at Tuyen Quang station 0.23 mm/yr and at Vu Quang station 0.23 mm/yr. Soil loss erosion and sediment load routing through the river network with the RUSLE and DIMOSHONG model, respectively, were employed to evaluate the soil loss. The simulated values with RUSLE and river network routing scheme were in good agreement with observations, with $R^2 = 0.89$ as shown in Figure 8 and indicated in Table 10 for eight stations in the Lo river basin over the 1959-2007 period.

4.2. RESERVOIR IMPOUNDMENT EFFECT ON SUSPENDED SEDIMENT LOAD

The Thac Ba reservoir ($2.49 \cdot 10^9$ m^3 storage) and the new Tuyen Quang reservoir ($2.245 \cdot 10^9$ m^3 storage) already changed sediment concentration since 1971 (Thac Ba) and 2005 (Tuyen Quang), respectively, when they have been in operations. Sediment impoundment in the reservoirs is affecting suspended sediment load in the river network. The reservoirs sedimentation efficiency was estimated in the range 0.71÷0.95 for the two reservoirs and assuming an average value of 0.71, estimated for Tuyen Quang reservoir, it was possible to reproduce quite well sediment load downstream after its completion. A fairly good agreement between simulated and observed values for the stations downstream reservoirs is reported in Table 10.

Table 10
Annual total sedimentation (tons/year) - Measured and RUSLE model
Asterisk * indicate stations downstream reservoirs

N°	*Station*	*Rivers*	*Area (km^2)*	*Obs. Period*	*Measured Sediment (No reservoir) (tons/yr)*	*RUSLE Sediment (No reservoir) (tons/yr)*	*Measured Sediment (With reservoir) (tons/yr)*	*RUSLE Sediment (With reservoir) (tons/yr)*
1	Bao Yen	Chay	5000	1983-2007	4 370 884 (0.58mm/yr)	2 000 728 (0.27mm/yr)	4 370 884 (0.58mm/yr)	2 000 728 (0.27mm/yr)
2	Thac Ba*	Chay	6170	1959-1975	3 221 854 (0.35mm/yr)	3 157 341 (0.34mm/yr)	186 249 (0.02mm/yr)	1 222 592 (0.13mm/yr)
3	Ha Giang	Lo	8300	1974-2007	3 628 797 (0.29mm/yr)	3 162 664 (0.25mm/yr)	3 628 797 (0.29mm/yr)	3 042 227 (0.24mm/yr)
4	Ham Yen	Lo	11900	1959-2007	4 431 441 (0.25mm/yr)	5 652 585 (0.32mm/yr)	4 431 441 (0.25mm/yr)	5 514 879 (0.31mm/yr)
5	Bao Lac	Gam	4060	1964-1976	1 181 968 (0.19mm/yr)	2 079 477 (0.34mm/yr)	1 181 968 (0.19mm/yr)	2 079 477 (0.34mm/yr)
6	Chiem Hoa*	Gam	16500	1965-2007	5 411 995 (0.22mm/yr)	4 326 636 (0.17mm/yr)	1 868 613 (0.08mm/yr)	639 120 (0.03mm/yr)
7	Tuyen Quang*	Lo Gam	29600	1960-2007	10 230 666 (0.23mm/yr)	10 018 721 (0.23mm/yr)	3 915 373 (0.09mm/yr)	4 087 866 (0.09mm/yr)
8	Vu Quang*	Lo Gam Chay	37000	1959-2007	11 000 128 (0.20mm/yr)	12 825 106 (0.23mm/yr)	4 188 439 (0.08mm/yr)	4 225 354 (0.08mm/yr)

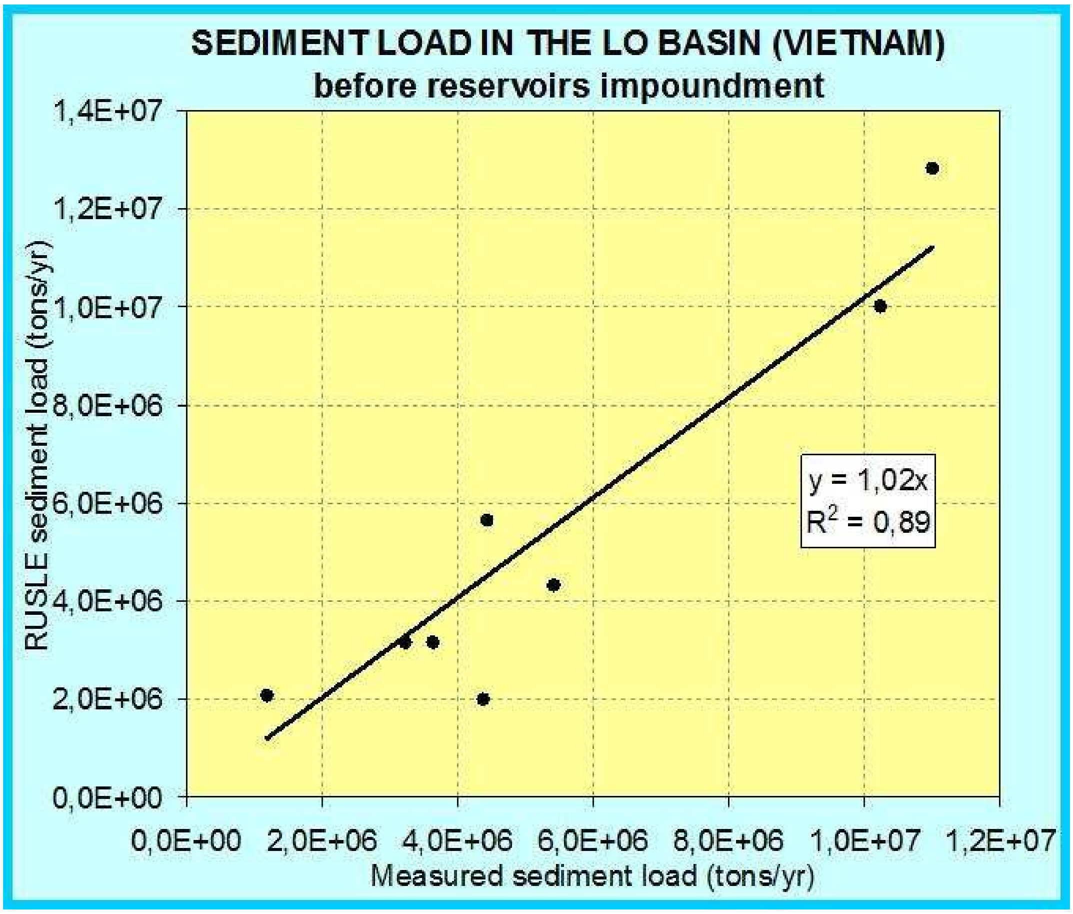

Figure 8

The relationship between RUSLE and measured sediment load (tons/year)

5 CONCLUSIONS

Soil erosion is a serious problem in the Lo river basin as suspended sediment load data from stations downstream Thac Ba and Tuyen Quang reservoirs after their construction show.

Rainfall factor is the most important of the factors affecting soil erosion in Vietnam. The precipitation data analysis shows that in the Lo river basin, about 83.3% of total annual rainfall falls with enough energy for soil detachment (intensity greater than 10 mm/day) according to Loureiro and Coutinho (2001) equation.

The RUSLE model, assumed as an index of the overall soil erosion, was employed to evaluate the soil loss and combined with a river network routing scheme and results of simulated suspended sediment load were in good agreement (R^2=0,89) with average annual soil loss estimated at eight stations in the Lo river basin. Both data of suspended sediment load under conditions prior and after the reservoirs operation are in agreement: at Bao Yen station 0.27 mm/yr, at Thac Ba station 0.34 mm/yr, at Ha Giang station 0.25 mm/yr, at Ham

Yen station 0.32 mm/yr, at Bao Lac station 0.34 mm/yr, at Chiem Hoa station 0.17 mm/yr, at Tuyen Quang station 0.23 mm/yr and at Vu Quang station 0.23 mm/yr). Monthly values of sediment erosion were compared with measurement of suspended sediment load, assuming that the sediment produced at the catchment scale is delivered to the outlet station within one month period. This data will be shown on a paper under preparation.

The impoundment of two large dams in the Chay river and the Gam river watersheds has resulted in a considerable reduction of the total suspended load. Using the RUSLE and river network routing scheme modeling, we estimated the reservoirs sedimentation efficiency with a sediment load reduction of about 71%÷95%. Assuming the value of 0.71 for the efficiency estimated for the Tuyen Quang reservoirs it was possible to reproduce quite well sediment load downstream reservoirs also after their completion. This indicates that our conceptual application of the RUSLE and river network routing model can provide realistic predictions of sediment load in the Lo river basin and sedimentation in the reservoirs, thus providing an useful tool to asses their effects on downstream river conditions.

ACKNOWLEDGMENTS

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