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SOIL EROSION IN DA RIVER BASIN AND SEDIMENTATION IN HOA BINH RESERVOIR

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Abstract

Da River is a main tributary of the Red river in the Northwestern part of Vietnam. It has the highest hydro-power potential in Vietnam. There are three key hydro-power plants built on the main stream of the river: Hoa Binh, Son La and Lai Chau. These three hydro-power plants have been contributing greatly to the power generation of Vietnam and flood control for Hanoi capital and the downstream. Because of the erosion process, Da is a sediment-laden river. Erosion has been causing severe deposition in the reservoirs. This paper presents the calculation of sediment yield, maps the suspended sediment module of Da river basin, estimate the lateral sediment flow of Hoa Binh reservoir, impacts of Son La reservoir and Lai Chau reservoir located at the upstream on the sedimentation process in Hoa Binh reservoir.

Keywords: Soil erosion; Sediment; Da river; Hoa Binh reservoir.

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1. Introduction

River discharge and sediment load are affected by various environmental changes within a drainage basin in an integrated way [11, 13]. In addition, human activities such as dam construction and agricultural irrigation, has seriously changed the hydrological cycle in most river basins. Streamflow or sediment load characteristics of a watershed are closely related to the geology, topography, climate, land use/vegetative cover and human activities within the basin. While geologic and topographic variables are fixed in the short term, long-term changes occur in climatic conditions [4, 6]. On the other hand, human activities or vegetative cover changes would produce abrupt alterations in streamflow, erosion process and sediment load [5, 11, 12]. All environmental changes play an important role in altering the surface flow and sediment yield [3, 16]. Average elevation in the whole river basin and in the territory of Vietnam is 1,130 m MSL and 916.5 m MSL respectively.

The river basin is in tropical-monsoon climate region with pronounced wet and dry seasons. It is cold and dry in the winter, hot and wet in the summer. Mean annual precipitation is about 1,600 mm. Typically, 85% of the rainfall falls during the months of the rainy season. Mean annual runoff of the Da river at Hoa Binh hydrological station which is around 55.7 cu.km, equivalent to water discharge of 1,770 m^3/s. Mean annual sediment load is 72.3 million tons, resulting in an average suspended sediment concentration of 1,310g/m3. Sediment is mainly fine sand with D50 ranging from 0.025 - 0.040 mm and D90 ranging from 0.20 - 0.25 mm. The duration of a flood event is generally 4 - 7 days. Distribution of water and sediment within one year is extremely uneven with 90% of annual water volume

and 78% of its sediment concentrated in a flood season from June to November.

The Hoa Binh reservoir in the Da river, which is some 80 km in the Northwest of Ha Noi, began construction on 6 November 1979. The blocking of the Da river channel was carried out on 12 January 1983 and 30 December 1988. On 20 December 1994, after fifteen years of construction, including nine years of operation management and construction supervision, Hoa Binh Hydropower Plant was inaugurated. With a total storage capacity of 9.45.109 cu.m, it is primarily used for flood control and power generation. The sketch of Hoa Binh reservoir is shown in Fig. 2, and its main technical parameters are summarized in Tab. 1.

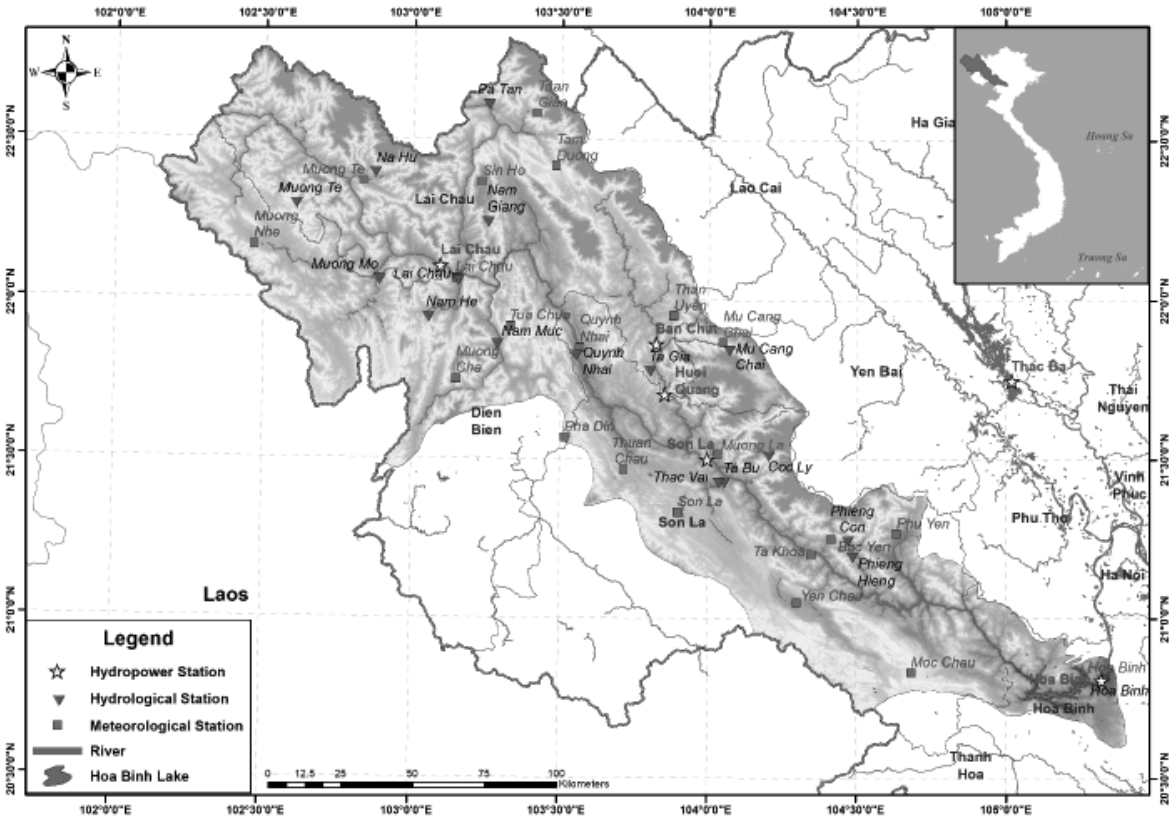

Figure 1: Study area map

Table 1. Some technical parameters of Hoa Binh reservoir

Technical parameter	Unit	Value
Gross capacity	106 m^3	9.45
Active storage	106 m^3	5.60
Dead storage	106 m^3	3.90
Maximum water level	m (MSL)	120
Active water level	m (MSL)	115 - 117
Dead water level	m (MSL)	80
Maximum surface area	km^2	200
Maximum length	km	200
Average width	M	1,000
Average channel slope	‰	0.45 - 0.55

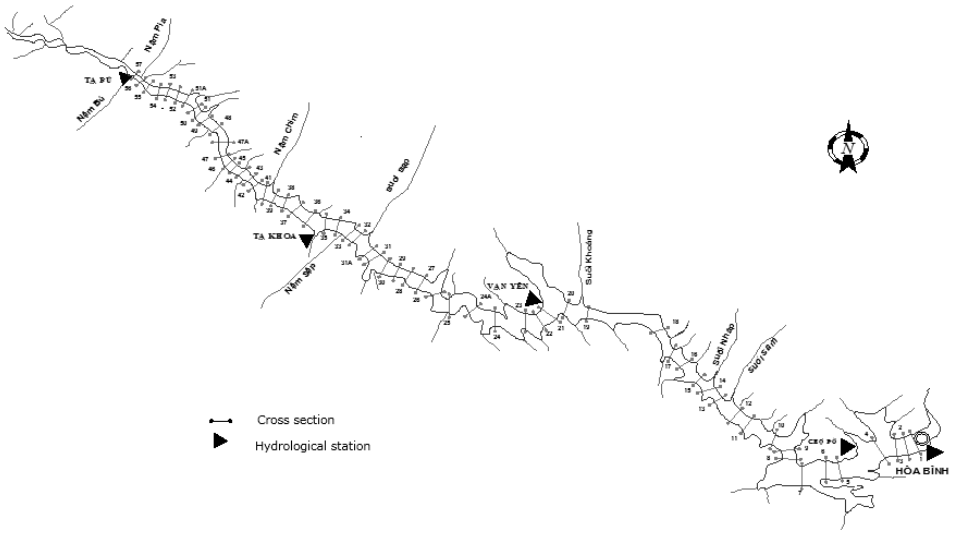

Figure 2: Hoa Binh reservoir in the Da river

2. Study area

2.1. Soil erosion experiment at Hoa Binh environmental station

2.1.1. Soil erosion experiment

Soil erosion experimental plots at Hoa Binh environmental station were built in 1997. They consist of four pairs of plots with various slopes: 15%, 10%, 7% and 5%. For each slope, two plots were constructed with area of 55 m^2 (2.5 x 22.0 m), one plot kept the natural/unvegetated cover and the other planted tea, cassava, corn, soya-bean. The soil erosion experiment has been conducted during each rainy seasons since 1998 [8]. Soil humidity and texture, plants and vegetative cover were measured periodically.

During the soil erosion experiment, the time of beginning and end of runoff for each storm event, rainfall volume, rainfall intensity, water volume, runoff flow rates and total sediment yield were monitored.

Sediment and water flow for each plot was collected in separate tanks. The eroded soil was dried and weighed to determine the total amounts of soil loss.

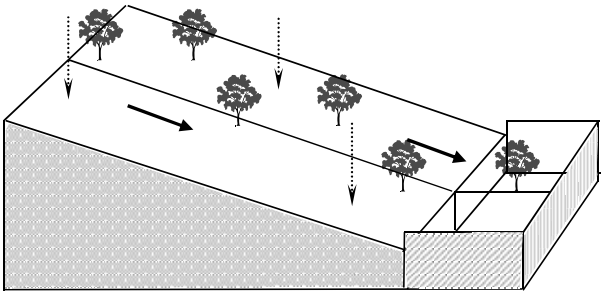

Figure 3: A pair of the experimental plots of erosion

2.2.1. Result of soil erosion experiment

Experimental results from the soil erosion plots at Hoa Binh environmental station indicated that soil erosion was severe. During the period of 1998 - 2001, the average annual soil loss was 39.1 ton/ha for the cultivated plots and 11.6 ton/ha for the natural plots. For the cultivated plots, the most serious soil erosion occurred in the plots planted with tea and reduced gradually in the plots which were planted cassava, corn, or soya-bean. Soil erosion in the plot that planted tea was 190 times greater than the plot that planted soya-bean. Soil erosion in the plot that planted cassava was only 1.5 times greater than the plot that planted corn. For the natural land (N), with the exception of the plot with a slope of 10%, soil erosion of was 5.62 to 6.22 ton/ha.year (Tab. 1).

Table 2. Soil erosion in the experimental plots in Hoa Binh (1998 - 2001)

Plot	S = 15%		S = 10%		S = 7%		S = 5%	
Year	N	Tea	N	Cassava	N	Corn	N	Soya-bean
1998	0.51	86.84	0.30	2.38	0.27	5.50	0.38	0.92
1999	18.7	183.5	33.3	1.49	19.5	0.92	8.41	0.95
2000	3.34	244.1	73.0	37.7	0.95	17.6	13.7	0.55
2001	2.37	23.55	7.76	8.58	1.77	9.86	0.82	0.42
Aver	6.22	134.5	28.6	12.5	5.62	8.46	5.83	0.71

The yearly variation of soil erosion was significant. For the cultivated land, the highest soil erosion could be 2 - 25 times the lowest one. For the natural land, the highest soil erosion could be 36 - 247 times the lowest value (Tab. 1).

The rainfall in May was only 17% of the annual total but its associated soil loss was 55 to 65% of the annual value. The rainfall for three month period from May to July was 61% but soil loss in this period was about 92 - 95% of the annual soil erosion (Fig. 2a, 2b, 2c, 2d).

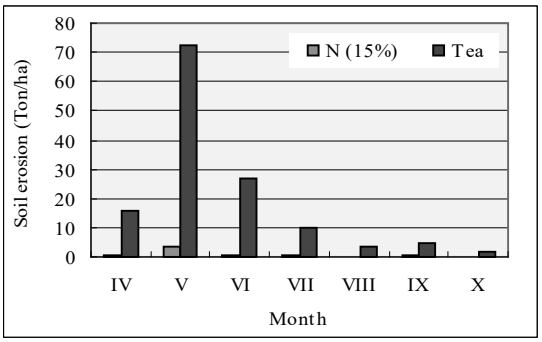

Figure 4: Soil erosion on a pair of plots with slope of 15%

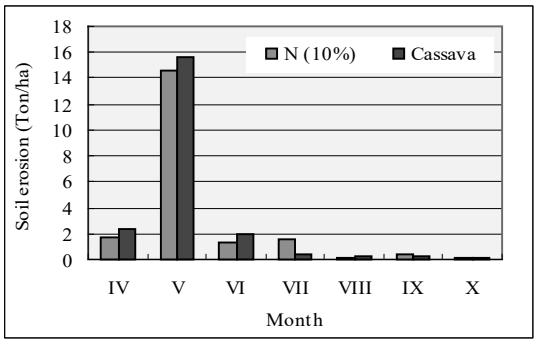

Figure 5: Soil erosion on a pair of plots with slope of 10%

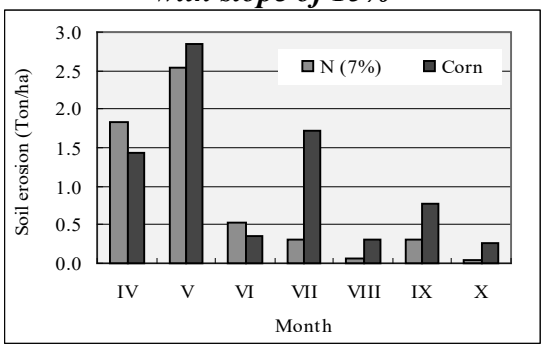

Figure 6: Soil erosion on a pair of plots with slope of 7%

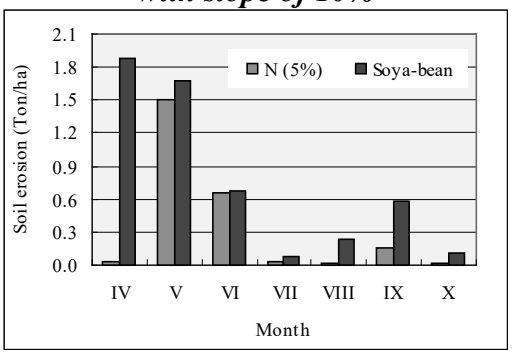

Figure 7: Soil erosion on a pair of plots with slope of 5%

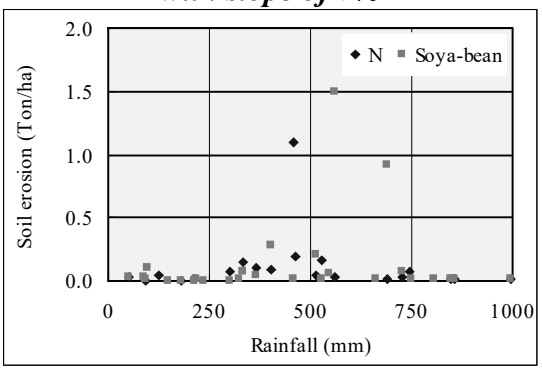

Figure 8: Relationship between rainfall event and soil erosion on a pair of plots with slope of 15%

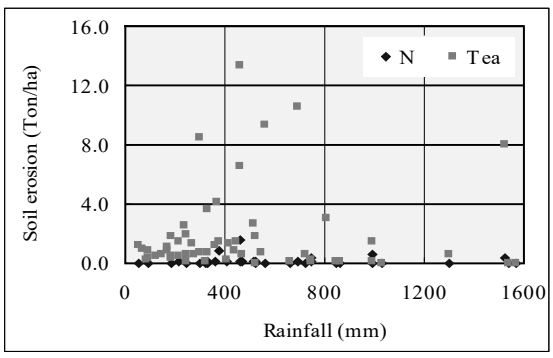

Figure 9: Relationship between rainfall event and soil erosion on a pair of plots with slope of 10%

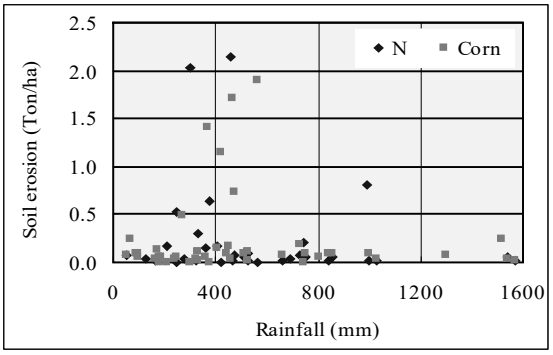

Figure 10: Relationship between rainfall event and soil erosion on a pair of plots with slope of 7%

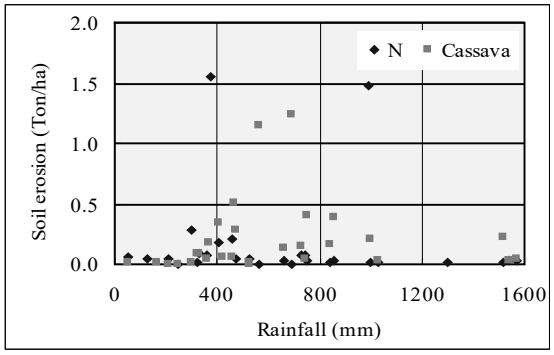

Figure 11: Relationship between rainfall event and soil erosion on a pair of plots with slope of 5%

2.2. Sediment yield in Da river basin

2.2.1. Degradation of forest cover in Da river basin

In the Da river basin, the area of forest cover has decreased rapidly. Forest cover in Son La Province in 1945, 1968, 1976 and 1986 was 55%, 35%, 17% and 6% respectively. In Lai Chau Province, forest cover in 1976 and 1989 was 28% and 10% respectively. In the 1990s, the area of forest cover of the Da river basin (within Vietnam territory) was 282,300 ha or about 10,8% of total land. Thick forest are was 4% of total land, mainly located in high mountainous areas of Hoa Binh and Son La with elevations over 1,000 - 2,000 m above MSL. The main reasons for the decrease of forest cover were (i) wood exploitation for houses, furniture and fuel; (ii) deforestation for agricultural cultivation; (iii) forest fire; and (iv) the lack of interest in reforestation. As a result, the forest cover has been destroyed and soil has been and is severely eroding.

2.2.2. Sediment yield in Da river basin

Sediment yield increases in upstream direction of the basin. There is a difference in sediment yield in two areas: (i) from Hoa Binh Dam to Ta Bu, and (ii) from Ta Bu to Vietnam - China Border. Sediment yield varies from 200 ton/km^2/year in area (i) to more than 500 ton/km^2/year in area (ii).

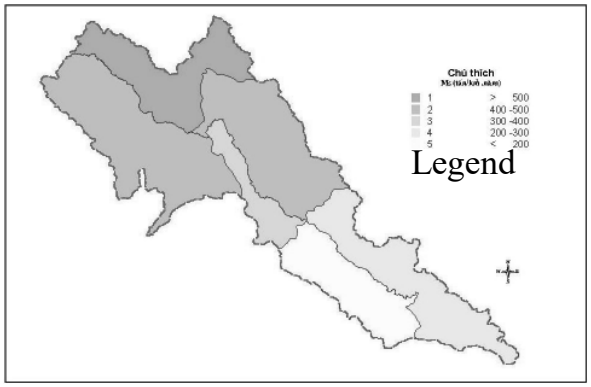

Figure 12: Variation of sediment module in Da river basin

2.3. Distribution of water and sediment flow in Hoa Binh reservoir

2.3.1. Some characteristics hydraulic regime of the Hoa Binh reservoir

Construction of the Hoa Binh reservoir on the Da river, which is some 70 kilometers in the Northwest of Ha Noi, began in 1979. With a total storage capacity of 9.45 billion m^3, it is primarily used for flood control and power generation. Some technical parameters of the reservoir are summarized in Table 3.

According to the reservoir operation rule, from May to the late August water level of the reservoir is kept at 90 - 95 m MSL to maintain minimum storage for downstream flood control. From September to the end of November, the reservoir is filled with the water level progressively increasing to 155 - 117 m MSL. From December to April the next year, the water level is gradually drawn down to 90 - 85 m MSL to supply water for power generation and irrigation in the Red river delta.

Table 3. Some technical parameters of Hoa Binh reservoir

Technical parameter	Unit	Value
Gross capacity	106 m^3	9.45
Active storage	106 m^3	5.60
Dead storage	106 m^3	3.90
Maximum water level	m (MSL)	120
Active water level	m (MSL)	115 - 117
Dead water level	m (MSL)	80
Maximum surface area	Km^2	200
Maximum length	km	200
Average width	M	1,000
Average channel slope	‰	0.45 - 0.55
Annual electric power production	106 KWh	8

2.4. Impacts of Son La reservoir on deposition in Hoa Binh reservoir

2.4.1. Deposition in Hoa Binh reservoir in case of Son La reservoir

The HEC-6 model was used to estimate the deposition in Hoa Binh and Son La reservoir [14]. Computation results as follows:

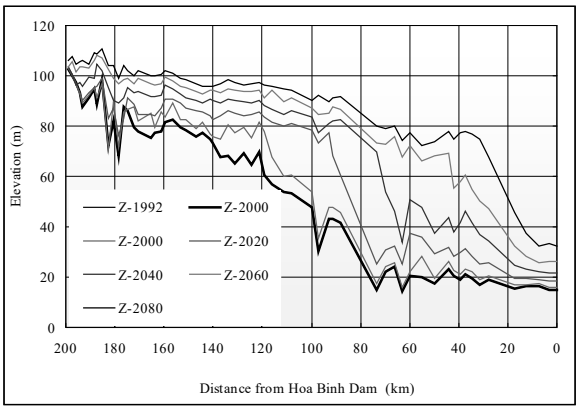

Figure 13: Predicting the sediment deposition in Hoa Binh reservoir

In the period 1992 - 2080, the predicted annual average sedimentation of Hoa Binh reservoir is estimated to be 54.5 million m^3. 70% of this sediment is deposited in the dead storage with and an effective trap coefficient of 0.72. The average active storage loss rate will be 0.6% per year. After 75 years of operation, by 2065, the sedimentation volume will approximate the dead storage volume. After 90 years of operation, by 2080, the deposited sediment delta will move downstream, about 20 km upstream of the dam. Sediment deposition near the dam will raise the reservoir bottom to nearly an elevation of 40 m MSL (Fig. 13) [7, 10].

2.5. Sediment deposition in Son La reservoir

The Son La hydropower project began construction in 2004. This dam is located upstream of Hoa Binh reservoir, and will be completed in 2010. This will be the largest hydropower plant in Southeast Asia. The total capacity of Son La reservoir is 9.26 billion m^3. The maximum water level is 215 m MSL, annual electric power production is 9.4 million kWh.

During 100 years of operation, annual average sediment deposition is 40.3 million m^3 with 47% of the sediment deposited in the dead storage. The mean active storage capacity loss rate will be 0.4% per year.

However, the deposition processes will rapidly in time. In the initial 20 years of operation, the sediment deposition will be 60.4 million m^3 per year with a sediment trap efficiency of 0.75. In the last 20 years

of operation, this value will decrease to 22.4 million m^3 per year with sediment trap efficiency of 0.28. After 70 years of operation, the amount of deposition will approximate the dead storage. After 80 - 100 years of operation, the leading edge of the deposited sediment delta will be 35 km upstream of the dam, and bed elevation at the dam site will be 148 - 160 m MSL [7].

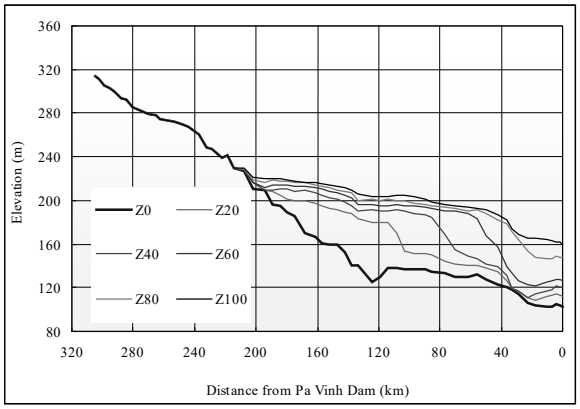

Figure 14: Predicting the sediment deposition in Son La reservoir

2.6. Sediment deposition in Hoa Binh reservoir in case of Son La reservoir

Once the Son La reservoir is completed and operational, it will significantly influence the sediment deposition processes in Hoa Binh reservoir. Most sediment in the Da river will be trapped in the Son La reservoir. Consequently, in the period from 1996 to 2160, the annual average sediment deposition is 26.7 million m^3, about 71% of which will be deposited in the dead storage, with sediment trap efficiency of 0.49.

After 160 years of operation, by 2150, the cumulative deposition will approximate the dead storage volume. The deposited sediment delta will continuously move toward the dam. The distance from the leading edge of the delta to the dam will be 30 km after 170 years of operation, and the bed elevation will rise up to 46.5 m MSL at the dam site. In the period from 2021 to 2140, because of the influence of the Son La reservoir, annual sediment deposition volume will be 16.4 million m^3. This represents 30% of annual deposited sediment volume for the case without the Son La reservoir. About 11.5 million m^3 of this sediment will be deposited in the dead storage with a sediment trap efficiency will be 0.4 (Fig. 15) [9].

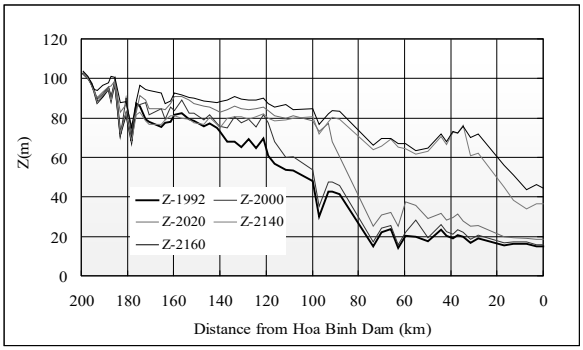

Figure 15: Predicting the sediment deposition in Hoa Binh in case of Son La reservoir

3. Conclusion

Severe soil erosion in the Da river basin is the main reason of high suspended sediment concentration and serious deposition in the Hoa Binh and Son La reservoirs. Research on the hydraulic and sediment regimes in Hoa Binh reservoir demonstrated that sediment laden flows could not be developed to the dam cross-section. The deposited sediment cannot be scoured and subsequently flushed from the reservoir by using the existing operation rule. Deposition in Hoa Binh reservoir will be significantly reduced when Son La reservoir begins operating.

A half of Da river basin is located in China. Therefore, it is very necessary to develop and enhance co-operation between Vietnam and China to exchange

information on hydrological and sediment conditions, river basin planning and basin development activities for the Da river.

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