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Consequences of large hydropower dams on erosion budget within hilly agricultural catchments in Northern Vietnam by RUSLE modeling

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Abstract. Our study dealt with the impacts on land-use change of building of 3 major hydropower dams and the consequence on erosion at catchment level. In this mountainous region of Northern Vietnam, the annual crops on sloping lands, mainly maize, represent a significant erosion risk that can exceed 31 t/ha/year. Then the agricultural use of slopes leads to a concern about non-sustainability use of sloping lands and a risk of off-site sedimentation in dam reservoirs. The RUSLE model has been used at regional scale to perform a diachronic analysis from 1973 till nowadays through Landsat remote-sensing images analysis. The specific erosion, i.e. the erosion rate for a comparable rainfall pattern, seemed to be stable from 1973 to 1993 (4.9 t/ha/yr) and increased of 20% for the next 20 years, to reach 5.5 t/ha/yr in 2000 and 5.9 t/ha/yr in 2009. The land-use change has been more important in seven years between 1993 and 2000, than in 10 years between 2000 and 2009. Indeed the land-use change appeared as soon as the early 2000's, before the dam building. The change is entirely due to the extension of cash crops (tea plantation, planted forest) on sloping lands by large companies.

Keywords: Hydropower Dam, Erosion, RUSLE modeling, Land use change, Southeast Asia

1. Introduction

Soil erosion, especially in combination with the agricultural use of sloping lands and population growth, is one of the most severe threats to the both the livelihoods and the life span of hydropower dams in Southeast Asia (McCartney, 2009 ; Nga Dao, 2010). High quality supplies of energy and drinking water are needed to fuel the industrialization and urbanization which is now providing millions with improved livelihood opportunities in the lowlands of South and Southeast Asia. To meet this demand, both the public and, importantly, private sectors are currently making significant investments in large dam construction on many of the regions' suitable rivers (WCD, 2000; WB, 2007). At the same time, poverty reduction strategies naturally call for a focus on upland regions. However, those regions tend to receive little direct benefit from dam construction (Duflo and Pande, 2007). Continued environmental degradation upstream, often poverty driven, is manifested in the form of soil erosion (Lal, 1998; Valentin et al., 2008). This impacts upland farmers in terms of productivity loss but also downstream water users as sediments reduce reservoir life span, power generating potential and flood prevention capacity and increase costs of water treatment (Bossio and Geheb, 2008; McCartney, 2009).

There is an urgent need for reformulating the relationship between hydropower dam management and agricultural upland management within the interests for economics, environment and livelihoods (Mc Cartney, 2009). In Northern Vietnam, three large hydropower dams (215 m tall for Son La and 100 m tall for Ban Chat and Huoi Quang) are built or in building since 2004 inside an area of less than 100 km long. They have already caused the displacement of about one hundred thousand people and flooded around more than 20,000 hectares (it means around 6% of the watershed closed by the Son La dam, cf. Figure 1), of which more than one third hectares was agricultural land including rice paddies, gardens and fishponds. Among the displaced households, more than 85% engaged in farming, depending entirely on arable land (Nguyen Van Thiet et al., 2011). This study is dealing with the impacts of the building of 3 major hydroelectric dams on land use change and the consequence on the erosion. In this region of small mountains, the annual crops, mainly maize, with heavy rains (Bernard-Jannin L. et al., 2011), showed significant erosion risk that can exceed 31 t/ha/year (Valentin et al., 2008), leading to a very large risk of non-sustainability use of sloping lands with moreover a large risk of off-site sedimentation in the dam reservoirs (Dang Thi Ha et al., 2010).

The RUSLE model has been used at regional scale to perform a diachronic analysis from 1973 till nowadays, and to discuss the causes of land-use change.

2. Materials and methods

This study was built on the analysis-diagnostic of remote-sensing images from Landsat satellite on 4 dates over a long-term period of 35 years: 1973, 1993, 2000 and 2009. Seven land-use categories have been defined by comparison of the NDVI analysis mapping with the land-use mapping based on land-use data of the regional districts in 2000 and 2009. Our main objectives have been to: (i) assessing the land-use and land-use change in the whole watershed impacted by three large hydropower dams (Son La, Ban Chat and Huoi Quang dams) (Figure 1); (ii) identifying the main crops leading the erosion output. The studied watershed matched with the addition of Tan Uyen, Than Uyen and Muong La Districts from Lai Chau and Son La Provinces. The total surface of the watershed is about 3,110 km^2. The landscape is characterized by a mountainous relief featuring a steep-sided hydrological network shaped in valleys mainly cropped within paddy fields. The Nam Mu River, running North-Southwards from Tan Uyen City, is under developing from 2008 of two dams (Ban Chat in the North and Huoi Quang 20 km southwards) and feed the Da River, one main tributary of the Red River. The Son La dam is exploited on the Da River from end of 2008, with a construction started in December 2005. The erosion and land-use data have been collected by a two-year study at commune level in 10 communes and from a long-term monitoring of erosion and land-use in Hoa Binh Province through the MSEC network (Valentin et al., 2008; IWMI, 2010).

The RUSLE (Revised Universal Soil Loss Equation) erosion model (Renard et al., 1997) has been used not only to calculate an estimate of soil erosion but also to get an information on the land-use change (Arekhi et al., 2012). The model uses rainfall monthly pattern, land use, soil properties, slope length and slope steepness as parameters. Slope length and slope steepness, SL factor, is directly calculated from the DEM on ArcGIS based on the remote-sensing image analysis. The rainfall-runoff erosivity factor, R, is calculated as the average yearly summation of the erosion index values (EI) for each year studied and based on 11 meteorological stations surrounding the studied watershed (Arekhi et al., 2012). The soil erodibility factor, K, represents both susceptibility of soil to erosion and the rate of runoff, then the K value is basically derived from the soil type. In this study, the K value is based on the tables used in Vietnam for northern mountainous areas (Vu Chi Kim, 2007). The cover-management factor, C, is estimated from the NDVI calculation within the remote-sensing images (Asis and Omasa, 2007). It is used to build land use maps and discriminate land-use categories by comparison with the land-use mapping from the land-use database from the districts. At last, the support practice factor, P, reflects the impact of support practices on annual erosion rate. For this study, the P value is chosen 1 for the erosion calculation.

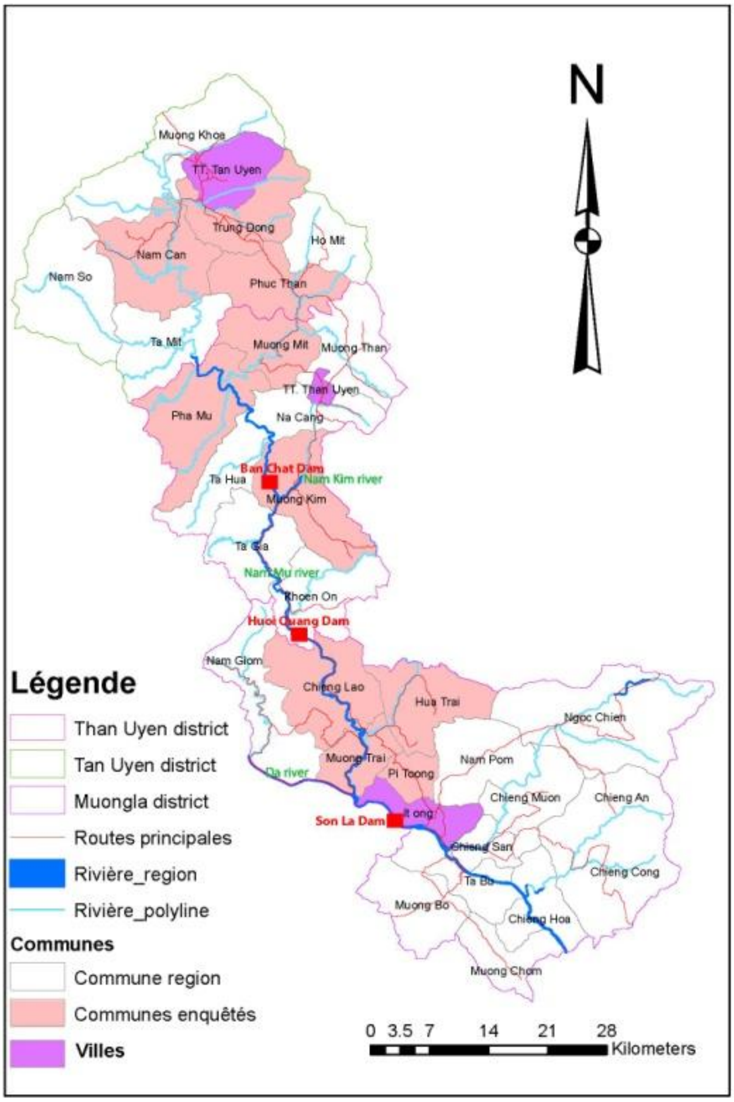


Figure 1 : Administrative map of the study area with localization of the three large hydropower dams and of the communes interviewed in pink color.

3. Results and discussion

3.1. Rainfall pattern

For the four years studied, the yearly rainfall amount averaged on the whole basin has been 1781 mm in 1973, 1802 mm in 1993, 1586 mm in 2000 and 1477 mm in 2009. Then the rain occurring during the two recent years is significantly weaker than the first ones. In term of erosivity, the rainfall-runoff erosivity factor is higher in 1973 and lower in 2009 (respectively 48.9, 47.5, 46.4 and 46.7).

3.2. Land-use evolution and human development

In the studied area, the population has increased from 90,000 inhabitants in 1973 to 130,000 inh. in 1993, 154,500 inh. in 2000 and 194,500 inh. in 2009. Then the population has continuously growth from 1973 to 2009, with a small increase after 1993 and mainly after 2000 (Figure 5).

In 2009, seven main land-use categories can be defined in this area: shrubs, secondary forest, annual crops on sloping lands (crops on slope), flat lands, planted forest, tea plantation and urban areas (urbanization). The shrubs correspond mainly to young fallow from 1 to 5 years. After 6 years, it is already a secondary forest. The land-use database of the districts has been used to discriminate annual crops on slope and tea plantation on the land-use mapping. In 2009, the shrubs cover around 42% of the total surface area, the secondary forest 23%, the flat lands only 9%, the annual crops on slope around 11%, the tea plantation 6% and 2% for the urban areas. The diachronic study over the last 10 years, from 2000 to 2009, underlines the increase of surface of tea plantation, urban areas and mainly planted forest. The other categories (flat lands, crops on slope, secondary forest) are quite similar over the time, and the shrubs area has largely decreased from 170,000 ha in 2000 to 130,000 ha in 2009 (Figure 2). The shrubs represented 54% of the studied watershed in 2000 and reduced to 42% in 2009.

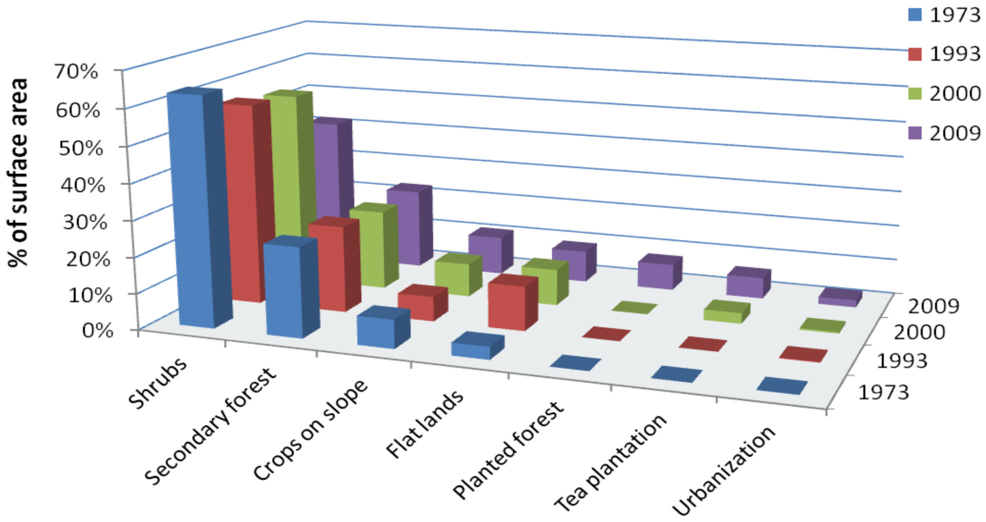
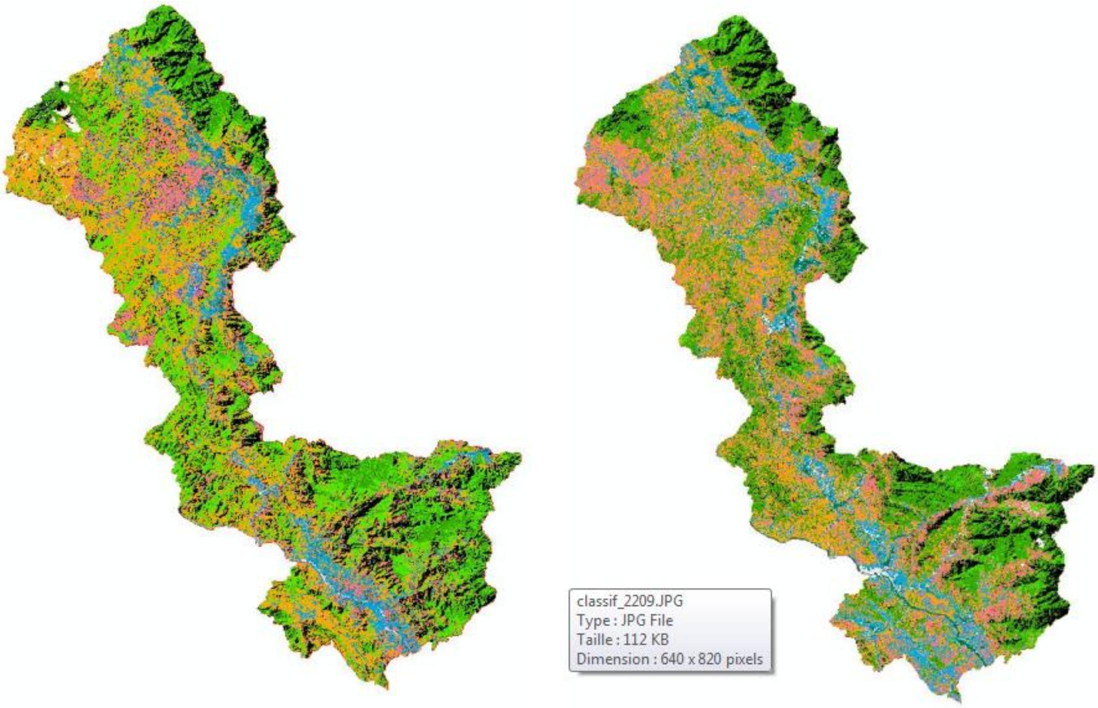


Figure 2: Distribution of land-use categories between 1973, 1993, 2000 and 2009.

The diachronic study between 1973 and 2009 (Figure 3) underlines that the surface of secondary forest did not change around 25% of the whole watershed, always at the top of hills and mountains. One reason is that the natural forest in the watershed belongs to the National Park of Hoang Lien Son, so the forestry policy of the Vietnamese government is strongly forced. The main changes have been provided by the increase of paddy fields on flats lands from 11,000 ha to 28,000 ha respectively in 1973 and 2009, (i.e. from 4% to 9% of the area), due to the population growth. In comparison, the annual crops on slope have not increased a lot (from 25,000 ha to 34,000 ha, i.e. from 8% to 11% of the total area). In fact, this land-use category on slope must be added with two other categories always applied on slope: tea plantation and planted forest. The total area of tea plantation and planted forest moves from zero to 42,000 ha, which has been deducted from the shrubs surface, decreasing from 63% to only 42% of the total area. The analyze of the land-use map from 1993 indicates that the main change from 1973 to 1993 was the increase of paddy fields on flat lands, to reach from 4% to 12% of the total surface area in 1993; and the surface of flat lands did not changed a lot until 2009 with 9% of the surface (figure 2). In 1993, there was no planted forest as in 2000, and the tea plantation is not yet appeared.



A: Land use map in 1973　　　　　　　　　　B: Land use map in 2009

Figure 3: Land-use map of the studied area based on NDVI discrimination in 1973 (A) and 2009 (B).

Finally the fallow areas, marked by shrubs, have decreased, mainly between 2000 and 2009, in favor of cash crops (Figure 4). Indeed the annual crops on slope, mainly Maize culture, are still few spread and their surface areas did not increased. In details, the expansion of the cash crops was mainly between 2000 and 2009 (Figure 4).

3.3. Erosion and Land-use change

The mean erosion (Er-RUSLE) has been calculated on the whole studied area by the RUSLE erosion model. The results at watershed level are ranged from 4.1 t/ha/yr to 5.1 t/ha/yr (Table 1). The years which should provide more erosion, it means more sediment to the river at the outlet of the studied area, are 1973 and 1993. Then the last 10 years seems to be less erosive than before.

Table 1: Average yearly rainfall (in mm) and R-factor, erosion value calculated by RUSLE erosion model (Er-RUSLE, in t/ha/yr) and erosion value for equivalent yearly rainfall (Er-specific, in t/ha/yr) from 1973 to 2009 in the whole studied area.

Year	Rainfall (mm)	R-factor	Population (inhabitants)	Er-RUSLE (t/ha/yr)	Er-specific (t/ha/yr)
1973	1781	48.9	90,000	4.9	4.9
1993	1802	47.5	129,000	5.1	4.9
2000	1586	46.4	154,500	4.4	5.5
2009	1477	46.7	194,500	4.1	5.9

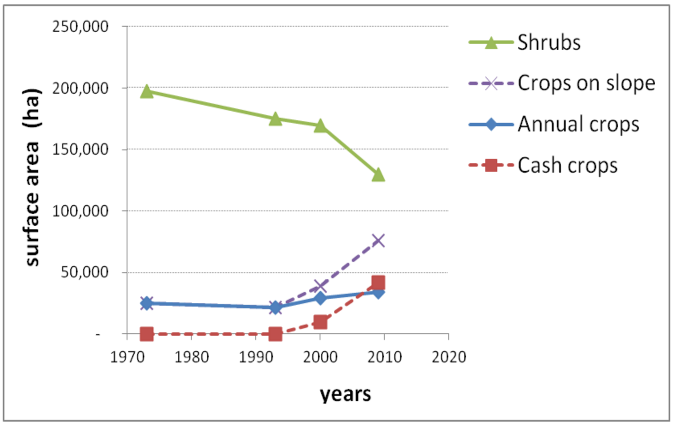


Figure 4: Evolution of surface area (in ha) of land-use categories occurring on slopes from 1973 to 2009 in the studied area.

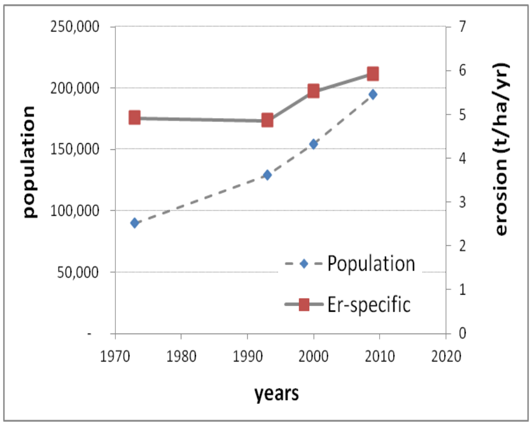


Figure 5: Comparison of erosion risk (in t/ha/yr) and population (in inhabitants) from 1973 to 2009 in the studied area.

However the yearly rainfall amount has significantly changed over the 35 years studied period. Then to be able to measure the impact of the land use change on the erosion process, we calculated specific erosion (Er-specific) such as it would be the erosion amount if the yearly rainfall would have been the same. Based on that, it appears that the erosion amount did not change between 1973 to 1993 with a value of 4.9 t/ha/yr, and then it increased of 14% in 7 years between 1993 and 2000 (to reach 5.5 t/ha/yr) and of 7% during the last 10 years from 2000 to 2009 (to reach 5.9 t/ha/yr). It means that the specific erosion has increased of 21% over the studied period.

In details, the increase of the erosion has been more important between 1993 and 2000, than after (Figure 5), in spite of a biggest increase of the population during this last period. The very significant correlation of the increase of Er-specific with population growth indicates that the increase of erosion after 1993 is directly linked with the increase of cash crop cultivation (Figure 4).

On the other hand, this study underlines that the increase of erosion has started before the beginning of dam construction, occurring from 2005. Indeed our field study at commune level has highlighted that the tea plantation has been doubled between 2000 in 2004, two years before the beginning of the dam building. It was the same trend for the planted forest with the first 12,000 ha by 2004 to reach 23,000 ha in 2009 (Nguyen Van Thiet et al., 2011). This extension of cash crop lands has been done in default of the fallow area (indicated shrubs) and has driven a huge pressure on the land availability for the farmers. As consequence, the economic pressure on people livelihoods occurred before the dams building. This situation is often not taken into account by the authorities in charge of people re-settlements.

Finally, from before 2000 to 2009, there has been a rapid change in land-use as soon as the early 2000's, before the dam buildings.

4. Conclusion

The new wave of dam construction in the region (ADB, 2008) can be seen as an opportunity to meet the regional economic development with a direct impact on the farmers' livelihood. But our study underlined that beside the changes in land-use, another major problem is the on-going erosion process due to the increase of the agricultural surface for large agricultural companies due to the expansion of cash crops, such as tea plantation and planted forest mainly for Acacia mangium. Clearly the risk of erosion is increasing by more than 20% on the last 15 years. And in the same time, the land pressure for the small farmers has increased.

Moreover, a diachronic analysis of remote sensing images from 1973 to 2009 highlighted that the main land-use change started before the beginning of the hydropower dams. We assumed that the land-use change is driven by the indirect impact of the hydropower dam planning. Then it is argued that appropriate approaches are required to reverse this downward trend.

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