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Assessment on Hydrological Ecosystem Services in Da River Basin, Northern Vietnam

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Abstract

Assessment on Hydrological Ecosystem Services in Da River Basin, Northern Vietnam

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Ecosystem services provide various benefits to humans. By assessing and valuing ecosystem services, it is possible to give incentives to ecosystem services suppliers to encourage proper forests management and alleviate the poverty in developing countries. Due to its increasing cognition of the ecosystem services assessment, the Vietnamese government adopted the "Payment for Forest Ecosystem Services" (PFES) policy that provides incentives to upper landowners for protecting their ecosystems. Since Vietnam is suffering from many hydrological problems accompanied with forest loss, such as an insufficient water supply in dry seasons and sediment loss from hilly areas, the current PFES policy is developed well on hydrological ecosystem services. However,

implementing PFES in nationwide requires quantitative and spatially explicit assessments that are thus far lacking in Vietnam.

In this study, to assess two hydrological ecosystem service, water yield and sediment retention, Da River basin was selected as it has the largest discharge to the delta, relatively rich forest, high vulnerability to forest degradation, and sufficient service payers such as water supplying company and hydro-electronic power companies. For a method, since ecosystem services highly depend on land cover, land cover was classified into seven classes, using both the dry and wet seasons' Landsat images. Then, on the basis of previous ecosystem assessment methods, water balance theory and the Universal Soil Loss Equation (USLE) were adopted as the water yield and sediment retention analysis respectively, and MODIS Enhanced Vegetation Index (EVI) in 2012 was adopted to assess forest quality to support K-coefficient included in PFES policy in Vietnam.

The land cover classification result for forest cover was 52%, which is lower than other referenced maps such as the MODIS land cover and FROM-GLC-agg map. This result might have been derived due to the site-specific land cover definition, higher resolution as compared to MODIS land cover and the consideration of both the dry and wet seasons in contrast to the one-scene classification of the FROM-GLC-agg map.

Annual precipitation was 1,301 to 2,384 mm and actual evapotranspiration MODIS ET was 5-1,671 mm, resulting in a water yield of 2.5-1,472 mm per year. Spatially, Yen Bai province and southern Dien Bien province were high in water yield. Potential soil loss was up to 8,874 tons/cell and sediment retention per cell was up to

25.323 tons per cell per year. Fansipan Mountain, Phu Tra Mountain, Dien Bien province, and Yen Bai province were high in sediment retention. The average EVI in 2012 ranged from 0.0308 to 0.5786, and Dien Bien province, the middle of Da River basin, and Hoa Binh province were high in EVI.

Finally, forest cover was extracted from the land cover classification results and clipped above the data to set prior forest region considering K coefficients that include both hydrological ecosystem services (K2 coefficient) and forest quality (K1 coefficient). After overlaying the data, in Dien Bien province, there was high forest quality with mid-high hydrological ecosystem services, showing the highest probability of achieving much incentives, according to the application of the K-coefficient described on PFES policy and acts.

This study was intended to give current information of forests existence and suggest valid grounds for assessing ecosystem services and supporting K coefficients to set priority forests region in implementing PFES policy in a more accurate and systematic way.

Keywords : payment for ecosystem service, Landsat, Land cover classification, water yield, sediment retention, northwest Vietnam
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I. Introduction

Ecosystem services provide various benefits to humans. Given the increasing awareness of the multitude of ecosystem services and their actual benefits, many recent studies have discussed the existence of ecosystem services and tried to demonstrate their values in monetary way. Thus far, deriving benefits from the ecosystem, such as supplying water and regulating sediment erosion, has occurred free of charge to the public due to the lack of the awareness and the market.

Recently, however, several developing countries have adopted a "Payment for Ecosystem Services" (PES) policy, implementing the ecosystem services concept to efficiently manage and conserve their national resources. The aim of the PES policy is to give incentives to landowners for conserving their ecosystems and to collect a certain fee from the service users. In Southeast Asia, Vietnam is the only country to enact PES policy, named as Payment for Forest Ecosystem Services (PFES) and it intends to expand the policy nationwide. To prepare to expand nationally, the Vietnamese government tested the policy's feasibility through pilot projects in two provinces. However, the scientific basis for designating the PFES site is insufficient, as a recent forest cover map and spatially explicit ecosystem service provision region are lacking. Also the lack of logical and systematic grounds for assessing and valuing ecosystem services makes it hard to persuade ecosystem service payers. Therefore, local governors suffer from various barriers such as (1) figuring out current forest region, (2) setting systematic, logical grounds for assessing details described on PFES policy and (3) setting PFES sites and payees to implement the policy based on actual ecosystem services in a spatially explicit way.

Northern Vietnam is the poorest region of the country, with many ethnic minorities continuing the slash-and-burn cultivation of hilly areas, which has been degrading the vegetation, soil, and nutrients. The degradation of the ecosystems in the north will affect not only the residents living near the Da River basin but the four million people living in lower lands, including the capital, Hanoi. Therefore, implementing PFES in northern Vietnam will effectively enhance the environmental condition of the region and contribute on alleviating poverty as well.

The Vietnamese government categorizes forests according to their usage, and one of these categories is "protection forest," which is intended to protect headwater and the water supply, and regulate soil erosion. However, the designation is very weak, meaning that it would be easy to convert it into a "production forest," where logging and exploitation activities are allowed. In addition, the Vietnamese government has devised a plan for increasing production forest and decreasing protection forest until 2020, according to Vietnam Forestry Development Strategy 2006-2020. Therefore, linking PFES law specifying water provision and soil erosion protection services with protection forests would be a win-win strategy for conserving forest with hydrological ecosystems.

To manage forests and their services more precisely, the Vietnamese government specified the use of the K-coefficient to classify more forests according to their quality (K1), function (K2), origin (K3), and remoteness from accessible roads (K4). Overall ecosystem services incentive is calculated by multiplying four of sub K-coefficients and ecosystem service's price per unit. However, the K-coefficient has yet to be implemented due to the lack of data to support the classifications of the forests, leading to the application of 1.0 equally to every region. However, to fulfill the primary goal of "further protecting and conserving the forest ecosystem through PFES implementation," classifying good quality forest and protection forest should be done with the provision of hydrological ecosystem services.

Despite all the matter of assessing methods, collected fees are not distributed well because of lacking data of where to be compensated. According to previous study, only 10 % of fees are spent and 10 % is supposed to be a commission for supporting the forest conservation funds in each committee. Therefore, still, the fee is not working for alleviating poverty to landowners in upper lands.

The study proceeded with the following three main objectives: (1) Make an updated land cover map to detect the actual forest using multi-temporal, relatively high resolution Landsat satellite images and (2) suggest systematic grounds to assess ecosystem services and forest quality on the basis of K-coefficients in PFES policy and (3) figure out the prior regions in spatially explicit way.

II. Literature Review

1. Payment for Ecosystem Services in Vietnam

1) Ecosystem services

Natural ecosystems provide a range of services, such as clean water, clean air, habitats for biodiversity, carbon sequestration, and recreational opportunities. Daily (1997) defined ecosystem services as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life." Further, Costanza et al. (1997) stated that ecological services, as natural capital stocks, produce critical functions of Earth's life-supporting systems and their contribution to human welfare both directly and indirectly.

Combining previous works on ecosystem services, the Millennium Ecosystem Assessment (MA 2005) defines ecosystem services as "the benefits people obtain from ecosystems" and categorizes four ecosystem services: providing service, regulating service, supporting service, and culture service (MA, 2005; de Groot et al., 2006). These services also contribute to natural systems and the well-being of humans. Furthermore, the Economics of Ecosystems and Biodiversity (TEEB) has published several reports to evaluate ecosystems and support policy makers (TEEB, 2010).

Table 1 Various ecosystem services (MA 2005; TEEB 2010)

MA 2005	TEEB 2010
Provisioning Services	**Provisioning Services**
food	food
fresh water	water
fiber	raw materials
genetic resources	genetic resources
biochemical, natural medicines and pharmaceuticals	medicinal resources
ornamental resources	ornamental resources
Regulating Services	**Regulating Services**
air condition regulation	air quality regulation
climate regulation	climate regulation
natural hazard regulation	moderation of extreme events
water regulation	regulation of water flows
water purification and waste treatment	waste treatment
erosion regulation	erosion prevention
soil formation	maintenance of soil fertility
pollination	pollination
disease regulation	biological control
supporting services	**habitat services**
nutrient cycling, primary production, photosynthesis, water cycling	lifecycle maintenance
	maintenance of genetic diversity
cultural services	**cultural, amenity services**
aesthetic values	aesthetic information
recreation and ecotourism	recreation and tourism
cultural diversity, inspiration, social relations, sense of place, cultural heritage value	inspiration for culture, art and design
spiritual and religious values	spiritual experience
knowledge systems educational values	information for cognitive development

However, the monetary costs of the various ecosystem services have not been directly borne by the public, even though they are distinct services to humans. Due to the increasing need to build a framework for converting ecosystem services into financial values, there has been an increase in the research on PES schemes by World Bank (WB), Asian Development Bank(ADB), World Wildlife Fund(WWF), International Union for Conservation of Nature and Natural Resources (IUCN), and non-government organizations (NGOs). A concept of the PES scheme is to compensate the current ecosystem services as incentives to landowners living in conservative lands. To implement the payment scheme, it is essential to quantify and determine the ecosystem services. Several studies have been carried out to suggest the quantitative amount of the ecosystem services in West Africa (Leh et al., 2013), Minnesota in the United States (Polasky et al., 2010), and a watershed in China (Bai et al., 2012). In addition, commissions and programs have been developed to deal with more comprehensive schemes, such as TEEB hosted by UNEP and the Wealth Accounting and Valuing Ecosystem Services (WAVES) program supported by the World Bank.

2) PFES Policy in Vietnam

(1) Forest Change of Vietnam

Until 1990, Vietnam had experienced large deforestation, dropping to 24.7% from about 40% of usual state of the whole country (Meifroidt and Lambin, 2008). The ecosystem degradation was credited for much of the increase in the number of natural disasters, such as floods and droughts, in both the upper lands and lowlands. In Vietnam, the reasons for the forest degradation varied, but the most significant reasons were the demand for high quality timber, particularly for furniture production for export, and forest clearance by 25 million people living in mountainous areas, especially the ethnic minorities sustaining themselves with slash-and-burn cultivation. In addition, the corruption of the remaining state-owned forest enterprises (SFEs) was highlighted as a cause of the forest degradation. SFEs had managed the forests throughout Vietnam for a long time, but they had more land than they could handle (McElwee, 2009).

Owing to the radical deforestation, in 1990, the Vietnamese government initiated large national afforestation/reforestation programs, including the most wide-spread and well-known “Greening the Barren Hills Program” (also known as Program 327) and “Five Million Hectare Reforestation Program” (also known as 5MHRP, Program 661) (Clement and Amezaga, 2009). Moreover, the devolution of SFEs contributed to the amendment of the Land Law requiring land to be distributed to small landowners and individuals as a long-term rent contract. This law was intended to give all land owners the responsibility of keeping their land in good condition. Especially in the northwest mountains, almost half of the land owned by SFEs was distributed to individuals (McElwee, 2009)

As a result, Vietnam’s forests have expanded since 1990, and Vietnam is considered to be the only country showing positive forest change in Southeast Asia between 1990 and 2005 (UNEP, 2009, p.12). However, the best remaining natural forests are under constant threat (McElwee, 2009).

(2) Payment for Forest Ecosystem Services

① Introduction of PFES Policy

To sustain and manage its forest resources more efficiently, the Vietnamese government required a new policy as a source of forest conservation funds. As a result, the PES concept was introduced in

2006 with the help of U.S. Agency for International Development (USAID) and Asia Regional Biodiversity Conservation Programme (ARBCP). The PES concept has been adopted in developing countries such as Mexico, Costa Rica, Ecuador, and Kenya to conserve their primary forests, biodiversity and natural resources. Further, Indonesia and China tried to implement policies similar to PES. In Vietnam, the government proposed a new policy, Payment for Forest Ecosystem Services (PFES), which is similar to PES, but its application is only related to forests. PFES is similar to Reducing Emissions from Deforestation and Degradation (REDD) programs in paying benefits to forest land owners. REDD focuses on estimating carbon sequestration, and PFES considers more comprehensive ecosystem services including carbon sequestration, water supply, sediment regulation, and recreation activities. However, compared to REDD programs, PFES programs are still in progress.

The PES scheme is known for being a win–win policy contributing to both conservation and poverty alleviation objectives (McElwee, 2009). In other words, PES is expected to help each landowner conserve important ecosystems, and they are to be compensated by incentives collected from the services users. The compensation can alleviate rural poverty, help communities to develop further, and provide funds to municipal officers lacking the state budget to manage forests. Moreover, PES projects are expected to support forest protection efforts and enhance associated ecological functions (To et al., 2012).

USAID described a PES project in Vietnam as helping to stimulate "local economic growth, public–private partnerships for biodiversity friendly economic activities, and increasing financial support for environmental protection [...] PES policy could provide additional income for thousands of poor families living in forest areas, and provide funds for meeting Vietnam's National Forest Management and

Biodiversity Conservation Action policies" (USAID, 2009, as cited in McElwee, 2009).

One condition for implementing PES is translating external, non-market values of the environment into real financial incentives for local actors to provide such services (McElwee, 2009). Therefore, the transaction between a buyer and a seller of a well-defined environmental service should be voluntary, whereby the sellers promise service provision in exchange for some type of conditional payment (McElwee, 2009). However, in the case of Vietnam, the payment is enacted by law and policy, which is different from voluntary transactions in other countries.

② Legal Framework of PFES

Before enacting the PES scheme, the Vietnamese government and USAID had tested the policy in Lam Dong and Son La provinces between 2008 and 2010. They estimated the carbon storage, water yield, hydroelectric power generation and eco-tourism values in the two regions. After a two-year pilot, the national decree on PES (Decree 99/2010)[1]) was approved by Prime Minister Nguyen Tan Dung on September 24, 2010, becoming the first PES policy in Asia. Hence, Vietnam became the first country in Southeast Asia with a national law on PES (McElwee, 2009). According to the Ministry of Agriculture and Rural Development (MARD), which takes charge of conducting the PFES scheme, there are five ecosystem services that can be financiallycompensated : (1) soil protection, reduction of erosion, and sedimentation of reservoirs, rivers, and streams; (2) regulation and maintenance of water sources for the production and living activities of the society; (3) forest carbon sequestration and retention, reduction of

1) On the Policy for Payment for Forest Environmental Services

emissions of greenhouse gases through measures for preventing forest degradation and loss of forest area, and for sustainable forest development; (4) protection of the natural landscape and conservation of the biodiversity of forest ecosystems for tourism services; and (5) provision of spawning grounds, sources of feeds, and natural seeds, use of water from forest for aquaculture (Article 4 clause 2 in Decree 99/2010). In addition, MARD and USAID set a monetary value for each unit of ecosystem services; hydropower companies are required to pay 20 VND/kWh (US$0.0013/kWh) of electricity, while water users must pay 40 VND/m3(US$0.0025/m3),andtourismcompaniesmustpay 1 −2% of their total revenue (Decision 380 in Vietnam, 2008).

③ K-coefficient

One of the key concepts of PFES is setting the K-coefficient that differentiates the payments to forest owners according to (1) forest quality, (2) type of forest, (3) origin of the forest, and (4) level of difficulty of forest management (MARD, 2011). These four coefficients are multiplied to calculate the total amount of the payment.

Table 2 PFES Policy and K-coefficients (MARD, 2011)

K-coefficient		status		
		high		low
K1	forest status and stock	rich (1.0)	medium (0.95)	poor, rehabilitated forest (0.9)
K2	types of forests	protection (1.0)	special-use (0.9)	production (0.75)
K3	origins of the forests	natural (1.0)		planted (0.8)
K4	level of difficulty in forest management	extremely remote (1.0)	difficult to manage (0.95)	less difficult (0.9)

In addition, with the Law on Forest Protection and Development enacted in 1991, the Vietnamese government classified forests into three categories on the basis of their intended use : (1) special-use forest with intended use for nature conservation (biodiversity preservation) and landscape protection (including historical and cultural heritage); (2) protection forest with intended use for water resources and soil protection; and (3) production forest with intended use for commercial activities: exploitation of timber or non-timber forest products (NTFPs) (Clement and Amezaga, 2009). According to the forest categories, the protection forests are intended to achieve two PFES objectives, namely, (1) protecting headwater, yieldwater, and preventing sediment loss, and (2) protecting soil erosion. Apparently, many afforestation/reforestation programs have focused on rehabilitating the forests in the protection forests category, accounting for 61% (185 sites) of the total projects (de Jong et al., 2006). Actually, among the five services enacted into the law, the hydrological ecosystem services are well developed. With both pilot projects in Lam Dong and Son La provinces, most of the payers are water supply companies and hydroelectric power plant companies.

Table 3 Forest Environment of Vietnam (Phuong, 2007)

Types	Definition
Production Forest	supplying timber, pulp, chipping and mining poles
Protection Forest	headwater protection, wind- and sand- shielding protection, tide-shieding protection and sea encroachment prevention
Special-use Forest	protecting and conserving biodiversity including national parks, protected areas(defined by IUCN), natural reserves

Forests protect watershed areas by retaining soil, controlling erosion, preventing sedimentation, regulating water flow, and improving water quality. Forest degradation, exploitation, and land cover/use change have caused serious consequences for watershed protection. Previous studies on Vietnam have shown that dense forest with 70–80 % canopy cover can reduce the probability of soil erosion and regulate water flow by delaying the immediate runoff. Recent floods and severe landslides in the central and northern regions are suspected to have been the result of deforestation in the steep mountainous areas.

The important roles of protection forests have been emphasized through several regulations and acts in Vietnam (Land Law, 1993, 2003; Forest Protection and Development Law, 1991, 2004; Environmental Protection Law, 2004; and Vietnam's Forestry Development Strategy, 2006–2020 [2007]). Among them, the Law on the Protection and Development of Forest (Decision 186/2006/QD-TTg) in 2004 developed strategies for forest management.

④ Current Limitation of PFES in Vietnam

The K-coefficient is determined by provincial people's committees according to the local conditions. However, incomplete recent forest data and a lack of researching manpower in each committee of province has disabled the reliable designation of the K-coefficient, and it was omitted and adjusted to be 1.0 in the two pilot provinces of Lam Dong and Son La (Hoang et al., 2013). To manage forests more effectively, assessment on forests regarding K-coefficients should be done.

In addition, the cost of monitoring the forests' status and checking the exact landowners' boundaries, which are the basis for setting the K-coefficient and payees for their compensation, was higher than that of implementing the policy (Hoang et al., 2013). Eventually, Son La province received about USD 3.5 million from contracted payers (water supply companies, hydropower plant companies), but only 10% has been distributed to the forest land owners (Hoang et al., 2013).

Furthermore, designating the spatial location of PES is not systematic; its category modification is quite flexible according to the intentions of the local governors. In fact, a MARD officer admitted that there is a lack of evidence to designate production versus protection forests (Clement and Amezaga, 2009). Consequently, the Vietnamese government asked the provinces to convert protection forest back to production forest to increase revenue (Clement and Amezaga, 2009). Therefore, more quantitative and structural bases should be set to designate protection forest and its ecosystem services.

Overall, the government is unavailable to get access to current forest cover map that covers real state of forests due to the lack of manpower and data to build the data. Also it is hard to figure out where forests in high ecosystem services and quality exist because of insufficient systematic basis. In the end, collected incentives couldn't be distributed well due to the lack of properties boundaries of each landowners. To achieve original goals in PES policy, it is highly recommended to present these informations in spatially explicit way.

2. Land cover classification

1) Landsat images

Due to its distinct characteristic 'noncontact', remote sensing is used extensively to get a data at inaccessible area or very large region. Nowadays there are several satellites embarked with sensors that are available to achieve data in varied resolutions and revisiting periods such as AVHRR, MODIS, SPOT and Landsat. Also there are private satellites obtaining very fine resolution data as well.

Above all, Landsat satellite is very useful one as being one of the oldest satellite and having quite high resolution. On July 23 1972, the Earth Resources Technology Satellite(Landsat 1) was launched. Continually, Landsat 2(January 22, 1975-January 22, 1981)), Landsat 3(March 5, 1978-March 31, 1983), Landsat 4(July 16, 1982-1993), Landsat 5(March 1, 1984~present), Landsat 6(fail) and Landsat 7(April 15, 1999-present). It have been acquired huge amount of images until now. In February 11, 2013, new Landsat satellite 'Landsat 8' was launched and it has been sending data from May 30, 2013. From Landsat 5, it acquires images in 170 kilometers by 183 kilometers in every 16~18 days.

Table 4 Landsat satellite specification

Satellite	Sensor	Swath(km)	Scene Size(km)	Altitude	Revisit days
L 1 - 5	MSS	180	170x180	917	18
L 4 - 5	TM	185	170x183	705	18
L 7	ETM+	185	170x183	705	16
L 8	OLI, TIRS	185	170x185	705	16

(http://landsat.usgs.gov/)

MSS sensor is the original one in Landsat 1~3. And Landsat 4,5 used both MSS and TM(Thematic Mapper) sensor. Landsat 7 was embarked improved ETM+(Enhanced Thematic Mapper Plus) sensor. On Landsat 8, new free-flyer spacecraft carrying an instrument referred to as the Operational Land Imager (OLI), and Thermal InfraRed Sensor (TIRS) were embarked with more specific band compositions.

Dataset images are comprised of several bands and each band represents a scope of wavelength. Band numbers in satellites are usually the same but there have been a little change with Landsat 8 with specified bands and Quality Assessment Band that sensoring clouds and ice.

Table 5 Wavelength of each band in Landsat series (http://landsat.usgs.gov/)

		Landsat 5 (TM sensor)		Landsat 7 (ETM+ sensor)		Landsat 8 (OLI sensor)		
	B	W	R	W	R	B	W	R
Coastal / Aerosol	–	–	–	–	–	1	0.433 – 0.453	30
Blue	1	0.45 – 0.52	30	0.45 – 0.515	30	2	0.450 – 0.515	30
Green	2	0.52 – 0.60	30	0.525 – 0.605	30	3	0.525 – 0.600	30
Red	3	0.63 – 0.69	30	0.63 – 0.69	30	4	0.630 – 0.680	30
Near Infrared	4	0.76 – 0.90	30	0.75 – 0.90	30	5	0.845 – 0.885	30
Short Wavelength Infrared	5	1.55 – 1.75	30	1.55 – 1.75	30	6	1.560 – 1.660	30
Short Wavelength Infrared	7	2.08 – 2.35	30	2.09 – 2.35	30	7	2.100 – 2.300	30
Panchromatic	8	–	–	.52 – .90	15	8	0.500 – 0.680	15
Long Wavelength Infrared	6	10.40 –12.50	120	10.40 – 12.5	60	10	10.30 – 11.30	100
						11	11.50 – 12.50	100
						9 –Cirrus	1.360 – 1.390	30

B: Band name; W: Wavelength(μm); R: Resolution (meters)

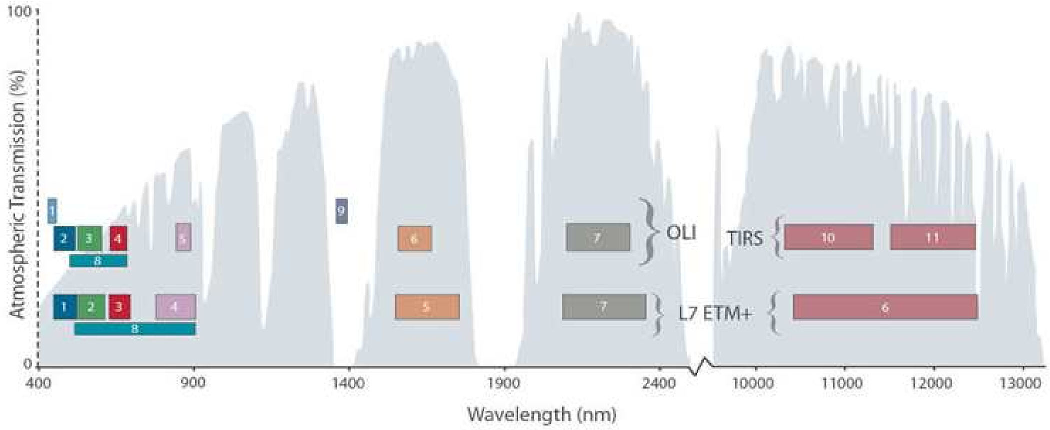

Figure 1 Comparison Landsat 8 Multispectral Bands to Landsat 7 (U.S. Geological Survey Department of the Interior/USGS website).

Landsat satellites have its own geographic system standing for the location on earth. It is called Standard Worldwide Reference Systems(WRS) indexes orbits. Landsat 8 and Landsat 7 follow the WRS2, like Landsat 5 and Landsat 4. Landsat 1, Landsat 2, and Landsat 3 followed WRS1. WRS index presents the location by combining 'path' and 'row'. Path and row respectively represent orbits (paths) and scene centers (rows) and overall they make a global grid system comprising 233 paths by 248 rows. The path/row notation was originally employed to provide a standard designator for every nominal scene center and allow straightforward referencing without using longitude and latitude coordinates (Landsat Handbook).

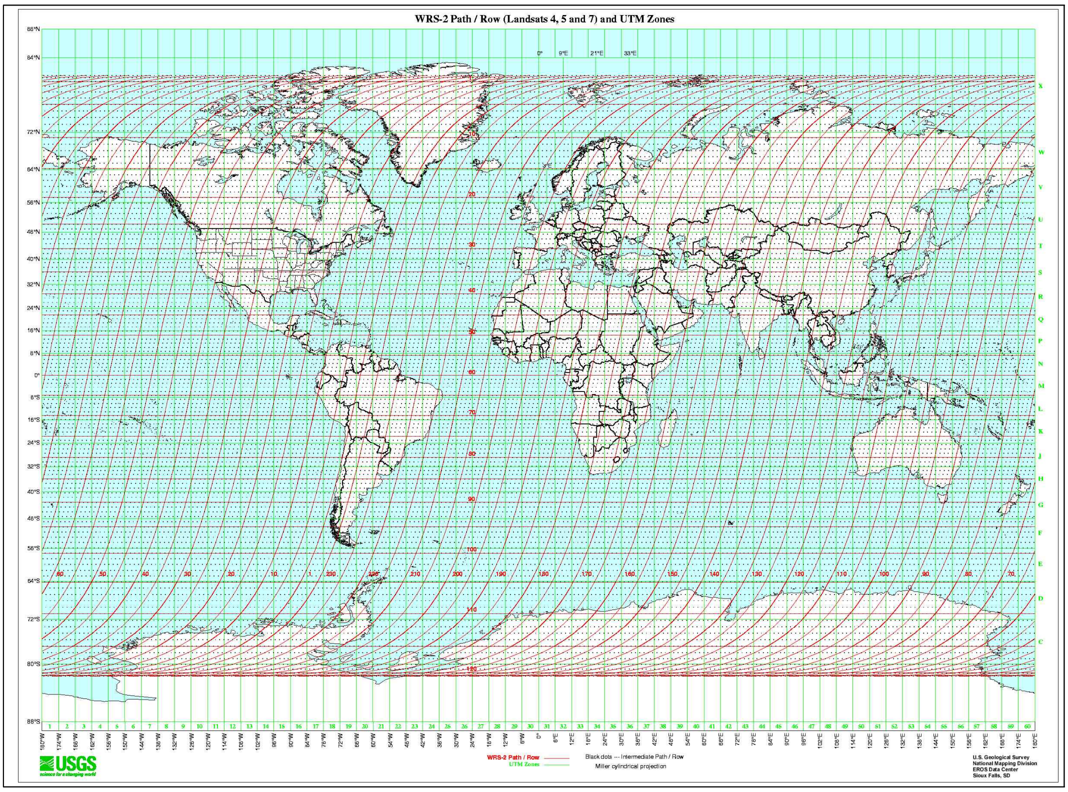

Figure 2 Worldwide Reference Systems 2 (http://landsat.gsfc.nasa.gov/)

2) Preprocessing

To work with multi-spectral images like Landsat images, several pre-processing should be checked; (1)Geometric Correction, (2)Ortho-rectification (3)Radiometric Correction and (4)Atmospheric Correction.

Natural characteristics of satellites make geometric errors. they are caused by some harsh environmental changes of Satellite during its launching and also occurred from change of height, curvature and rotation of earch. So Geometric correction should be done to manipulate image data such that the image's projection precisely matches a specific projection surface(Wikipedia). Without geometric correction, it is hard to overlay the image to current maps such as GIS spatial informations.

Satellite images take spectral pictures revolving the earth with pushbroom or whiskbroom type sensors. So the images are slightly tilted. So ortho-rectification, which is the process of correcting the geometry of an image to make it looked as each pixel were acquired from directly overhead. Ortho-rectification usually uses elevation data to correct terrain distortion in satellite imagery.

As images are acquired from satellites, radiometric consistency among ground targets in multi-temporal imagery is difficult to be maintained due to changes in sensor characteristics, atmospheric condition, solar angle, and sensor view angle. Therefore, radiometric corrections are often performed to reduce any or all of the above influences and increase sensitivity (Chen et al 2005).

Solar radiation reflected by the Earth's surface to satellite sensors is modified by its interaction with 1) the atmosphere in terms of absorption and scattering and 2) the diminution from topography. This problem is especially significant when using multi-spectral satellite data for monitoring purposes (Hadjimitsis et al 2010). But not every scene need to correct the effect of atmosphere because the necessity of atmospheric correction depends on the information of user's interest. When user want to expand the training sets obtained from one scene to other ones, atmospheric correction is necessary. it means, when user classifies a image one by one, the need to conduct atmospheric correction decreases (Jensen 2005). Contrary, when user wants to calculate biophysical value like NDVI from image values, atmospheric effects should be removed (Jensen 2005).

In addition to four preprocessing in multi-spectral images, Landsat 7 images acquired after 2003 need an additional process. Landsat 7 ETM+ sensor have a image scratch(gap) though image edges by the sensor defection on SLC since May 31st, 2003. Therefore, to use a

Landsat 7 ETM+ image after 2003, image correction filling scratch (gap) should be done to correct the default value on scratched image.

3) Classification

In image classification method, there are many classification approaches using mathematical dispersions and clusters with spectral characteristics. Most popular classification with multi-spectral image is supervised classification and unsupervised classification. If the study region is topographically complicated or hard to extract its characteristics, unsupervised classification could be used. It is commonly called clustering, because it is based on the natural groupings of pixels in image data which means its basic theory is splitting and merging clusters. Representative unsupervised classifications are ISODATA (Iterative self-organizing data analysis technique) and K-means algorithm. However it has probability of misclassification resulting in high uncertainty compared to other classification methods.

On the other hand, supervised classification uses spectral representative regions (Region of Interest (ROI)) selected by supervisor who is aware of the region. According to statistical classification approaches applying ROIs, there are minimum distance classification, parallelepiped classification, maximum likelihood classification and mahalanobis classification. Most frequently used method is maximum likelihood classification, calculating the probability that a given pixel belongs to specific class and distributing to the highest probability (Richards, 1999).

3. Quantifying hydrological ecosystem services

According to increasing conscious to enormous ecosystem services, many researches have quantified ecosystem services in various way. However the lack of standardized assessment method, it is often difficult to measure the output of ecosystem services, so some researchers calls for standardized method to assess ecosystem services (Fisher et al., 2009; Crossman et al., 2013).

1) Water yield

The movement of water through terrestrial, atmospheric and oceanic systems is an important process, supplying water to ecosystems for their living, regulating energy budget. Assume that there is a catchment system with circulating water; then a water movements can be summarized with water input as rainfall, evaporation from system surface, transpiration of vegetation, runoff on system surface, recharge in soil as infiltration and percolation and remaining water. To present a total water budget in a spatial region, water balance theory is generally adopted:

$$P = ET + Q + D + \Delta S$$

where precipitation(P), evapotranspiration(ET), runoff(Q), groundwater recharge(D) and changes of stored water in the region(ΔS). In long-term and large-scale catchment, soil water storage(ΔS) is negligible (Donohue et al., 2007).

For an available water in terrestrial space to human, runoff, groundwater recharge and stored water is considered, which is equal to ‘precipitation minus evapotranspiration’. Accordingly, changes in precipitation and evapotranspiration control water availability to human (Tallis et al., 2013).

Many researchers adopted a 'precipitation minus evapotranspiration' concept to estimate available water to human (water yield), within a viewpoint of ecosystem service which limits ecosystem functions to human availability.

To estimate water yield of ecosystem through subtracting evapotranspiration from precipitation, these two values should be calculated. Compared to other hydrological cycles, measuring precipitation is relatively easy, collecting rainfall in meteorological stations. In case of evapotranspiration, it is invisible and varied with heterogeneous land surface conditions, radiative environments etc. There are direct and indirect ways of estimating evapotranspiration. For a direct ways, there are sap-flow measurement, pan-evaporation. However, direct measurement requires much efforts and it is only available at very limited region, so measurement on evapotranspiration usually adopts indirect method such as empirical equation or remote sensing approaches. Estimation of remote sensing adopts indirect approach using radiation, which is able to be calculated with infrared waves.

Among various satellites, MODIS16 is specialized in supplying evapotranspiration data without recalculation of users. To estimate evapotranspiration, MODIS16 adopts latent heat estimation with revised RS-PM algorithm. When water is vaporized, water absorb latent heat to change its status. Based on energy budget, latent heat (λE) is described as followed when energy storage by the canopy is negligible;

$$\lambda E = Rn - H - G$$

where Rn is surface net radiation, H is sensible heat flux and G is ground heat flux (Wang and Dickenson 2012). At early 2000s, estimating ET was based on estimating latent heat through subtracting sensible heat calculated from surface temperature to net radiation. After launched MODIS satellite, it is possible to calculate ET from its own sensors covering various factors that affect estimating ET as werll as radiation. Cleugh et al (2007) developed Resistance-Surface Energy Balance & Penman-Monteith algorithm utilizing MODIS images and ground-based meteorological observation data.

$$\lambda E = (sA + \rho^* C_p(e_{(sat)} - e)/r_a)/(s + \gamma(1 + \frac{r_s}{r_a}))$$

$$s = d(e_{sat})/dT$$

where is the slope of the curve relating saturated water vapor pressure (unit : :Pa) to temperature; e (Pa) is the actual water vapor pressure; A (W/㎡) is available energy partitioned between sensible heat, latent heat and soil heat fluxes on a land surface; ρ (kg/㎥) is air density; Cp (J/kg/K) is the specific heat capacity of air and r_a (s/m) is the aerodynamic resistance. The psychrometric constant γ (Pa/K) is given by

$$\gamma = C_p{}^* P^* M_a/(\lambda^* M_w)$$

where Ma (kg/mol) and Mw (kg/mol) are the molecular masses of dry air and wet air, respectively, and P (Pa) is atmospheric pressure (Mu et al., 2007). Surface resistance r_s(s/m) is effective resistance to evaporation from the land surface and transpiration from the plant canopy. Cleugh et al (2007) verified the algorithm at two flux towers in Australia showing result good agreement (R^2=0.74). Surface conductance is estimated by using NDVI and LAI.

However two assumptions in Cleugh et al (2007) became problems;

they assumed (1) surface resistance is equal to canopy resistance, so calculate surface resistance with NDVI and LAI, and (2) soil evaporation is negligible compared to plant transpiration. Contrast to an assumption, soil transpiration was high when canopy cover is low and soil surface is wet at most of time. To fix them, Mu et al (2007) modified previous algorithm supplementing soil evaporation, substituting previous vegetation index NDVI (Normalized Difference Vegetation Index) to EVI (Enhanced Vegetation Index), constrain stomata conductance using the vapor pressure and minimum air temperature, use LAI (Leaf Area Index) as a scalar to estimate canopy conductance, and named it as Revised RS-PM (MODIS16 algorithm).

Mu et al (2011) improved previous algorithm including 1) simplifying the calculation of vegetation cover fraction; 2) calculating ET as the sum of daytime and nighttime components; 3) adding soil heat flux calculation; 4) improving estimates of stomata conductance, aerodynamic resistance and boundary layer resistance; 5) separating dry canopy surface from the wet; and 6) dividing soil surface into saturated wet surface and moist surface.

Many previous researches estimating water yielding ecosystem services calculate water yield through Budyko's equation (Zhang et al 2001) which deducts actual evapotranspiration through potential evapotranspiration and environmental informations such as crop coefficient, soil depth and root depth (Tallis et al., 2013). However, before calculation, it requires Budyko curve of the region in advance, which is very empirical and data-demanding information. So globally available MODIS is a better option, but currently few researches adopts MODIS evapotranspiration data to estimate regional water yield service of ecosystem in spite of its reliability and accessability of data.

2) Sediment retention

Soil erosion and sedimentation are natural processes but some anthropogenic activities trigger excessive soil loss. Excessive soil export and sedimentation can reduce agricultural productivity through reducing sediment and nutrient and shorten longevity of reservoir, dams and hydropower plants (Tallis et al., 2013). So it is important to figure out where source of soil loss and manage sediment retention spots. Vegetation cover is known as filtering sediment flows and its efficiency was reported up to 75% in Vietnam. Therefore sediment retaining function of vegetation is considered as one of regulating ecosystem services.

First, to estimate potential soil loss, many previous researches have adopted Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978; Renard et al., 1997) to estimate potential soil loss from rill and gully erosion. USLE equation is expressed as below (Wischmeier and Smith, 1978);

$$Potential\,soil\,loss = R \times K \times LS \times C \times P$$

where

- R is the rainfall erosivity that erosion potential of rainfall ((MJ/ha)*(mm/h)). If rainfall intensity is high, soil is prone to be detached;
- K is the soil erodibility factor showing more vulnerable soil properties to erosion ((ton/MJ)*(h/m)). Generally, sandy texture and soil containing less organic matter are prone to soil erosion;

LS is the slope length-gradient factor; it is another critical factor for dissipating energy from rain and sediment. LS is calculated under given conditions compared to a reference site with the “standard” slope of 9% and slope length of 72.6 feet (22.12m) (Wischmeier and Smith, 1978).

C is the crop management factor and P is the support practice factor; C and P are reflecting land use condition that might reduce or cause additional soil loss under anthropogenic activities.

Due to steep topography and hilly cultivation in northern Vietnam, many researches have studied sediment loss in the region. Above all, Da river basin has much more steeper topography (37%) than Thao river basin (33%) and Lo rover basin (20%) (Le et al., 2007). However, several studies on Da river are limited on small scale, focusing on site measurements. There is a research on estimating potential sediment loss in Lo river basin using RUSLE equation (Ranzi et al., 2012).

Sediment loss at upper basin could lead to reduce longevity of dam, reservoir and hydropower plants and devastate the soil and nutrient condition (Nguyen et al., 2013).

Based on potential soil loss, retained sediment could be derived through vegetation's function. Vegetation on soil surface keep sediment from eroding and also traps sediment that has eroded from upstream (Tallis et al., 2013). As potential soil loss flows via a flowstream delineated from topological variation, retained sediment by vegetation could be calculated as below;

$$Retained\,Sediment = (USLE \times Vegetation\,Retention\,Efficiency)^{n}$$

USLE equation and Retaining ability assessment are popular approaches in ecosystem service assessment (Leh et al., 2013), which is recommended in prevailed assessment toolkit, InVEST (Tallis et al., 2013).

III. Scope and method

1. Aim of the study

Vietnam is the only country in Southeast Asia that has implemented PES nationwide. However, due to the lack of a specific methodology and available recent forest data, assessment on the nationwide implementation of the policy in a frame of PFES is successful or not is somewhat controversial. In this study, I intended to set the priority region for implementing PES in spatially explicit way, by considering hydrological ecosystem services which are considered to be important in this region.

The first step toward designating the priority region for PFES is verifying where the forests are located. Satellite images, like MODIS12, has provided several land cover maps, but they were too coarse to be applied in detail. On the other hand, collecting field measurement data can guarantee the detailed data but they had the shortcoming of only being applicable to a very limited area due to high costs. As such, Landsat satellite images can be an alternative for supporting a land cover map that provides relatively high resolution (30 m) with multi-spectral images every 16 days for free of charge. In this research, land cover was classified with the latest Landsat images, considering both the dry and wet seasons.

The next step was assessing two hydrological ecosystem services—water yield and sediment retention—which were developed in the pilot tests in Vietnam. Hydrological ecosystem services have been considered very important in northern Vietnam, affecting the basin and lowlands, including the capital.

The areas that are important for maintaining ecosystem components and functions that provide ecosystem services must be carefully managed to secure the provision of ecosystem services today and in the future (Chan et al., 2006; Egoh et al., 2007). Furthermore, without the valid classification of current forest and forest functions in spatially explicit ways, the benefit distribution would not function.

For this study, Da River basin in northwest Vietnam was selected. Da River has two of the largest hydropower dams in Vietnam—Hoa Binh Dam and Son La Dam—and the water and electricity supplier (companies) has been the most powerful contributor to the PFES policy during pilot periods.

In summary, the aims of the study are as follows: (1) to classify the current forest land cover; (2) to assess two hydrological ecosystem services to determine a valid reason for the benefit distribution; and (3) to suggest spatially explicit PES priority regions in Da River basin.

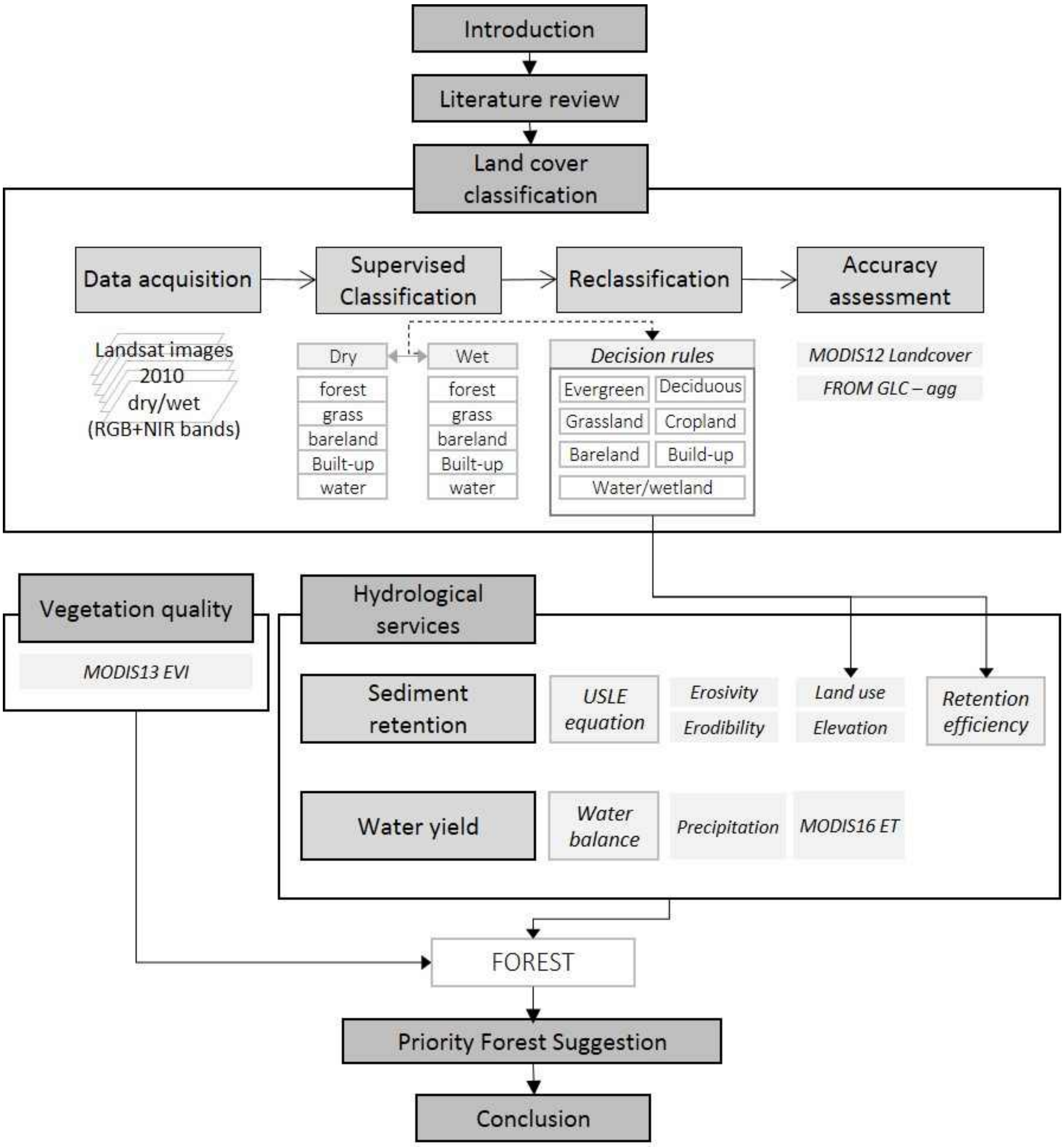

Figure 3 Research flow

2. Study Site

The Red River basin, which originates from Yunnan province in China and flows into the national capital Hanoi, is located in northern Vietnam. 48% (81,240 ㎢) of the river is in China and 52% (84,460㎢) is in Vietnam. Further, the Red River basin comprises three tributaries: RedRiver (Thao River in the Vietnamese territory), Lo River and Da River. They join together at Viet Tri (T. P. Q. Le et al., 2010), located near Hanoi.

In this research, Da River basin (27,300 ㎢) within the Vietnamese territory is considered a spatial scope in the Red River basin. Da River basin is located in the northwest region of Vietnam, and it has complex relief from the delta at a 3,000m altitude in Hoang Lien Son Mountain, which is the highest region in Vietnam. Moreover, the largest dams are located within Da River basin, Hoa Binh, and Son La dam.

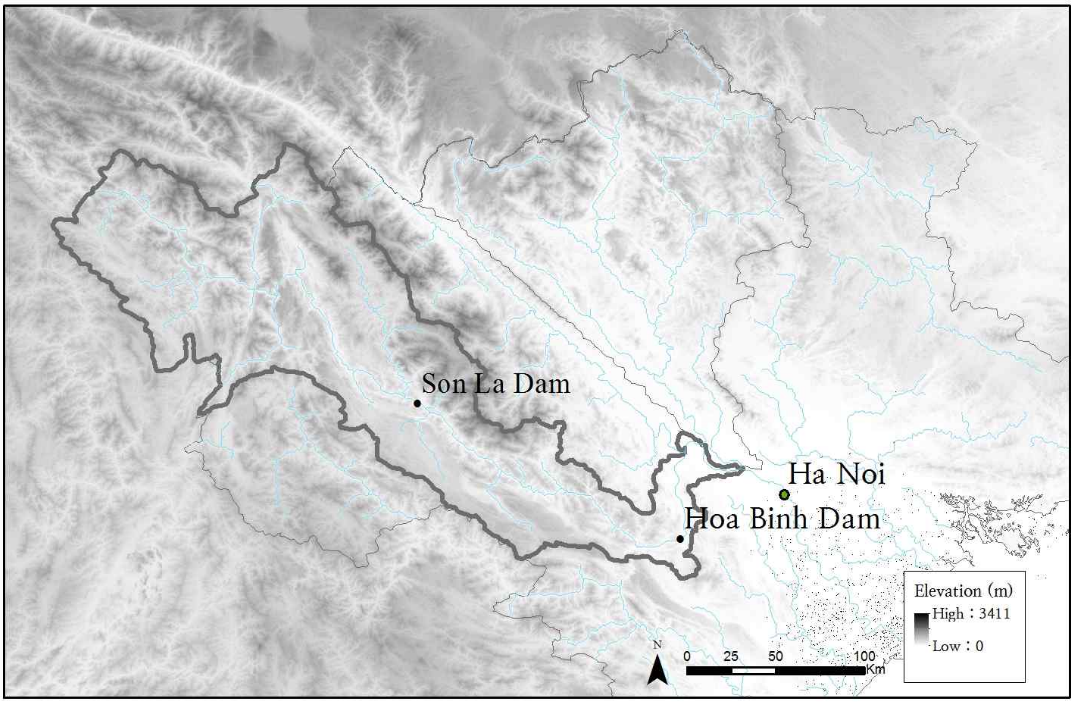

Figure 4 Location of Da river basin

The administrative districts in Da River basin are Dien Bien, Ha Tay (currently altered to Ha Noi), Hoa Binh, Lai Chau, Phu Tho, Son La, Vinh Phuc, and Yen Bai provinces.

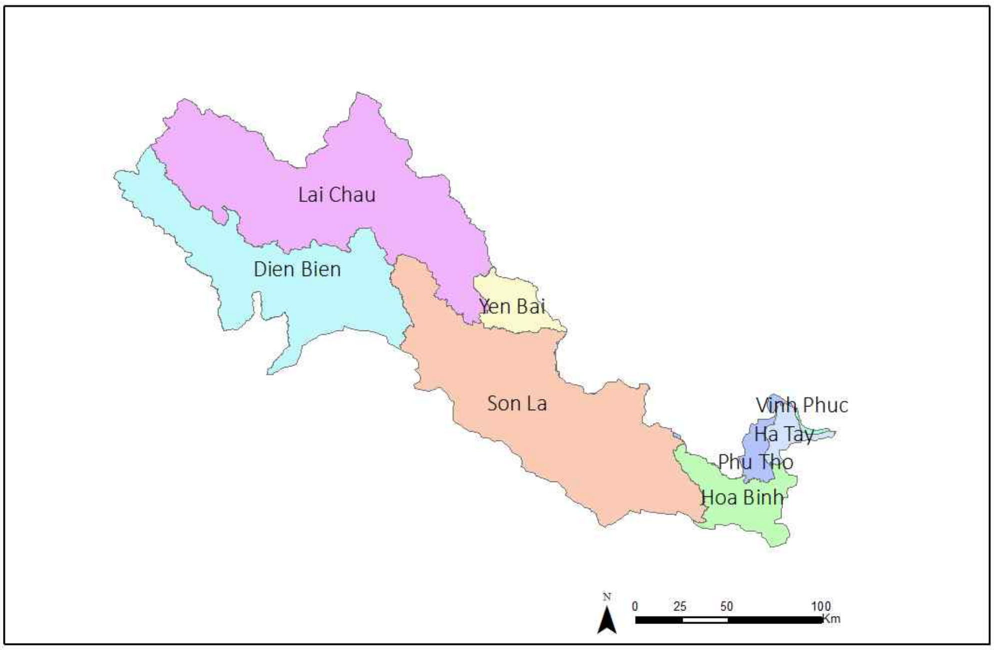

Figure 5 Provinces in Da River basin

Table 6 Composition of Provinces in Da river basin

Province	total area (㎢)	within Da river basin (㎢)	
Dien Bien	9529.13	5932.14	62.3%
Ha Tay (Hanoi)	2225.88	430.44	19.3%
Hoa Binh	4642.32	1525.55	32.9%
Lai Chau	9060.44	9054.72	99.9%
Phu Tho	3530.06	461.51	13.1%
Son La	14106.74	8958.56	63.5%
Vinh Phuc	1375.20	44.84	3.3%
Yen Bai	6885.64	901.82	13.1%

Located within a subtropical, humid, monsoon climate, it has distinct seasonal differences, in the form of wet and dry seasons. Eighty percent of the total annual precipitation falls during the wet season, from May to October, from northern Indian tropical cyclones. Further, the soil properties in this region are mostly Acrisols and Luvisols, and soil organic matter is generally poor (World Harmonized Soil Database).

Among the three rivers (Da, Thao, and Lo) in Red River basin, Da River basin contributes the greatest discharge (53~57%) to the delta (Le et al., 2007), and Da River basin has the most abundant forests in Vietnam. For several reforestation programs, Eucalyptus and Acacia were intensively planted, but in the northwest region, fewer plantation programs were initiated due to poor accessibility (FSIV, 2009). Therefore 92.7% of the current forest in the northwest region is natural forest (FSIV, 2009).

However, abundant forests in Da River basin are threatened constantly due to several deforestation activities. Most of the people living in the area are ethnic minorities, who inhabit the remote mountains. Their livelihood depends on the conventional agricultural method, slash-and-burn. However, slash-and-burn and paddy cultivation in the hilly area (Wezel et al., 2002) are causing problems, such as sediment loss, nutrient loss, and the loss of water resources through fast runoff.

3. Land Cover Classification

1) Data Acquisition

Ecosystem service assessment is highly dependent on land cover. Moreover, since PES in Vietnam pertains only to forests, the accurate detection of forests is important. Several land cover maps available on the Food and Agriculture Organization (FAO) GlobCover and MODIS websites have 300 m to 1 km resolutions; however, they are too coarse to present actual ecosystem services in detail. Furthermore, the land cover types in those coarse resolution maps are built for whole continents; therefore, the vegetation characteristics might differ from continent to continent . Since previous land cover maps define their 'forests' as trees above 5 meters, most of real forests in northern Vietnam are considered as 'shrubs'. Therefore, in this study, land cover was classified according to Landsat data to assess this particular region.

First, the Landsat satellite images were downloaded from USGS Glovis website (glovis.usgs.gov). According to World Reference System 2 (WRS2), a study site can be covered with six Landsat scenes distributed at Path Rows 127/45, 127/46, 128/44, 128/45, 129/44, and 129/45. All satellite images were geometrically corrected to the WGS1984 UTM zone 48N.

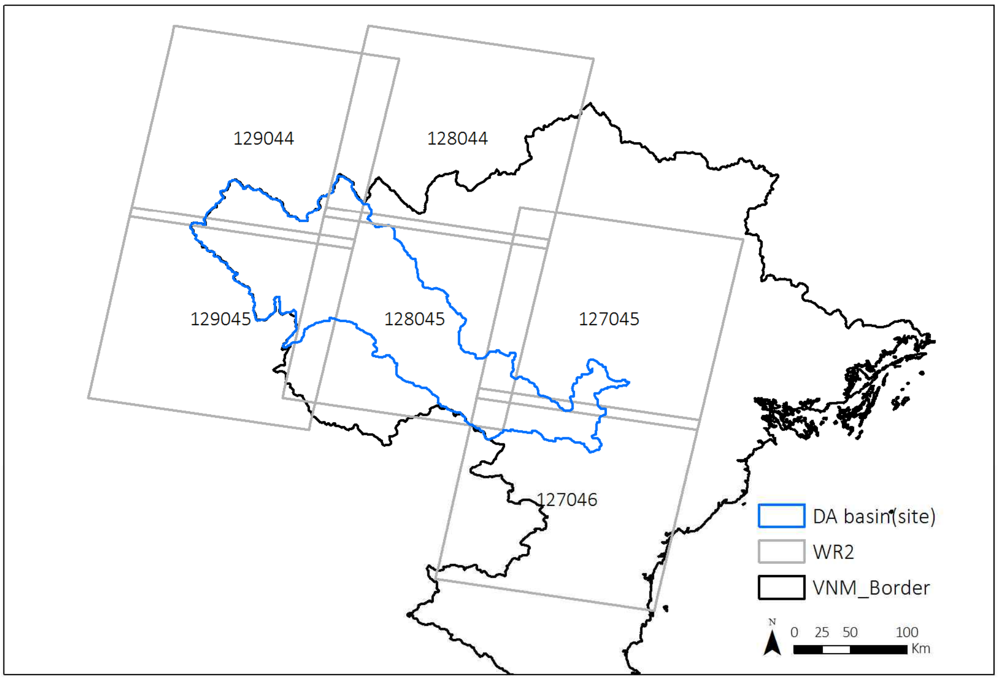

Figure 6 Landsat images location in WR2 within the study site

To maximize the phenologic difference between evergreen forests and croplands, which are the most prevalent land covers according to several land cover maps, the driest month (the last month of the dry season, April) and the month with the most moisture (the end of monsoon, November) in the Landsat images with less cloud cover were collected. In addition, since April and November are the harvesting seasons for paddy rice in this region (Oo et al., 2013), this approach would significantly reduce the misclassification of evergreen forest and paddy cultivation.

Table 7 Acquired Landsat images specification

Location	Date (DOY)	Season	Sensor	Qlty	Cloud cover	Data type
P129 R44	2013.4.20. (110)	dry	OLI_TIRS	9	1%	L1T
	2009.11.3. (307)	wet	TM	7	0%	L1T
P129 R45	2013.4.20. (110)	dry	OLI_TIRS	9	19%	L1T
	2009.11.3. (307)	wet	TM	7	0%	L1T
P128 R44	2013.3.20. (79)	dry	ETM+	9	18%	L1T
	2010.10.22. (295)	wet	ETM+	9	0%	L1T
P128 R45	2010.2.8. (39)	dry	ETM+ (SLF-off)	9	18%	L1T
	2010.10.22 (295)	wet	ETM+ (SLF-off)	9	0%	L1T
P127 R45	2009.2.14 (45)	dry	ETM+	9	34%	L1T
	2013.10.7 (280)	wet	landsat 7 (ETM+)	9	0%	L1T
P127 R46	2009.2.14 (45)	dry	ETM+	9	3%	L1T
	2013.10.7 (280)	wet	landsat 7 (ETM+)	9	0%	L1T

2) Preprocessing

When a satellite sends raw Landsat images to the ground station, it is called “Level 0” by NASA and the USGS. In order to make the images usable, the data must be preprocessed. All available Landsat data at GLOVIS or EarthExplorer have been corrected already. According to the Data Format Control Book published by USGS, a radiometric corrected image is L1R, and L1R with geometric correction is L1G, and after being processed with systematic geometric correction, it is L1T. Finally, L1T products are corrected using ground control points, Digital Elevation Model (DEM) and ephemeris (USGS, 2012). In this study, the downloaded data were all pre-processed L1T data, and thus these preprocessing procedures were omitted. A remaining reprocess is atmospheric correction, which is only mandatory when applying a sampling classification to other scenes at once (Jensen, 2005). In addition, it is unnecessary when it is clear day. I limited all datasets to clear days in the study region, and as the classification process would be applied to each scene independently, this process was also omitted in this study.

After checking all of the data, I stacked RGB (321 for Landsat 5,7 and 432 for Landsat 8) bands and NIR band at each scene. One problem with using ETM+ images is the nodata stripes that have appeared on images since May 31, 2003, due to the failure of the Scan Line Corrector (SLC). To destripe the nodata stripes, the triangular destripe method was adopted to fill the nodata. Then each image was masked with Da River basin using ENVI 4.5.

3) Classification

Northwest Vietnam has diverse land cover types because of its complex topography, diverse climate, and soil conditions. The mountainous forests have diverse tree species mostly according to their altitudes. In the low to middle altitude forests, moist deciduous forests dominate, such as Dipterocarpaceae, Meliaceae, and Sapindaceae (Phuong, 2007). As the elevation increases, Dipterocarpaceae gradually disappear. Lauraceae (*Phoebe cuneata, Lindera spp., Litsea spp., Cinnamomum spp.*), Fagaceae (*Castanopsis spp., Lithocarpus spp., Quercus spp.*), Magnoliaceae, Juglandaceae, and conifers have become major components of the upper mountains (Phuong, 2007). Above 1,700 m, mountain forests dominate, with Fagaceae, Ericaceae, and conifers (*Pinus krempfii, P. armandii, Fokienia hodginsii, and Keteleeria davidiana*) (Phuong, 2007). After several forest clearances by slash-and-burn cultivation, this type of forest is replaced by strands of *Macaranga denticulata, Mallotus cochinchinensis, Trema velutina, Rhus semialata, Styrax spp.*, bamboo, and shrubs (Phuong, 2007).

Furthermore, in the northwest region, an important agriculture system in the high uplands is the composite swidden agriculture (slash-and-burn cultivation) that is used to cultivate annual food crops, such as maize and cassava (Oo et al., 2013), and upland rice. According to Wezel et al. (2002), in northern Vietnam, 0.7 million hectares are under paddy cultivation, and of these, 60% are located in steep mountainous areas, therefore necessitating the use of terrace cultivation. The crop species and cultivation cycles are varied due to the complex topography, varied elevations, and climate. In the lowlands, permanent wet rice fields are prominent (Oo et al., 2013).

Table 8 Land cover composition of provinces in Da river basin (1,000ha) (Statistical Yearbook of Vietnam 2012)

	Total area	Forest		Agriculture			
						paddy	maize
Ha Tay (Ha noi)	332.4	24.0	7.2%	150.2	45.2%	205.4	20.7
Vinh Phuc	123.6	32.5	26.3%	49.9	40.4%	59.4	13.7
Yên Bái	688.6	474.1	68.8%	107.8	15.7%	40.4	24.7
Phú Thọ	353.3	178.6	50.6%	98.5	27.9%	69.2	17.4
Điện Biên	956.3	602.1	63.0%	154.4	16.1%	48.3	29.2
Lai Châu	906.9	418.7	46.2%	89.7	9.9%	24.8	21.3
Sơn La	1417.4	624.6	44.1%	261.5	18.4%	48.2	133.7
Hoà Bình	460.8	288.3	62.6%	65.2	14.1%	41.3	36.2

Most northern uplands have rotation cycles for maize and rice cultivation. The most popular rice varieties in the northwest region are spring rice and summer rice. Spring rice, which is usually grown using an irrigation system, is transplanted in February and harvested in late June. Summer rice, which is cultivated by rainfall, is transplanted in late July and harvested in early November (Schmitter et al., 2010; Schmitter et al., 2012; Oo et al., 2013).

Figure 7 Rice cultivation cycle according to rice varieties (Schmitter et al., 2012)

Rice varieties	1	2	3	4	5	6	7	8	9	10	11	12
Spring rice (Lua dong xuan)												
Summer rice (Lua he thu)												

The second most popular crop after rice is maize (Zea mays L.), as it is a cash crop. It is cultivated through slash-and-burn, which is carried out by many ethnic minorities living in the northern highlands (so-called swidden agriculture, shifting cultivation). Slash-and-burn cultivation removes the current forest with fire to create fertile soil that is then cultivated for a several years and abandoned or re-cultivated after a long rest period (Young et al., 2002). Slash-and-burn is considered the main reason for deforestation and disasters. Among the varieties of maize, summer-autumn varieties are common in the highly elevated area (Son La province) and winter-spring and summer-autumn varieties are common in the relatively low lands (Vinh Phuc and Phu Tho provinces) (Maize in Vietnam, 2004). Spring-summer varieties are planted in January/February and harvested in May; winter-spring varieties are planted in September/October and harvested in January; and summer-autumn varieties are planted in April/May and harvested in August (Maize in Vietnam, 2004).

Winter-spring and spring-summer maize are usually planted after rice crops, comprising 45.4% and 17.8%. Most northern uplands have rotation cycle of maize and rice cultivation.

Figure 8 Maize cultivation cycle according to maize varieties (Maize in Vietnam, 2004)

Maize varieties	1	2	3	4	5	6	7	8	9	10	11	12
spring-summer												
summer-autumn												
winter-spring												

In addition to forest species or cultivation cycles, several land cover maps and their classes were considered with references such as Google

Earth images, GlobCover 2009, and multi temporal Landsat images. Subsequently, five land cover types were selected: (1) forest and shrublands, (2) grasslands and croplands, (3) bareland and baresoil, (4) built-up and artificial surfaces, and (5) water and wetlands. Here, shrubs and forest were combined because it was difficult to distinguish between them with satellite images due to the ruggedness of the mountainous relief and secondary vegetation on degraded land in northern Vietnam (Castella and Verburg, 2007).

Table 9 Classified land cover classes and their images on RGB combination

1		
2		
3		
4		
5		

After classifying each Landsat image with five classes, the dry and wet seasons were overlapped and analyzed according to the criteria as follows.

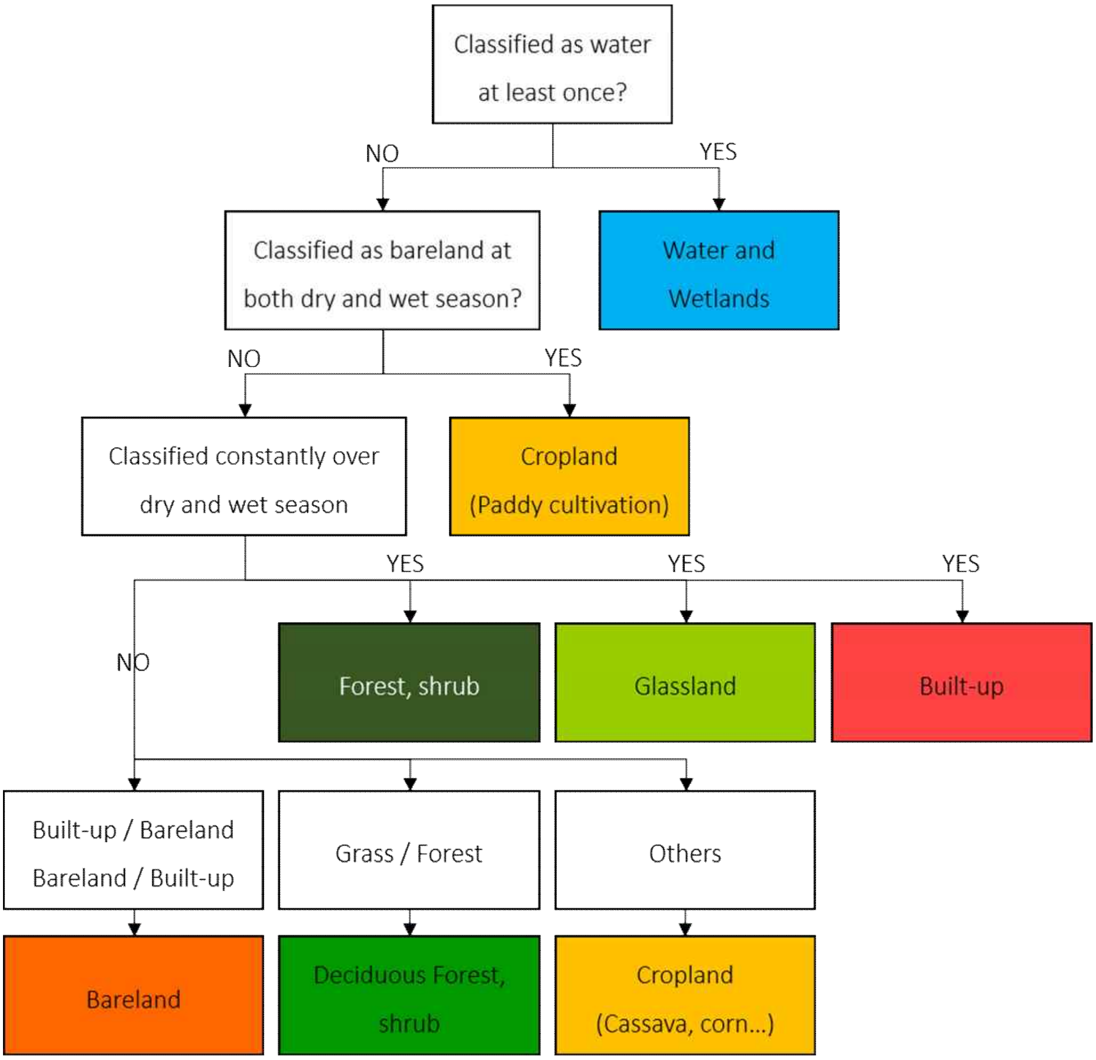

Figure 9 Decision rules for land cover classification

Rule 1. If a pixel is classified as water at least once, it would be concluded as water and wetlands. After construction of Son La hydropower dam in this region, lots of lowlands and wetlands were submerged. So in this study, separating water and wetlands were omitted.

Rule 2. If a pixel is classified as bareland at dry and wet season, it would be concluded as croplands like paddy cultivation. Most of acquired images were late April and late October, and these periods are harvest season of paddy rice in northern uplands.

Rule 3. If a pixel is classified as same class over dry and wet season, it would be concluded as that class.

Rule 4. If a pixel is classified as bareland/built-up in dry season and built-up/bareland in wet season, it would be concluded as barelands. Dur to the spatial adjacency and spectral similarity between bareland and built-up area, Built-up land is limited to a pixel which shows constant built-up class.

Rule 5. If a pixel is classified as grass in dry season and forest in wet season, it would be concluded as open forest.

Rule 6. Others are classified as croplands.

Table 10 Final land cover classes in this study

#	Land cover classification	Land cover description
1	Evergreen Fores/shrub	constant forest, shrublands
2	Deciduous Forest/shrub	forest, shrublands which degrades in dry season including open forest, deciduous forest.
3	Grassland	grassland, sparse vegetation including natural grassland and irregular croplands
4	Cropland	croplands such as maize, cassava
5	Bareland	little vegetation, barelands
6	Built-up	artificial surface such as road, dam and urban area
7	Water	shallow, deep waterflows includes river, stream and reservoirs. wetlands

ENVI 4.5 software is utilized for classification and supervised classification with maximum likelihood was adopted.

4. Hydrological Ecosystem Services Assessment

1) Water yield

The water yield ecosystem service can be estimated by using water balance theory, subtracting evapotranspiration from precipitation. To eliminate the precipitation fluctuations from year to year, long-term precipitation is considered to be an appropriate temporal scale. The precipitation for the study site was collected from the WorldClim website, taking the average of 50 years (1950–2000), at about 900 m resolution. Moreover, the actual precipitation during a 32-year period (1975–2006), measured by the meteorological stations within Da River basin, was collected for validating if the WorldClim data reflected the site-specific environments. Actual evapotranspiration was collected from MODIS16 ET, which has the most reliable evapotranspiration algorithm (Mu et al. 2011). However, since MODIS16 ET data are only available from 2000 to 2012, the 13 years of evapotranspiration were averaged to reduce the fluctuation.

Table 11 Input data description on water yield

Input data	Description	Resolution	Source
Precipitation	1950-2000 average	899.23m	WorldClim
	1975-2006 average	-	17 Meteorological Stations in Da river basin, Vietnam
Actual Evapotranspiration	2000-2012 MODIS16 ET	923m	http://www.ntsg.umt.edu/project/mod16
Basin	Da river basin	-	FAO geonetwork

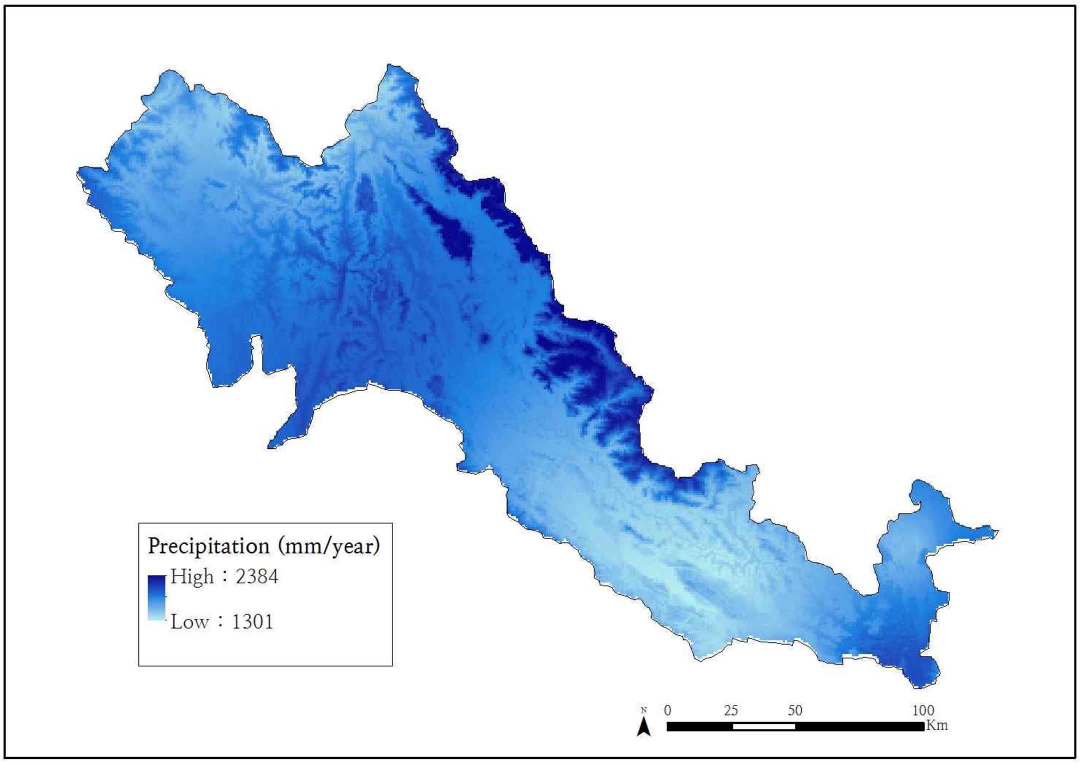

Figure 10 50 years(1950-2000) of mean precipitation in Da river basin

2) Sediment retention

To estimate the retained sediment, soil loss must first be calculated. To calculate the potential soil loss, the Universal Soil Loss Equation (USLE) is adopted widely. The USLE is expressed by multiplying R, K, LS, C, and P. Each factor stands for contribution of rain, soil, topography and land cover on soil loss.

To estimate R (rainfall erosivity), the El-Swaify equation was adopted (Renard and Freimund, 1994), as it is known as an appropriate estimator of rainfall erosivity in subtropical climate regions and is already utilized in Thailand, Indonesia, and Myanmar (Lee and Heo, 2011).

$$R = 38.5 + 0.35P$$

K (soil erodibility) was deducted from Wischmeier and Smith's (1978) equation, where m refers to the soil characteristics, presented as (silt + sand) * (100 – clay); a refers to soil organic matter (%) and is derived from the van Bemmelen factor (1.724 * SOC) and SOC from the World Harmonized Soil Database; b refers to soil structure; and c refers to profile permeability. They are considered as defaults due to the lack of information in this region.

$$K = (27.66 \times m^{1.14} \times (12 - a) \times 10^{-8}) + (0.0043(b-2)) + (0.0033(c-2))$$

There are many equations for calculating LS in USLE, but for high slopes, Huang and Lu's (1993) equation is considered appropriate (Tallis et al., 2013). λ is the flow direction value and prct_slope refers to the percent slope calculated from DEM.

$$LS = 0.08 \times \lambda^{0.35} \times (prctslope)^{0.6}$$

C and P were adopted from Ranzi et al. (2012) and Yang et al. (2003), respectively. Slope threshold was set to 75% (67.5°), which is the maximum stabilized slope for cultivating in northern Vietnam.

Table 12 Input data description on sediment loss and retention (spatial)

Input data	Description	Resolution	Source
R	Rainfall erosivity derived from mean annual precipitation in 1950-2000 (El-Swaify equation)	899.23m	WorldClim
K	Soil erodibility from %clay, %sand, %silt and SOC (Wischmeier and Smith, 1978)	899.23m	Harmonized World Soil Database
LS	Topographic factor derived from Digital Elevation Model(Huang and Lu, 1993)	213m	USGS/NASA SRTM NE
Basin	Da river basin	-	FAO geonetwork

Table 13 Input data description on sediment loss and retention (land cover)

LULC class	C factor (Ranzi et al., 2012)	P factor (Yang et al., 2003)	Sediment retention efficiency (Leh et al., 2013)
1	0.003	1.0	0.95
2	0.003	1.0	0.85
3	0.018	0.8	0.6
4	0.500	0.5	0.3
5	0.018	0.5	0.25
6	0	1.0	0.03
7	0	1.0	0.10

After calculating the potential soil loss from each land cover cell using the USLE, it was possible to estimate the retained soil from vegetation by multiplying by vegetation retention efficiency (Leh et al., 2013).

To calculate potential soil loss and sediment retention, the InVEST sediment retention module was adopted. InVEST is a set of toolkits for estimating ecosystem services, developed by Natural Capital Project (Tallis et al., 2013), and one of the module supplies potential soil loss and retention calculation algorithm.

5. Forest Quality

In PFES policy, K1 coefficient is illustrated as a forest states that involves forest stocks and quality. To assess forest quality, MODIS13 Enhanced Vegetation Index (EVI) was adopted as a proxy indicator, in accordance with previous research that indicated that MODIS vegetation indices, such as NDVI and EVI, can show the empirical relationship with forest quality, such as carbon stock (Foody et al., 2003).

In this study, MODIS13A3 in 500 m resolution was summed and averaged to year scale with 24 scenes of 16-day intervals from 2011353 (DOY) to 2012353 (DOY).

IV. Results and Discussion

1. Land Cover Classification

1) Land Cover Map

Land cover was classified into seven categories according to previous decision rules considering both the dry and wet seasons in Da River basin. As a result, evergreen forest/shrub was 10,762.54 km^2 (39.38%), deciduous forest/shrub was 3,457.37km^2 (12.65%), grassland was 3,670.05 km^2 (13.43%), cropland was 6,259.68km^2 (22.9%), bareland was 2,378.67km^2 (8.70%), built-up land was 207.70km^2 (0.76%), and water and wetland was 593.15km^2 (2.17%).

Large evergreen forest/shrub land covers were found at high altitudes, such as in the northwest, Phu Tra (Hoang Lien National Park), Fansipan in the northeast, and the small mountains in the middle and southern areas near Hoa Binh reservoir (dam). Deciduous forest/shrub was located along the edge of the evergreen forest/shrub, where the altitude is relatively lower. Grasslands, croplands, and barelands were distributed along the low lands and valleys of the mountainous areas. Large water and wetlands were detected at the two largest dams: Son La dam in the middle and Hoa Binh dam near the delta.

In this study, land cover classification result showed some features in finer resolutions, detecting small water bodies or croplands, bare soils at where previously classified as forests from other land cover maps such as MODIS or GlobCover.

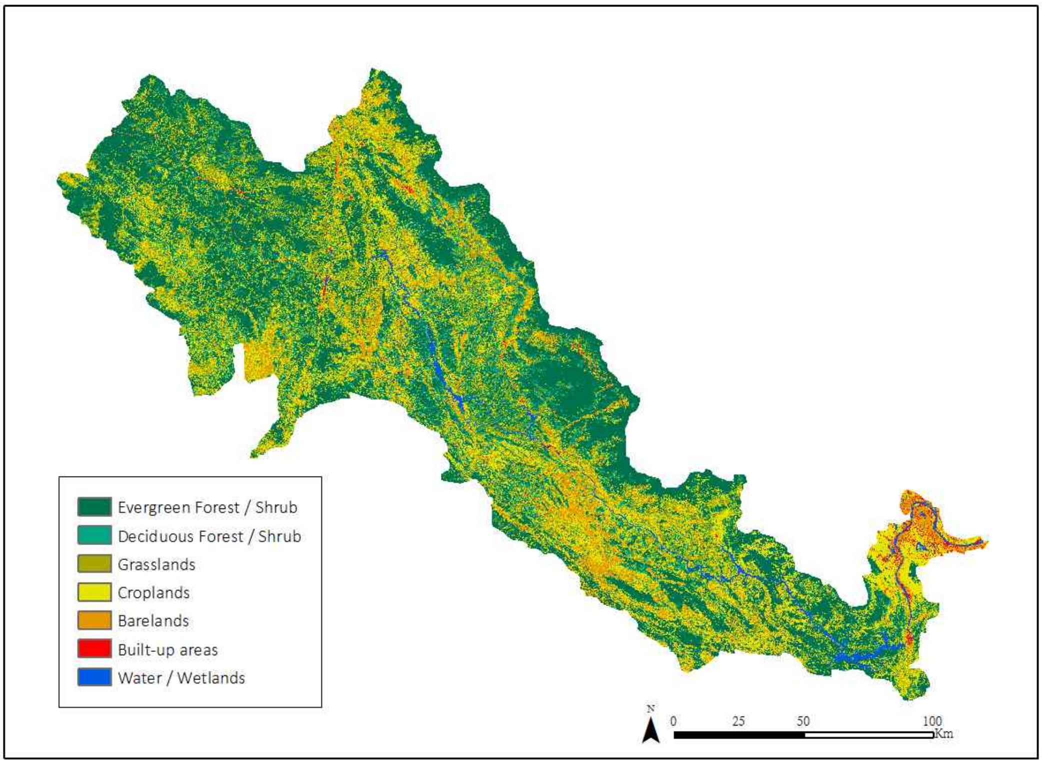

Figure 11 Land cover classification result

Table 14 Land cover classification result (area)

Land cover classification			
#	Class	Area(㎢)	Area(%)
1	Evergreen Forest/shrub	10762.54	39.38%
2	Deciduous Forest/shrub	3457.37	12.65%
3	Grasslands	3670.05	13.43%
4	Croplands	6259.68	22.90%
5	Barelands	2378.67	8.70%
6	Built-up areas	207.70	0.76%
7	Water/wetland	593.15	2.17%
Total		27329.14	100.00%

2) Accuracy Assessment

For an accuracy assessment, FROM-GLC-agg (Finer Resolution Observation and Monitoring of Global Land Cover - aggregation) (Yu et al. 2013b) was adopted to compare with the classified land cover in this research. FROM_GLC was developed by Gong et al. (2013), using Landsat TM/ETM+ images classified with four types of supervised classifiers, showing an overall classification accuracy of 64.9%. Then Yu et al. (2013a) improved the result of Gong et al. (2013) by integrating Landsat TM/ETM+ and MODIS EVI time series (250 m), Bioclimatic variables (1 km), global DEM (1 km), and soil-water variables (1 km). FROM-GLC-agg is the up-to-date result of continuous research classifying land cover with 30 m resolution images, by aggregating previous results and two coarse resolution images of Nighttime Light Impervious Surface Area and MODIS urban extent (Yu et al., 2013b). FROM-GLC-agg has an overall accuracy of 65.51% (Yu et al., 2013b).

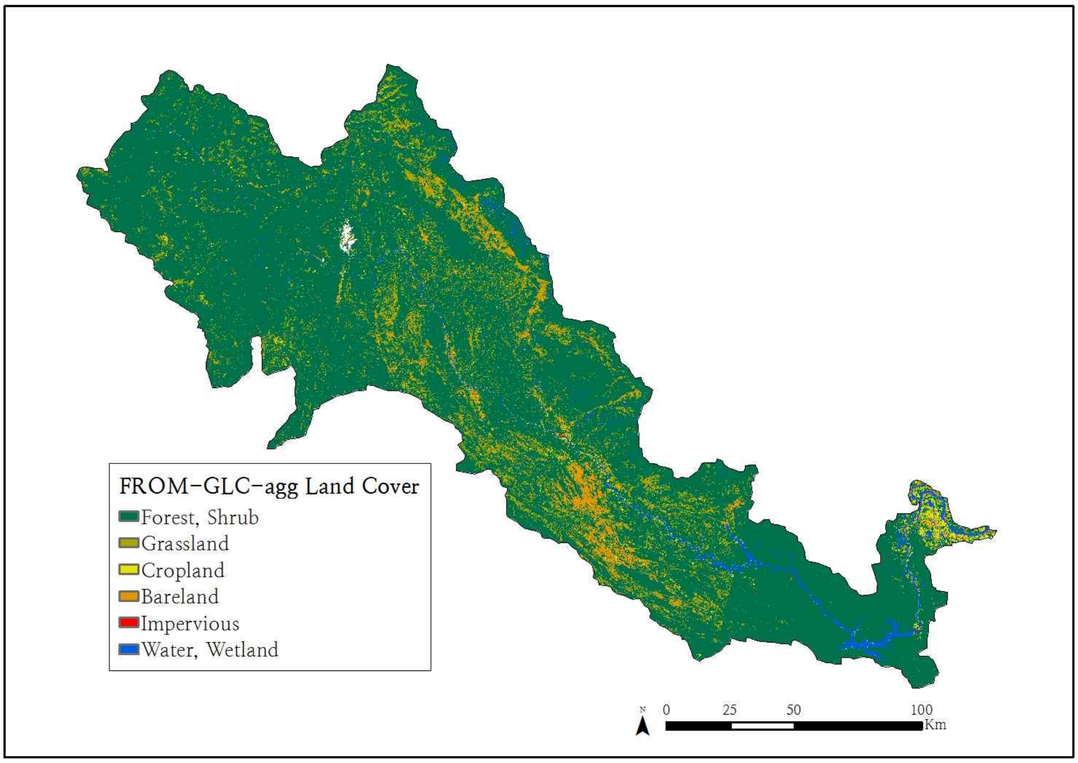

Figure 12 Reference Land cover map (FROM-GLC-agg (Yu et al., 2013))

Similar to GlobCover 2009 and MODIS12 land cover, FROM-GLC-agg overestimates forest cover up to 84% of the study region. It also shows the discrepancy in land cover, where the path-row border passes, due to temporal differences (2000 to 2009). Furthermore, it is a one-scene-based classification of the Landsat images, and the dates of the image acquisition are at the end of the wet season, which can lead to the overestimation of the vegetation (Table 15).

Table 15 Landsat image used in FROM-GLC-agg (Yu et al., 2013b)

Path Row	Date of acquisition
129044	20091103
129045	20091103
128044	20081109
128045	20061104
127045	20001104
127046	20000917

Table 16 Class composition of Land Cover Classification Result and referenced FROM-GLC-agg landcover

Land cover classification (this study)			FROM-GLC-agg (Yu et al, 2013b)		
Class	Area(㎢)	Area(%)	Class	Area(㎢)	Area(%)
Evergreen, deciduous Forest/shrub	10762.54 3457.37	39.38% 12.65%	Forest Shrub	22932.21 135.70	83.86% 0.50%
Grass	3670.05	13.43%	Grass	2271.79	8.31%
Cropland	6259.68	22.90%	Cropland	412.62	1.51%
Bareland	2378.67	8.70%	Bareland	947.91	3.47%
Built-up	207.70	0.76%	Impervious	8.20	0.03%
Water	593.15	2.17%	Water/Wetland	601.99	2.20%
			Snow/Ice/Cloud	36.59	0.13%
Total	27322.29	100%	Total	27347.00	100%

The overall accuracy of the land cover map derived from this study was 54.60%. Most of the errors were detected between FROM-GLC-agg forests and other classes in the classified result in this study. In other words, the large number of pixels being classified as forest resulted in the overestimation of forest cover in the referenced land cover map. In summary, compared to FROM-GLC-agg, classification results underestimate forest and water, and overestimate other classes.

Table 17 Error matrix between Land Cover Classification Result and referenced FROM-GLC-agg landcover

		FROM-GLC-agg							
		forest/shrub	grass	crop land	bare land	imper-vious	water/wetland	snow/ice/cloud	Total
classified	forest/shrub	15,007,587	494,966	48,805	56,458	267	170,708	15,422	15,794,213
	grass	3,301,940	615,120	54,924	83,614	176	9,833	8,908	4,074,515
	crop land	5,457,021	889,021	162,319	376,144	2,236	54,498	12,468	6,953,707
	bare land	1,519,530	460,732	141,315	450,456	3,560	64,326	2,823	2,642,742
	built-up	92,063	23,277	35,970	41,870	2,298	34,546	709	230,733
	water	226,600	38,345	14,731	43,665	566	334,382	291	658,580
	Total	25,604,741	2,521,461	458,064	1,052,207	9,103	668,293	40,621	30,354,490

above numbers refer to number of pixel (30m*30m)

User’s accuracy, which refers to the probability that a pixel labeled in a classification certainly indicates the class, was especially accurate for forest/shrub land cover, explaining that 95% of the classified forest in this study corresponded to the forest in the reference data.

Except for forest/shrub and water, the accuracy of the land cover was greater for the producer’s accuracy than the user’s accuracy, showing that the land cover in the referenced land cover corresponded to the land cover classification result in this study. However, the land cover showed low accuracy in general. Considering the fact that forest/shrub cover in the referenced land cover was up to 84%, most of the errors were the result of overestimating the forest cover.

Table 18 Producer’s accuracy and User’s accuracy

	Producer’s accuracy	User’s accuracy
forest/shrub	58.61%	95.02%
grass	24.40%	15.10%
cropland	35.44%	2.33%
bareland	42.81%	17.05%
built-up	25.24%	1.00%
water	50.04%	50.77%

To verify the classification results, more accurate reference data had to be compared to the result, such as ground truth points from actual sites.

2. Water Yield

1) Precipitation

In this study, the average of 50 years of precipitation, from 1950 to 2000, was used to calculate water yield. To verify the reliability of the data, actual precipitation data recorded from 1975 to 2006 at 17 meteorological stations in Da River basin were compared. As a result, WorldClim precipitation tended to underestimate the quantity of rainfall, showing a range of 1,385 mm to 1,721 mm, while the meteorological station data showed 1,285 mm to 2,734 mm. Thus, the WorldClim data and actual precipitation data yielded a determination coefficient of 0.644, RMSE of 494.80, and a bias of 305.84.

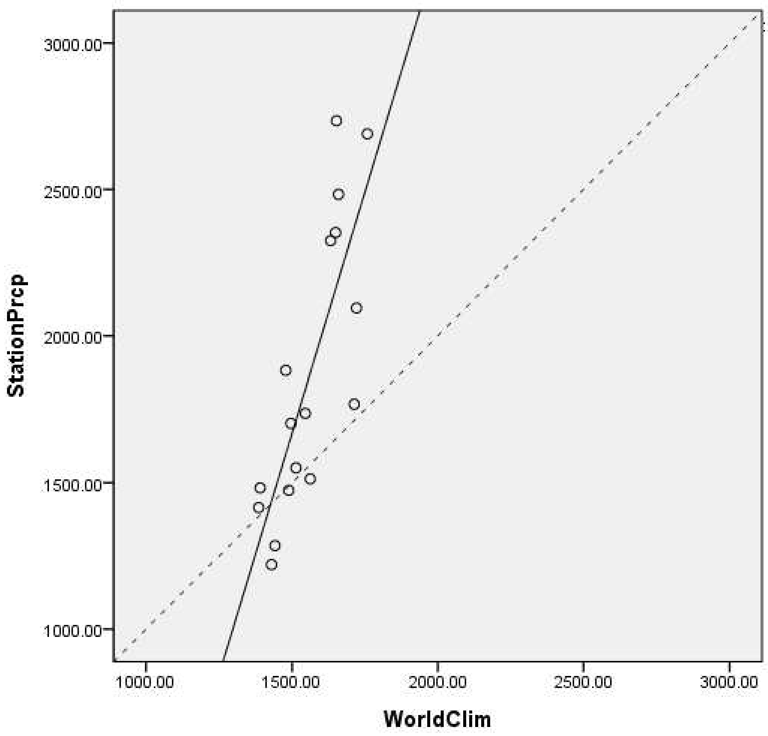

Figure 13 Scatter plot of rainfall data between WorldClim(1950-2000) and Meteorological Station Precipitation(1975-2006) in Da river basin

Several large biases were caused by the precipitation recorded at meteorological stations located in Lai Chau province showing over 2,000 mm of rainfall. Lai Chau province is located at the highest altitude in northern Vietnam, and it actually has a large rainfall during monsoon season. However, the discrepancies should be reconsidered carefully with each source of data to identify the error.

Table 19 Rainfall data from meteorological stations and WorldClim

Meteorological Station in Da river basin						WorldClim (mm)
ID	ST_name	Province	Lon	Lat	rainfall (mm)	
003	Lai Chau	Lai Chau	103.09	22.04	2095.02	1721
005	Muong Te	Lai Chau	102.50	22.22	2325.32	1632
008	Sin Ho	Lai Chau	103.14	22.22	2734.60	1652
009	Tam Drung	Lai Chau	103.29	22.25	2483.17	1659
012	Bac Yen	Son La	104.25	21.15	1482.65	1390
013	Co Noi	Son La	104.09	21.08	1285.06	1441
016	Phu Yen	Son La	104.38	21.16	1415.01	1385
023	Yen Chau	Son La	104.18	21.03	1220.26	1429
038	Lao Cai	Lao Cai	103.58	22.30	1767.84	1713
041	Sa Pa	Lao Cai	103.49	22.21	2689.59	1758
046	Mu Cang Chai	Yen Bai	104.03	21.52	1736.74	1545
048	Van Chan	Yen Bai	104.31	21.35	1473.93	1488
067	Viet Tri	Phu Tho	105.25	21.18	1550.67	1513
069	Tam Dao	Vinh Phuc	105.39	21.28	2352.63	1649
071	Vinh Yen	Vinh Phuc	105.36	21.19	1513.02	1562
109	Ba Vi	Ha Tay	105.25	21.09	1882.25	1478
113	Son Tay	Ha Tay	105.30	21.08	1702.58	1496

2) Actual Evapotranspiration

The MODIS-derived actual evapotranspiration in Da River basin ranged up to 1,672 mm per year. Spatially, northern Dien Bien province and southern Son La province showed high evapotranspiration, and the uplands in Son La province and the delta region showed low evapotranspiration. All water bodies were excluded from the estimation.

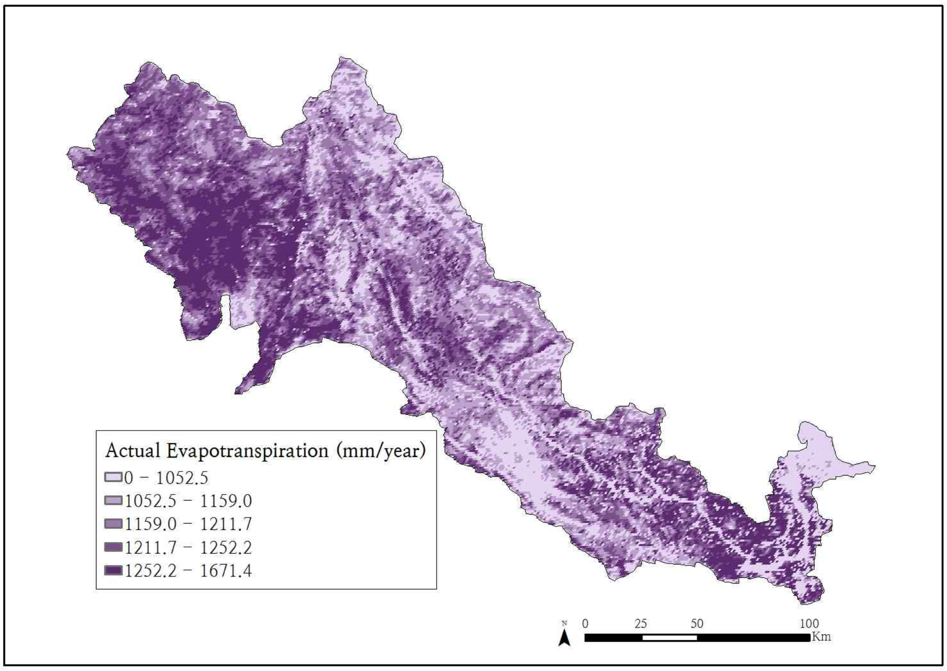

Figure 14 Actual Evapotranspiration in Da river basin (mm/year)

3) Water Yield

The water yield in Da River basin ranged to 1,472 mm. High water yield was detected near Fansipan region and Phu Tra Mountain in eastern Lai Chau province. High water yield was also shown near the delta region. On the contrary, northern Dien Bien province and most of Son La province yield low water compared to other regions. Some regions in the middle of Son La province showed negative values of water yield, meaning a lack of water to sustain the vegetation that might lead to drought.

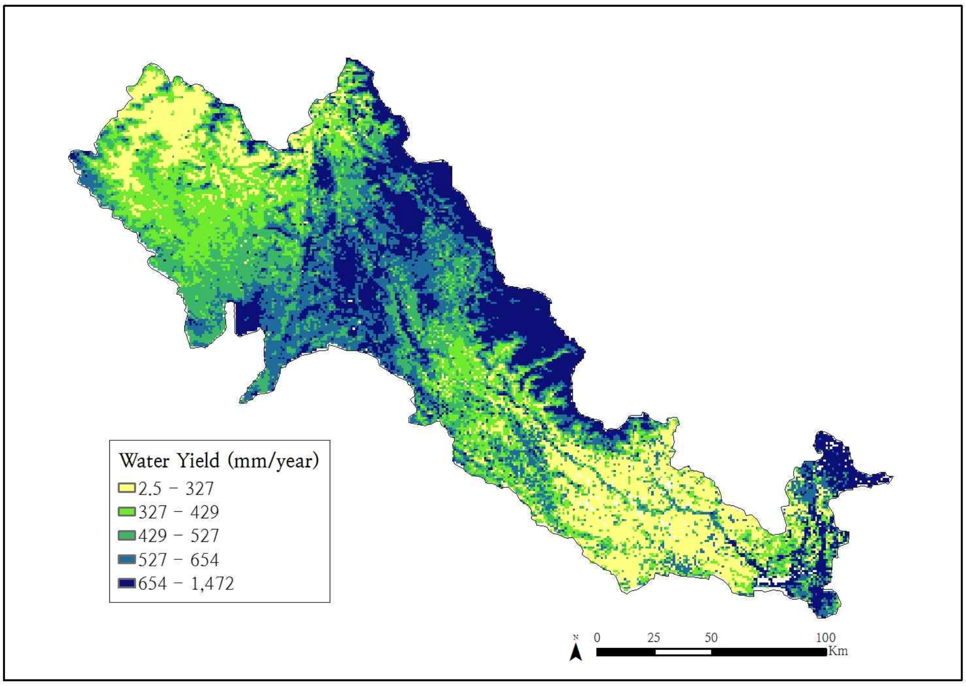

Figure 15 Annual Water Yield in Da river basin (mm/year)

Estimated water yield was clipped to forest region to

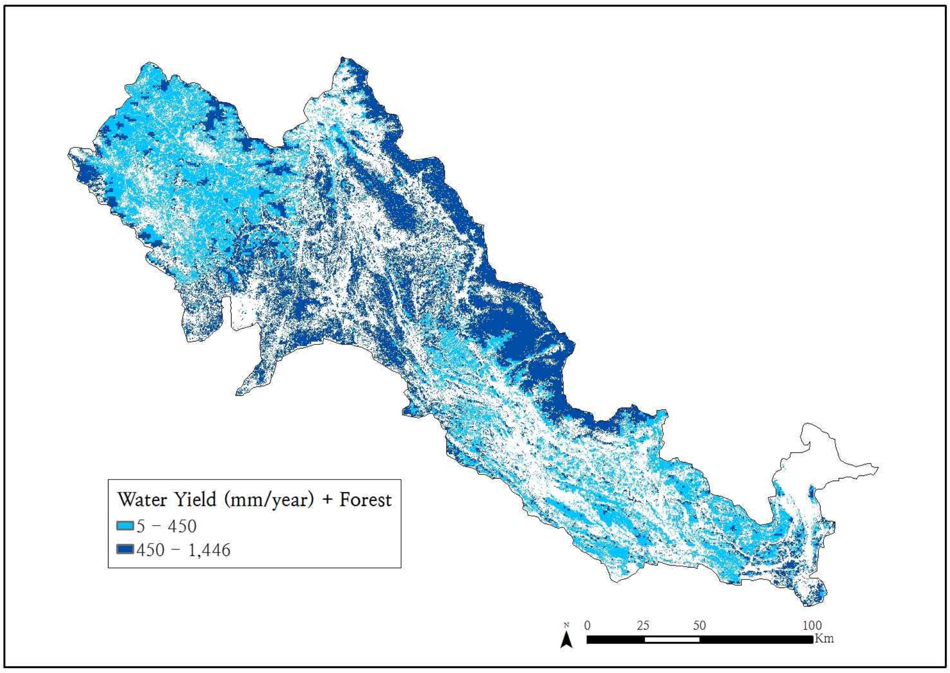

Figure 16 Water yield in forest cover in Da river basin

3. Sediment Retention

1) Potential Soil Loss

The estimated potential soil loss ranged from 0 to 8,000 tons per year per cell (900 m2), but most of the values were distributed below 300 tons per year per cell. Water bodies did not show soil loss.

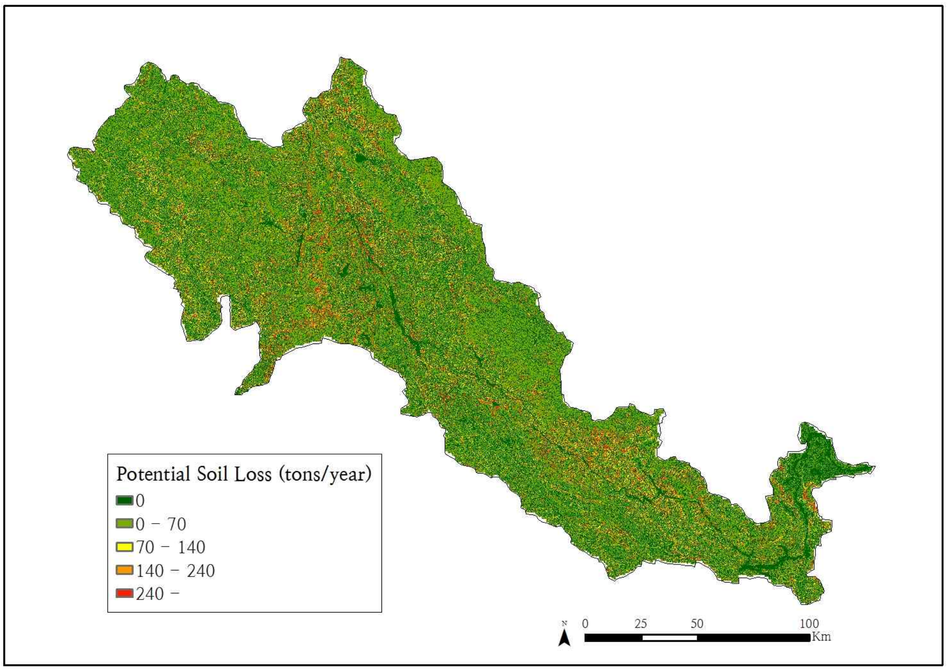

Figure 17 Potential Soil Loss in Da river basin (tons/year/each cell)

Overall, the potential sediment loss in Da River basin within the Vietnamese territory was 119.93 million tons per year. Considering the previous facts, the suspended solid load at Red River (Da, Thao, and Lo Rivers) ranged from 100 to 160 million tons per year (Mikahailov and Isupova, 2012). Mikahailov and Isupova (2012) showed 1.018kg/m3 and ~122.8 million tons per year. At Son Tay station, it was 114 million tons per year during the period 1958–1985, which was before Hoa Binh reservoir came into operation in 1985 (Le et al., 2007). Therefore, the result was reasonable for explaining the sediment loss for this basin. However, USLE only estimates surface soil loss, such as rill and gully erosions, and the previous studies achieved results estimated from Viet Tri, where the three tributaries of Thao, Lo, and Da Rivers meet. Thus, there is a probability of overestimation in this study.

2) Sediment Retention

Sediment retention presents the sediment retained in each spatial scope according to the hypothesis that the vegetation in each cell can retain an unlimited amount of sediment. Since retained sediment is related not only to soil loss but to the flow direction with topographic elevation, the source of the soil loss and sink of the retained soil might be different.

According to the results, the sediment retaining regions were located at the lowlands, and the high altitude areas showed low sediment retention. Although forests have high retention efficiency, there was less inflow of soil loss, resulting in less soil retention in the high altitude forest areas.

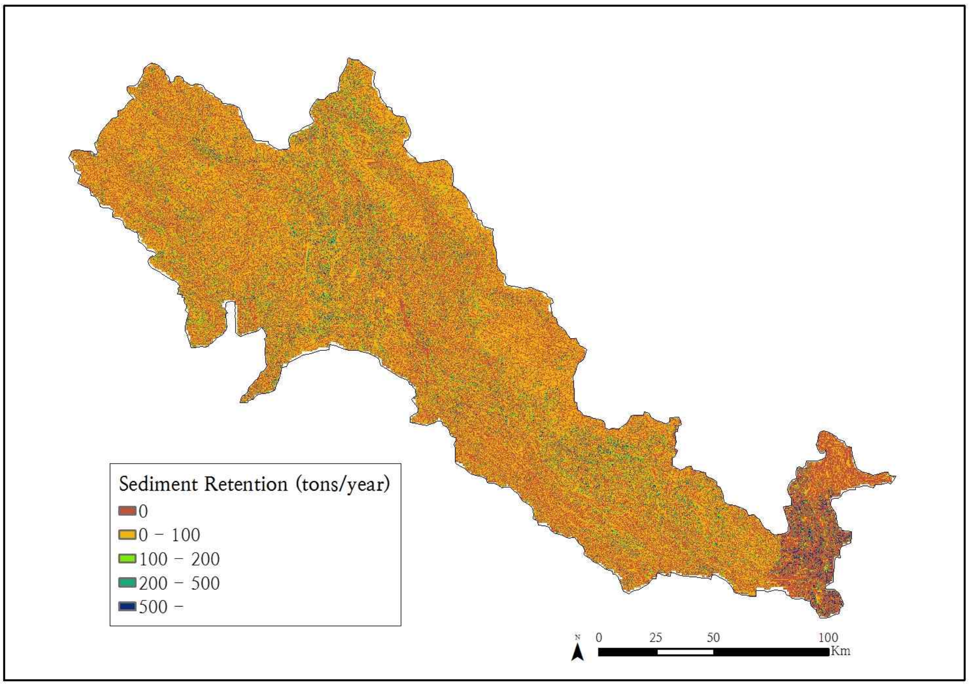

Figure 18 Sediment Retention in Da river basin (tons/year/each cell)

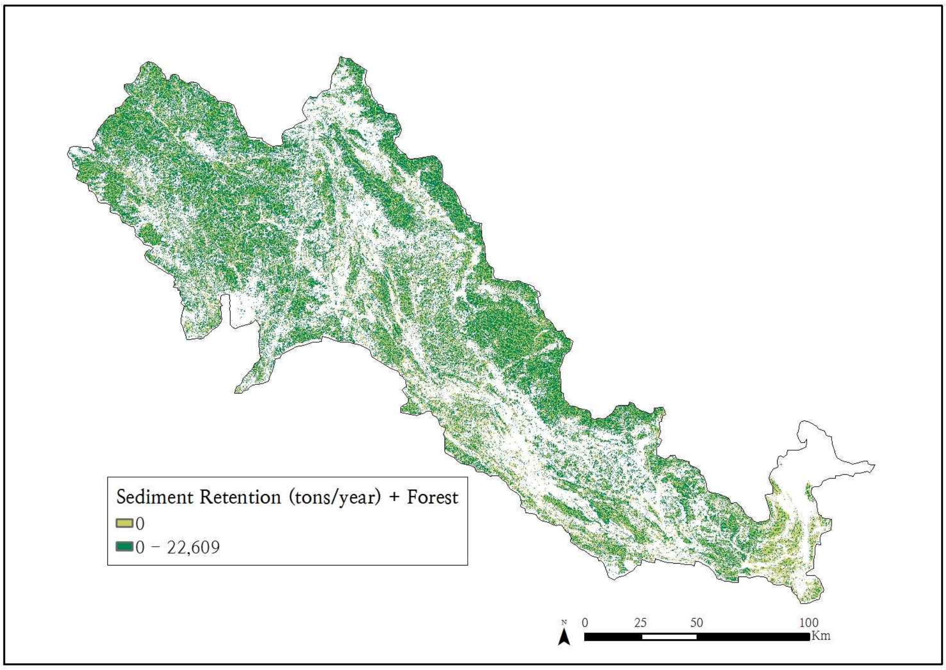

Figure 19 Sediment retention in forest cover in Da river basin

4. Forest Quality

The averaged MODIS EVI in 2012 showed a range from 0 to 0.5786. Spatially, there was a high EVI in southern Dien Bien province and in northern Son La province. Fansipan Mountain and the highlands in Son La province, however, showed low EVI values, even though these areas are known for their dense and primary forests.

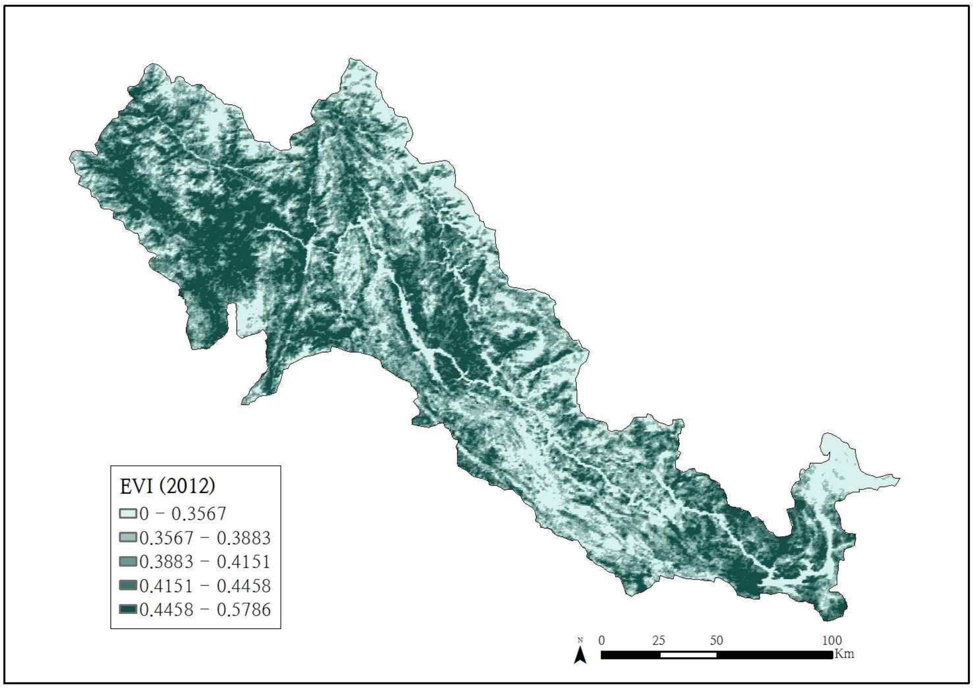

Figure 20 Averaged MODIS Enhanced Vegetation Index in 2012

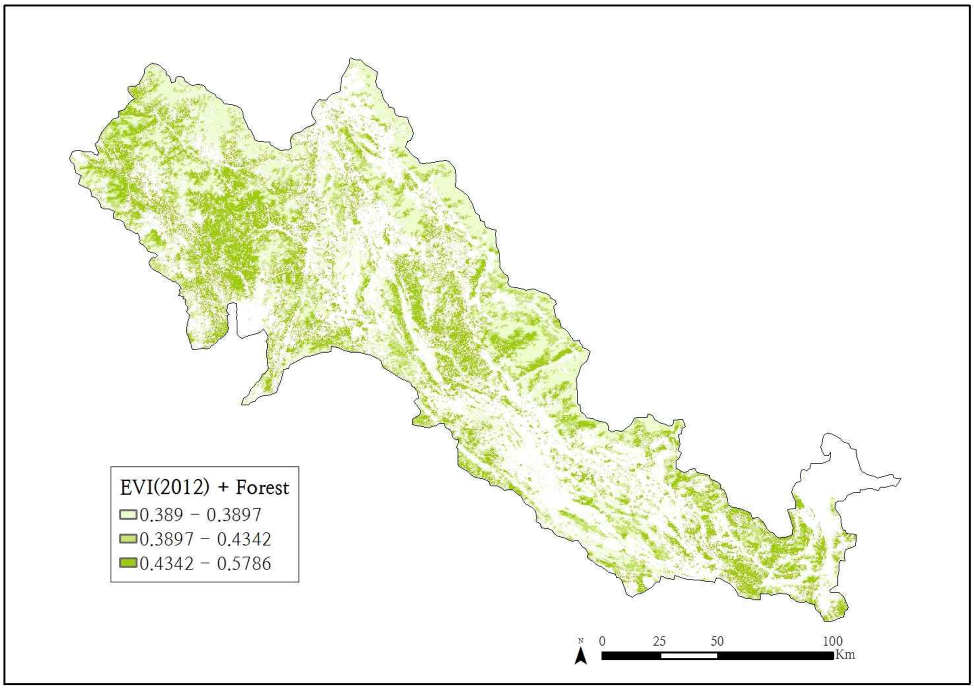

Figure 21 Vegetation quality index in forest cover in Da river basin

5. Priority Forest Suggestion to Support PFES Policy

Forest cover was extracted from the land cover classification result, to assess the hydrological ecosystem services and forest quality with EVI limited to forest area. Then EVI, water yield, and sediment retention were clipped by forest cover. EVI was classified into three types using Quantile classification, classifying the same number of pixels in each type. Water yield and sediment retention were classified into two types using quantile classification: low–high for water yield and no–existing for sediment retention.

First, the classified water yield and sediment retention were overlapped to verify the hydrological ecosystem service supply status. As a result, high water yield and high sediment retention regions were identified in southern Dien Bien province, all of Yen Bai province, Phu Tra Mountain, and Fansipan Mountain. On the contrary, northern Dien Bien province and Lai Chau province showed medium water yield and high sediment retention.

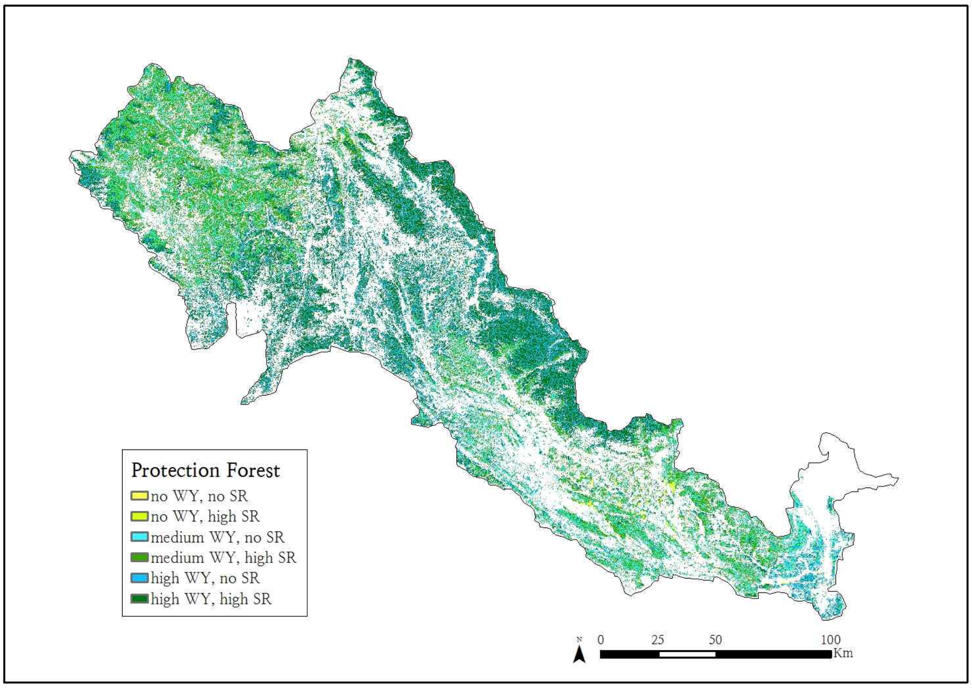

Figure 22 Suggested prior forest with hydrological ecosystem services assessment

When the quality index was applied, stratification within the forest cover was shown in the more detailed map. Phu Tra Mountain and Fansipan Mountain (red) showed high functions of hydrological ecosystem services, but their vegetation quality was low according to a low EVI. Yen Bai province, however, showed mixed vegetation quality with high hydrological ecosystem services. On the contrary, middle Dien Bien province (green) showed high to medium water yield and high sediment retention with high forest quality, resulting in a high probability of receiving the largest incentives for its functions and vegetation quality.

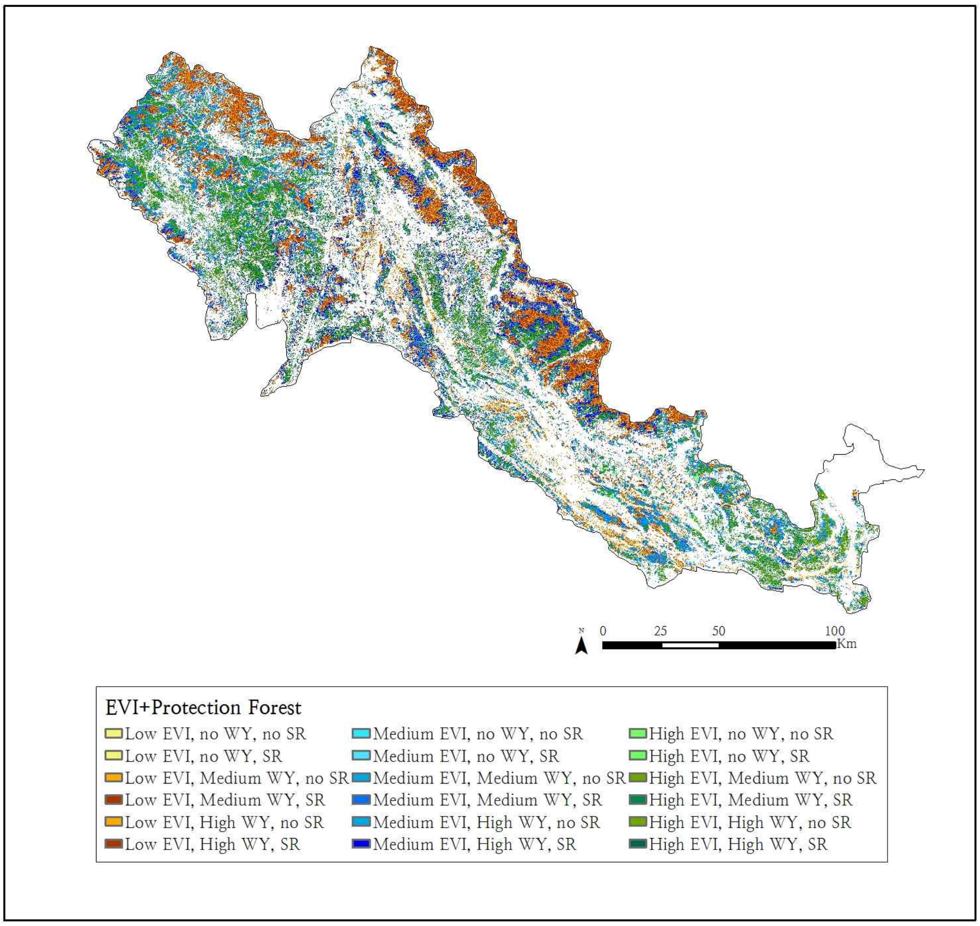

Figure 23 Prior forests to implement PFES policy considering both hydrological ecosystem services and vegetation index

With the spatial assessments of priority regions, policy makers can recognize conservation priority regions to guarantee efficient ecosystem services, and municipal officers can differentiate incentives by multiplying K-coefficients and determining who should be compensated for managing certain properties according to spatially explicit maps. For example, a forest that is both water-yielding and sediment-retaining is considered a protection forest, according to the Vietnamese forest usage categories. It has a K-coefficient of 1.0 , while medium water-yielding, sediment-retaining forests have a K-coefficient of less than 1.0. Similarly, forests with high vegetation quality can have a K-coefficient of 1.0 and those with lower vegetation quality would have a smaller

K1-coefficient. A high K-coefficient directly relates to the amount of incentive that the landowner can receive. Further, a large incentive can persuade the landowner to restrain destructive cultivation, such as slash-and-burn.

Table 20 An exapmle of K coefficient application

K-coefficient (MARD, 2011)		In this study	status		
			high		low
K1	forest status	EVI grades	rich (1.0)	medium (0.95)	poor (0.9)
K2	types of forests	hydrological services (water yield (WY), sediment retention (SR)	high at both WY, SR (1.0)	high at WY or SR (0.95)	medium to poor (0.9)

V. Conclusion

To support the hydrological ecosystem services of PFES policy in spatially explicit way, (1) land cover was classified using Landsat images to detect recent forests, (2) two hydrological ecosystem services - water yield and sediment retention - were analyzed with the land cover map and the basis of prevailed theories, and (3) the vegetation quality index was adopted to assess forest quality to support K-coefficient of PFES policy in Da River basin in northern Vietnam.

Despite its vague designation criteria, hydrological ecosystem service payment has been actively implemented in Vietnam. Especially in Da River basin, implementing PFES is more practical and feasible than any other region and one of the pilot program has progressed in 2010 in this area. This is because two of the largest dams and the largest hydroelectric power plant in Vietnam are located in Da River basin, and they are considered as main forest ecosystem services payers in PFES law. Furthermore, there has been a devolution of SFEs in northern Vietnam. Consequently, more than half of the northern lands have been distributed to individual landowners, in contrast to the central highland region, where SFEs still control the national forests. The well-distributed land to individual landowners in northwest Vietnam means that each landowner cares for his or her asset and the compensation from the payment for ecosystem services would be directly distributed to the landowners, rather than to a public authority, like SFE. Also northern Vietnam is known for its rich and primary forest but still it is threatened from slash-and-burn cultivation and unplanned logging. Forest ecosystem in northern Vietnam is important for its habitants and lowlands such as capital Hanoi in its water basin as well. Therefore implementing PFES policy in this region has been considered as a panacea to support forest conservation and alleviate poverty from incentives from ecosystem service users (payers).

However, there is no concrete basis for deciding where the compensation for high ecosystem services should go. Even the legal framework sets different incentive coefficients according to forest quality (K1) and forest ecosystem services (K2), the criteria for determining which region is set to a certain coefficient remains vague, due to a lack of exact threshold values and data. Even it is hard for local officers to detect the existence of real forests in an extensive approach.

This study was intended to suggest priority forests to support the current PFES policy in Vietnam. The results show that the forests with high water yield, sediment retention, and quality should be considered priority forests. These three factors were shown to support the K1 and K2 factors enacted as PFES law in Vietnam but there weren't any objective, quantitative ground to determine their states. In this study, those factors were assessed with scientific theories and supplementary data that can be applied and acquired easily. And they were classified into two to three classes by Quantile to stratify their grades according to their functions. Sincethelogicalbasisforthesecriteriadoesnotrequire complex theories or modeling procedures, the criteria could be applied to other regions and other developing countries as well.

However, there are several limitations to implementing those mehtods and data. First, this study limited its spatial boundary to Da River basin, where forest cover is more abundant than other regions. Therefore, classifying three grades of both ecosystem services and forest quality according to Quantile classification in Da River basin might lead to an underestimation of the good functions and quality of the forests in Da River basin, compared to the poor forests in other regions. To fix this problem, an exact threshold value that can classify good, medium, and poor states must be set. In addition, for the PFES policy to be implemented nationwide, a national assessment of the ecosystem services would be mandatory to further the management and compensation. Also the other important thing to be considered is that the results are highly dependent to input data. So the end-users should recognize their results and limitation of input data. Also the input data should be elaborated with conscious.

Despite its limitations, this study tried to suggest logical and scientific theories and a basis to support the current vague PFES policy. This was one primary assessment of Da River basin that addresses important issues and implementation possibilities in the whole Vietnamese territory.

To achieve its original PFES goal, it is necessary to build a logical, concrete background and basis to persuade ecosystem service payers that it is worth spending their money to support upland landowners. In addition, spatially explicit plans are necessary to support government officers in distributing benefits to individual landowners. Distribution of national land by long-term contract to small landowners and their responsibility on land have leaded the sustainable management of national properties than previous management system. However, intact forests are constantly threatened as the roads and trails keep developing and ethnic minorities scattered in remote mountains keep their living in unsustainable way. In this situation, implementing PFES policy is suitable to support their living and pursue forest conservation.

References

Bai, Y., Zheng, H., Ouyang, Z., Zhuang, C. & Jiang, B, 2013. Modeling hydrological ecosystem services and tradeoffs: a case study in Baiyangdian watershed, China. Environmental Earth Sciences, 70(2), pp.709–718.

Castella, J. & Verburg, P., 2007. Combination of process-oriented and pattern-oriented models of land-use change in a mountain area of Vietnam. Ecological Modelling.

Castelletti, A. & Pianosi, F., 2012. Assessing water reservoirs management and development in Northern Vietnam. Hydrology and Earth System Sciences, 16, pp.189–199.

Chan, K., Shaw, M. & Cameron, D., 2006. Conservation planning for ecosystem services. PLoS biology, 4(11), pp.2138–2152.

Chen, X., Vierling, L. & Deering, D., 2005. A simple and effective radiometric correction method to improve landscape change detection across sensors and across time. Remote Sensing of Environment, 98(1), pp.63–79.

Clement, F. & Amezaga, J.M., 2009. Afforestation and forestry land allocation in northern Vietnam: Analysing the gap between policy intentions and outcomes. Land Use Policy, 26(2), pp.458–470.

Cleugh, H.A., Leuning, R., Mu, Q., Running, S.W., 2007. Regional evaporation estimates from flux tower and MODIS satellite data. Remote Sensing of Environment 106 (3), 285–304.

Costanza, R. et al., 1997. The value of the world's ecosystem services and natural capital. Nature, 387(6630), pp.253–260.

Crossman, N. D., B. Burkhard, S. Nedkov, L. Willemen, K. Petz, I. Palomo, E. G. Drakou. 2013. A blueprint for mapping and modelling ecosystem services. Ecosystem Services, 4, pp.4–14.

Daily, G.C. 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, D.C

De Groot, R.S., 2006. Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. Landscape Urban Plann. 75, 175–186.

Donohue, R., 2007. On the importance of including vegetation dynamics in Budyko's hydrological model. Hydrology and Earth System Sciences, 11,

pp.983–995.
Dung, N. Van, Vien, T. & Lam, N., 2008. Analysis of the sustainability within the composite swidden agroecosystem in northern Vietnam. Agriculture, Ecosystems and Environment, 128, pp.37–51.
Egoh, B. et al., 2007. Integrating ecosystem services into conservation assessments: A review. Ecological Economics, 63(4), pp.714–721.
Ellison, D., Futter, M. & Bishop, K., 2012. On the forest cover–water yield debate: from demand-to supply-side thinking. Global Change Biology, 18, pp.806–820.
Fisher, B., Turner, R.K. & Morling, P., 2008. Defining and classifying ecosystem services for decision making. Ecological Economics, 68(3), pp.643–653.
Foody, G.M., D.S. Boyd, and M.E.J. Cutler, 2003. Predictive relations of tropical forest biomass from Landsat TM data and their transferability between regions, Remote Sensing of Environment, 85:463–474.
Forest Science Institute of Vietnam (FSIV). 2009. Vietnam Forestry Outlook Study, Food and Agriculture Organization of the United States Regional Office for Asia and the Pacific
Gong, P., Wang, J., Yu, L., Zhao, Y., Zhao, Y., Liang, L., Niu, Z., Huang, X., Fu, H., Liu, S., Li, C., Li, X., Fu, W., Liu, C., Xu, Y., Wang, X., Cheng, Q., Hu, L., Yao, W., Zhang, H., Zhu, P., Zhao, Z., Zhang, H., Zheng, Y., Ji, L., Zhang, Y., Chen, H., Yan, A., Guo, J., Yu, L., Wang, L., Liu, X., Shi, T., Zhu, M., Chen, Y., Yang, G., Tang, P., Xu, B., Ciri, C., Clinton, N., Zhu, Z., Chen, J., Chen, J. 2013. Finer resolution observation and monitoring of global land cover: first mapping results with Landsat TM and ETM+ data, International Journal of Remote Sensing. vol.34, n.7, pp.2607−2654.
Hadjimitsis, D. & Papadavid, G., 2010. Atmospheric correction for satellite remotely sensed data intended for agricultural applications: impact on vegetation indices. Natural hazards and earth system sciences, 10, pp.89–95.
Hoang, M., Do, T. & Pham, M., 2013. Benefit distribution across scales to reduce emissions from deforestation and forest degradation (REDD+) in Vietnam. Land Use Policy, 31, pp.48–60.
Huete, A., Didan, K., Miura, T., Rodreguez, E., Gao, X., & Ferreira, L. 2002.

Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sensing of Environment, 83(1-2), pp.195–213. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0034425702000962.

Jong, W. De, Sam, D. & Hung, T., 2006. Forest rehabilitation in Vietnam. Histories, realities and future. CIFOR, Bogor.

Khoi, D. & Suetsugi, T., 2012. The responses of hydrological processes and sediment yield to land-use and climate change in the Be River Catchment, Vietnam. Hydrological Processes.

Kolinjivadi, V. & Sunderland, T., 2012. A Review of Two Payment Schemes for Watershed Services from China and Vietnam: the Interface of Government Control and PES Theory. Ecology and Society, 17(4).

Le, T. & Seidler, C., 2012. Proposed methods for potential evapotranspiration calculation of the Red River basin (North Vietnam). Hydrological …, 26(18), pp.2782–2790.

Le, T. et al., 2010. Nutrient (N, P, Si) transfers in the subtropical Red River system (China and Vietnam): modelling and budget of nutrient sources and sinks. Journal of Asian Earth Sciences, 37, pp.259–274.

Le, T.P.Q. et al., 2007. The changing flow regime and sediment load of the Red River, Viet Nam. Journal of Hydrology, 334(1-2), pp.199–214.

Lee, J. & Heo, J., 2011. Evaluation of estimation methods for rainfall erosivity based on annual precipitation in Korea. Journal of Hydrology, 409, pp.30–48.

Leh, M. & Matlock, M., 2013. Quantifying and mapping multiple ecosystem services change in West Africa. Agriculture, Ecosystems & …, 165, pp.6–18.

McElwee, P., 2009. Reforesting "bare hills" in Vietnam: social and environmental consequences of the 5 million hectare reforestation program. Ambio, 38(6), pp.325–33.

Meyfroidt, P. & Lambin, E.F., 2008. Forest transition in Vietnam and its environmental impacts. Global Change Biology, 14(6), pp.1319–1336.

Meyfroidt, P. & Lambin, E.F., 2008. The causes of the reforestation in Vietnam. Land Use Policy, 25(2), pp.182–197.

Meyfroidt, P. & Lambin, E.F., 2009. Forest transition in Vietnam and displacement of deforestation abroad. Proceedings of the National Academy of Sciences of the United States of America, 106(38), pp.16139–44.

Mikhailov, V. & Isupova, M., 2012. Sediment regime and morphological processes in the Hong Ha (Red River) mouth area. Water Resources and the regime of water bodies, 39(5), pp.497–513.

Mu, Q. et al., 2007. Development of a global evapotranspiration algorithm based on MODIS and global meteorology data. Remote Sensing of Environment, 111(4), pp.519–536.

Mu, Q., Zhao, M. & Running, S.W., 2011. Improvements to a MODIS global terrestrial evapotranspiration algorithm. Remote Sensing of Environment, 115(8), pp.1781–1800.

Nguyen, T., Pham, V. & Tenhunen, J., 2013. Linking regional land use and payments for forest hydrological services: A case study of Hoa Binh Reservoir in Vietnam. Land Use Policy, 48(2), pp.219–242.

Oo, A.Z. et al., 2013. Toposequential variation in soil properties and crop yield from double-cropping paddy rice in Northwest Vietnam. , 4(August), pp.65–75.

Phuong, V.T. 2007. Forest environment of Vietnam : Features of forest vegetation and soils. Forest Environments in the Mekong River Basin. 189–200

Polasky, S. et al., 2010. The Impact of Land-Use Change on Ecosystem Services, Biodiversity and Returns to Landowners: A Case Study in the State of Minnesota. Environmental and Resource Economics, 48(2), pp.219–242.

Ranzi, R., Le, T. & Rulli, M., 2012. A RUSLE approach to model suspended sediment load in the Lo river (Vietnam): Effects of reservoirs and land use changes. Journal of Hydrology, 422–423, pp.17–29.

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., Yoder, D.C., 1997. Predicting Soil Erosion by Water — A Guide to Conservation Planning With the REVISED Universal Soil Loss Equation (RUSLE). United States Department of Agriculture, Agricultural Research Service (USDA-ARS) Hand book No. 703. United States Government Printing Office, Washington, D. C.,USA.

Schmitter, P. H.L. Frohlich, G. Dercon, T.Hilger, N. Huu. Thanh, N.T. Lam, T.D. Vietn and G. Cadisch, 2012. Redistribution of carbon and nitrogen through irrigation in intensively cultivated tropical mountainous watersheds. Biogeochemistry, 109(1–3), pp.133–150.

Schmitter, P., Dercon, G. & Hilger, T., 2010. Sediment induced soil spatial variation in paddy fields of Northwest Vietnam. Geoderma, 155, pp.298-307.

Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Sharp, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., and Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M. 2013. InVEST 2.5.6 User's Guide. The Natural Capital Project, Stanford.

TEEB (The Economics of Ecosystems and Biodiversity). 2010. TEEB for Policy Makers - Summary

The Millenium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: General Synthesis (http://www.maweb.org/en/)

To, Phuc Xuan, Wolfram H Dressler, Sango Mahanty, Thu Thuy Pham, and Claudia Zingerli. 2012. The prospects for payment for ecosystem services (PES) in Vietnam: a look at three payment schemes. Human Ecology: An Interdisciplinary Journal 40 (2) (April): 237-249. doi:10.1007/s10745-012-9480-9.

UNEP. 2009. Vital Forest Graphics.

Vezina, K, F Bonn, and CP Van. 2006. Agricultural land-use patterns and soil erosion vulnerability of watershed units in Vietnam's northern highlands. Landscape Ecology 21. 1311-1325

Wang, K. and Dickinson, R.E. 2012. A review of global terrestrial evapotranspiration: Observation, modeling, climatology, and climatic variability. Reviews of Geophysics 50

Wezel A, Steinmüller N, Friederishen JR. 2002. Slope position effects on soil fertility and crop productivity and implications for soil conservation in upland Northwest Vietnam. Agric. Ecosys. Environ. 91:113-126.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agriculture Handbook No. 537. USDA/Science and Education Administration, US. Govt. Printing Office, Washington, DC. 58pp.

Young K. B., E. J. Wailes, G. L. Cramer and T. K. Nguyen. 2002. Vietnam's rice economy: Developments and Prospects. Arkansas Agricultural

Experiment Station

Yu, L., Wang, J., Clinton, N., Xin, Q., Zhong, L., Chen, Y., Gong, P. 2013b. FROM-GC: 30 m global cropland extent derived through multisource data integration, International Journal of Digital Earth.

Yu, L., Wang, J., Gong, P. 2013a. Improving 30 meter global land cover map FROM-GLC with time series MODIS and auxiliary datasets: a segmentation based approach, International Journal of Remote Sensing. vol.34,n.16, pp.5851-5867.

Zhang, L., Dawes, W. & Walker, G., 2001. Response of mean annual evapotranspiration to vegetation changes at catchment scale. Water resources research, 37(3), pp.701-708.

〈Textbook〉
Jensen, J. R. 2005. Introductory digital image processing: A remote Sensing Perspective, 3rd edition
Thanh Ha, D., T. Dinh Thao, N. Tri Khiem, M. Xuan Trieu, R. V. Gerpacio and P.L. Pingali. 2004. Maize in Vietnam: Production Systems, Constraints and Research Priorities. Mexico, D.E: CIMMYT
Statistical Yearbook of Vietnam 2012
J .A. Richards, 1999, Remote Sensing Digital Image Analysis, Springer-Verlag, Berlin
USGS 2012 Landsat Data Continuity Mission (LDCM) Level 1 Data Format Control Book (DFCB) ver6.0

〈Legal frame〉
Decision 380 Payment for Forest Ecosystem Services published in 2008
Decree on the Policy for Payment for Forest Environmental Services, Socialist Republic of Vietnam(No. 99/2010/ND-CP), Ha Noi, Septemver 24, 2010.
Law on Protection and Development of Forest (Decision 186/2006/QD-TTg) in 2004
Forest Protection and Development Law (1991, 2004),
Environmental Protection Law (2004)
Ministry of Agriculture and Rural Development. 2007. Vietnam forestry development strategy for the period of 2006-2020.
Ministry of Agriculture and Rural Development. 2011. Draft 5 of the Circulation guiding K-facfor for PFES

〈Websites〉
http://support.esri.com/en/knowledgebase/GISDictionary/term/orthorectification
http://www.fao.org/docrep/004/ad466e/ad466e0a.htm
http://landsat.usgs.gov/
http://glovis.usgs.gov
http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/
Landsat 7 Science Data Users Handbook (http://landsathandbook.gsfc.nasa.gov/)

국문초록

북부 베트남 DA 강 유역의 수문 생태계 서비스 평가

공 인 혜
조경·지역시스템공학부 생태조경학 전공
지도교수 이 동 근

생태계는 직간접적으로 인간에게 서비스를 제공한다. 하지만 기존에 무상으로 이용하던 생태계 서비스에 대해, 최근에야 그 가치를 정량화하고 보전할 수 있도록 정책에 반영하려는 연구가 진행되고 있다. 특히 생태계서비스를 정책적으로 활용하는 것은, 생태계 보전과 빈곤 경감을 동시에 달성할 수 있는 것으로 알려져 있어 저개발 국가에서 적극적으로 도입되고 있다. 그 중 베트남은 2년간 두 지방에서의 파일럿테스트를 거쳐 동남아시아에서 유일하게 생태계서비스 평가를 통한 인센티브 지급을 규정하는 정책과 법(Payment for Forest Ecosystem Services, PFES)을 제정하였으며, 이 정책을 국가전체로 확대 시행하는 법을 제정한 상태이다.

그러나 베트남에서는 PFES 정책을 적용할 때, 산림질, 산림기능 등에 따라 차등적으로 인센티브를 부과하도록 법적으로 K-coefficient를 설정하고 있으나, 이를 평가하기 위한 적절한 근거 및 데이터베이스가 부족하여 일괄적으로 1.0을 적용하고 있어, 실제로 산림질이 좋고, 높은 생태계 서비스를 제공하고 있는 지역에 대해 저평가되고 있으며, 이에 대한 구체적인 공간적 평가가 체계적으로 이루어지지 않고 있다.

베트남 북부에 위치하는 Da 강 유역은 수도 하노이에 주요한 수문학적 생태계 서비스를 제공하는 주요한 지역이자, 베트남에서 가장 큰 두

수력발전소 및 댐이 위치하고 있는 중요한 지역이다. 그러나 동시에 화전 등 지속불가능한 농업방식으로 살아가는 소수민족의 인구비율이 높고 베트남 전역에서 가장 빈곤률이 높아 PFES 정책으로 인한 인센티브가 생태계 보전과 빈곤경감에 기여할 수 있는 가능성이 높다.

따라서 본 논문은 Da 강 유역을 중심으로, 베트남에서 특히 발달한 수문학적 생태계 서비스인 수원제공 및 토사유실방지 기능을 체계적인 근거를 바탕으로 평가하고자 하며, 추가적으로, PFES 정책에서 반영되지 못했던 산림질 항목을 도입하여 인센티브 차등지급을 위한 근거를 설정하고 기능과 질이 높은 지역을 구별하여 PFES 정책 설정의 우선순위를 제안하고자 한다.

우선 최신의 토지피복 현황 파악을 위해, 30m 해상도의 Landsat 영상을 이용하여 2009~2013년 사이의 Dry season, Wet season을 구분하여 토지피복분류를 실시하였으며, 생태계서비스평가 연구에서 주로 이용하는 이론 리뷰를 통해, Water balance 이론 및 USLE 식을 선정하여 연간 수원 제공량 및 토사 유실 방지량을 계산하였다. 산림질 평가를 위해서는 2012년의 MODIS EVI 연평균값을 선정하였다.

토지피복 분류 결과 산림은 전체 유역의 52%로서, 타 자료에 비해 낮게 나타났으나 Dry, Wet season을 동시에 고려하였고, 높은 해상도로 인한 결과라고 사료된다. 연평균 강수량은 1301~2384mm였으며 실제증발산량은 5~1671mm로 나타났다. 이 차이로 인한 연평균 수원 제공량은 2.5~1472mm로 나타났으며, Yen Bai province, 남부 Dien Bien province에서 높은 수원제공기능을 확인하였다. 잠재 토사 유실량은 0~8874tons/cell로 나타났으며, 토사유실방지량은 0~25,323tons/cell로 확인되었으며, 이는 산림이 집중적으로 분포한 높은 산악지대보다는 경작활동이 이루어지고 있는 중저지대 산림에서 높은 것으로 나타났다. 2012년 평균 MODIS EVI는 0.0308~0.5786으로 나타났으며 높은 산악지대보다는 Dien Bien province, Da 강의 중부유역, Hoa Binh province 등의 산지에서 높게 나타났다.

이후 Da 강 유역 내 산림지역만을 대상으로 위 데이터들을 추출하여 Quantile로 배열하였고, 이를 중첩한 결과, 그 결과 Yen Bai province에서는 다양한 산림질을 가진 높은 수문생태서비스가 확인되었고, Fan xi pan 산, Phu Tra 산을 중심으로는 낮은 산림질의 높은 수문생태서비스,

Dien Bien province에서는 높은 산림질과 중간정도의 수문생태계서비스가 확인되었다. 이를 바탕으로 수문학적 생태계 서비스 및 산림질을 고려한 지역 선정을 위한 근거 마련을 제안하고자 하며, K-coefficient 지원을 통해 인센티브 상향조정 및 PFES 우선설정지역을 제안하고자 하였다.

하지만 Quantile로 상중하 등급을 매기는 방법은 연구지역 설정에 따라 상대적으로 적용될 수 있다는 점을 확인할 수 있었다. 따라서 K-coefficient의 타당한 등급설정을 위해서는 전 국가적인 분석을 통해 임계단위를 설정하여 지역적인 상대성을 최소화할 필요가 있다. 또한 본 연구의 결과는 저개발국가에서의 응용성을 중시하여 방법을 단순화한데 따라, 입력 자료가 결과에 크게 영향을 미칠 수 있어 입력 자료의 타당성과 정확성이 크게 요구된다는 점을 확인할 수 있었다.

PFES의 국가적 적용은 베트남 내에서 생태계 보전 및 빈곤 경감을 동시에 추구할 수 있을 것으로 기대하고 있지만, 이의 실질적인 적용을 위해서는 이론 및 적용방법을 구체화해야 하는 부분이 여전히 남아 있다. 본 연구는, PFES의 적용을 위한 중요한 배경이자, 베트남의 산림자원을 적절히 관리하기 위해 중요하게 여겨지는 K-coefficient를 실현할 수 있는 수단을 보완하기 위한 제안으로서 의의를 가지며, 이를 통해 베트남의 생태계서비스 평가를 통한 지불제의 성공적인 적용에 기여하고자 하였다.

주요어 : payment for ecosystem service, Landsat, Land cover classification, water yield, sediment retention, Da river
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