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수문학적 생태계 서비스를 고려한 북부베트남의 우선보전산림 설정

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Establishment of Priority Forest Areas Based on Hydrological Ecosystem Services in Northern Vietnam

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국문초록

최근 생태계 서비스의 가치를 정량화하고, 경제적 보상을 통해 보전할 수 있도록 하는 생태계 서비스 직불제 (Payment for Ecosystem Services, PES)에 대한 연구가 활발히 진행되고 있다. PES를 정책에 반영시키는 것은 생태계 보전과 빈곤경감을 동시에 달성할 수 있는 방안으로 여겨지면서, 주로 개발도상국에서 적극적으로 도입하고 있다. 그 중, 베트남은 선구적으로 PES를 범국가적인 법 제정을 통해 시행하고 있으나, 공간적 정량화를 통한 광범위한 생태계 서비스 평가는 부족한 실정이다.

본 연구에서는 북부 베트남에서 수도 하노이를 흐르는 홍강(Red River)의 상류인 Da 강 유역을 중심으로 수문학적 생태계 서비스를 평가를 통해 우선보전산림을 설정하고자 하였다. 우선 평가를 위해 기본적인 최신의 토지피복지도를 구축하고자 Landsat영상을 통해 토지피복분류를 수행하였다. 그리고 이 지역의 수자원공급 및 토사 유실량 방지의 수문학적 생태계서비스를 평가하기 위해 물수지이론 및 USLE 공식을 도입하였으며, 이를 통해 도출된 서비스량을 산림지역에 한정하여 서비스공급 우위지역을 도출함으로써 우선보전 산림지역으로 설정하도록 제안하고자 하였다.

그 결과, 산림지역 내에서도 지형, 기후, 토지피복에 따라 생태계서비스공급량의 범위가 달라짐을

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확인하였으며, 수문학적 생태계 서비스 공급우위지역은 푸롱산(Mt. Phu Luong), 판시판산(Mt.Fanxipan), 호앙리엔 국립공원(Hoang Lien National Park) 등으로 나타났다. 이 연구의 결과는 Da 강 유역에서 생태계 서비스 보전을 위한 우선 지역을 확인하는 것뿐만 아니라, 어느 지역의 토지소유주가 더 보상받아야 하는지를 판별하는데 이용함으로써 보상공유(Benefit Sharing) 달성에 기여할 수 있을 것이다.

ABSTRACT

Ecosystem services provide various benefits to human beings, but are considered to be free of cost. To protect ecosystems in an economically sustainable way, several developing countries have adopted a policy known as the Payment for Ecosystem Services (PES) that compensates upstream services with monetary incentives collected from service users. Vietnam is one of the countries that have enacted a nationwide PES policy. However, the policy in Vietnam requires further development in order to evaluate the spatial priority zones based on the quantification of ecosystem services.

To obtain a recent and high-quality land cover map, we first classified the land cover in the Da River basin, in northern Vietnam, using Landsat dataset. We then applied a water balance theory and an USLE equation to assess hydrological ecosystem services concerning water supply and sediment retention. Following the assessment, we identified the priority areas for hydrological ecosystem services exclusively for forest environments.

We found that the quantity and distribution of services from forests varied, due to the topography, climate, and land cover. According to a quantile distribution, Mt. Phu Luong, Mt. Fansipan, and Hoang Lien National Park were evaluated as high service areas in terms of both water yield and sediment retention.

As a result, this assessment method can help construct spatial priority zones concerning ecosystem service distribution, and can also contribute to benefit sharing by indicating which forest and landowners require compensation.

Key Words : *Payment for ecosystem service, priority region, water supply, sediment retention, PFES.*

I. Introduction

Ecosystems provide various benefits to human beings such as providing and regulating air, water, natural resources, and habitat for wildlife and those benefits are called as ecosystem services (Daily, 1997). Given the increasing awareness of ecosystem services and their actual benefits, many previous studies have emphasized the importance of preserving ecosystems to sustain the well-being of humans, as well as natural environments (MA, 2005). However, many developing countries have experienced difficulties with ecosystem preservation, due to increasing demands from economic development, and a lack of funding allocated towards ecosystem protection (Porras et al., 2008;

McElwee, 2012).

When the Payment for Ecosystem Services (PES) policy was proposed, it was considered to be a win-win policy to meet the goal of ecosystem conservation, and to support the opportunity costs of economic development (McElwee, 2012). The framework of the PES policy is to provide incentives to landowners for conserving their ecosystems and ecosystem services by collecting a fee from the service users. This policy has been intensively implemented in developing countries over the last decade (Porras et al., 2008).

Therefore evaluating current ecosystem services and their sources in a quantified manner is of increasing importance for policy makers and stakeholders. Such an evaluation can help prioritize the regional management of natural resources with limited financial resources and to develop circumstances under which the exchange or compensation of ecosystem services at a market can be monetarily achieved (Chan et al., 2006; Egoh et al., 2007; Fisher et al., 2008).

Vietnam is a pioneering Asian country that adopted the PES policy in early 2000, after suffering severe forest loss and degradation (Meyfroidt and Lambin, 2008). Currently, Vietnam is the only country that enacts their own policy known as the Payment for Forest Environmental Services (PFES), on a national scale since 2010 (McElwee, 2012).

However, ecosystem service quantification has not yet been thoroughly assessed and the grounds for PFES site designation is unreliable. The lack of systematic grounds for assessing and valuing ecosystem services makes it difficult to persuade ecosystem service payers. In addition the collected money is not distributed properly due to a lack of information regarding the policy of compensation for providing ecosystem services (To et al., 2012).

In this study, we focused on two hydrological ecosystem services, water supply and sediment retention, which are especially important in mountainous northern Vietnam due to the steep topography, high precipitation, and inappropriate land use in that region. Also, these hydrological ecosystem services are included in the PFES law that was published in 2010, with regard to watershed protection services with soil protection, reduction of erosion and sedimentation, and the regulation and maintenance of water sources (McElwee, 2012). Supplying water resource is one of the most important ecosystem services, supporting millions of living organisms, and people who retrieve water from river basin flow. Therefore, river basin ecosystems are important in their role as water quantity and quality regulators. In particular, forests are known to reduce water flow fluctuation and improve water quality by reducing suspended solid (sediment) concentrations through physical and chemical removal from soil and vegetation.

In this study, we evaluated priority forest areas by assessing the two ecosystem services in a quantitatively and spatially explicit way to support the current PFES scheme in Vietnam.

II. Study site

Northern Vietnam is located in a subtropical, humid, monsoon climate region. It exhibits distinct seasonal differences between dry and wet seasons and more than 80% of the total annual precipitation falls during the wet season from May to October (Castelletti et al., 2012).

Soils show a high erosion rate and soil organic

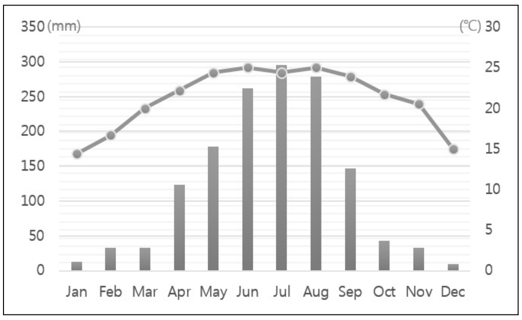

Figure 1. Rainfall and temperature in Son La province, northern Vietnam(worldweatheronline.com).

matter quantities are generally poor (FAO, 2012). People residing in this region live under poor conditions and many ethnic minorities continue to practice slash-and-burn cultivation on hilly areas. This agricultural method involves the burning of forests for cultivation, leading to the degradation of vegetation, soil, and nutrients (Wezel et al., 2002; Vezina et al., 2006). As a consequence of forest degradation, many people living on-site and in the lowlands including the capital Hanoi, have suffered due to sediment accumulation and landslides during the wet season and severe droughts during the dry seasons (Le et al., 2007; Castelletti et al., 2012).

The Da River basin (area: 27,300 km^2) is located in the northwest region of Vietnam within the Red River and shows a complex relief from the lowland delta to 3,000m altitude in the Hoang Lien Son Mountains, which is the highest region of Vietnam (Figure 2). Of the three main Red River tributaries, the Da River contributes more than 40% of the water discharge (Castelletti et al., 2012). Therefore, the Da River is utilized for the development of hydroelectric plants, and is currently host to the two largest multi-purpose dams in Vietnam (Nguyen et al., 2013).

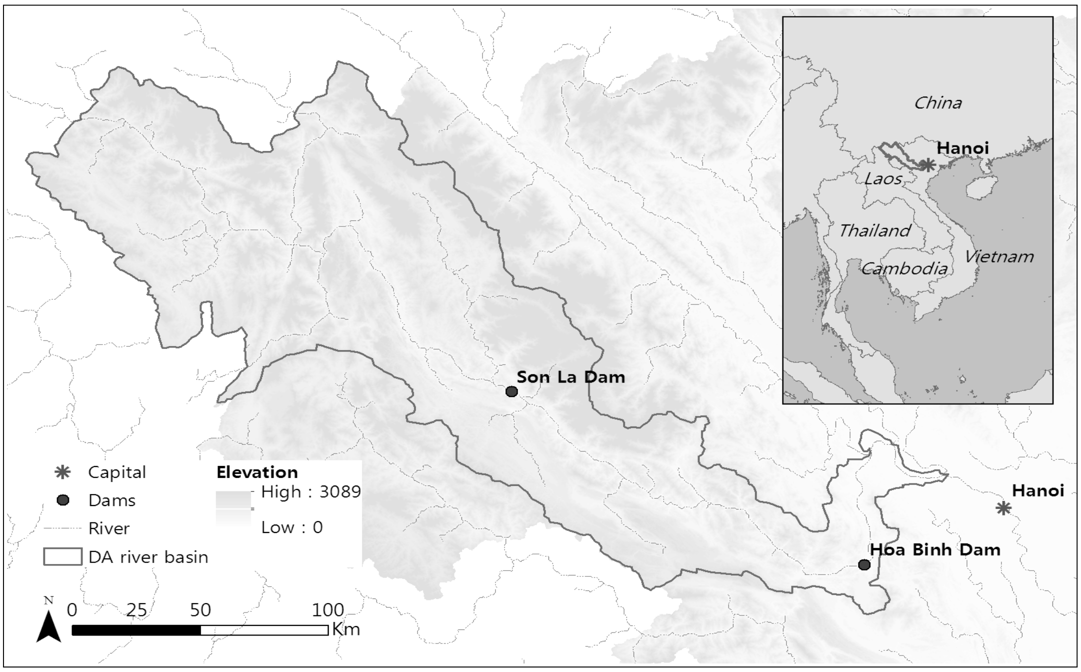

Figure 2. Da river basin. Located in the mountainous northwestern in Vietnam, it has complex topographic relief, varied climate regions, and two major multi-purpose dams for capital Hanoi.

Ⅲ. Method

To evaluate hydrological ecosystem services and propose a priority region in the Da River basin, we first developed a land cover map. To retrieve a recent and high quality map, we classified the land cover using Landsat dataset. Within the study site, there were six Landsat frames, at Path Rows 127/45, 127/46, 128/44, 128/45, 129/44, and 129/45 according to World Reference System 2 (WRS2). The images were limited to the L1T type, which is published and preprocessed with radiometric and geometric correction, and the data was downloaded from the USGS Glovis website (glovis.usgs.gov). All satellite images were re-projected to WGS1984 UTM zone 48N and missing data stripes in ETM+ images were filled with a triangular de-stripe function in ENVI 4.5. To maximize the phenologic differences in the most prevalent land cover types, evergreen forests and croplands (Yu et al., 2013; GlobCover 2009), the driest month and the most humid month were collected under conditions of lesser cloud cover.

According to the supervised classification used in ENVI 4.5, the land cover was classified with consideration of both dry and wet seasons. Land cover classes were referenced from GlobCover 2009 (Arino et al., 2012), and the classification difference between forest and shrub was omitted due to the technical limitations of spectral classification and the dissimilar definitions of forests and shrubs (Yu et al., 2013). An accuracy assessment was conducted after FROM-GLG-seg, which was developed on a multi-source dataset that included Landsat TM/ETM+, MODIS, and DEM on a global scale (Yu et al., 2013).

Secondly, the estimation of ecosystem services was conducted using a water balance theory to estimate water supply quantities, and a Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) for sediment retention. In the developed water balance theory, the water supply service can be estimated by subtracting evapotranspiration

Table 1. Acquired Landsat images in the study.

Location	Date (DOY)	Season	Landsat Sensor	Qlty	Cloud cover	Data type
P129 R44	2013.4.20 (110)	dry	Landsat 8 (OLI_TIRS)	9	1%	L1T
	2009.11.3 (307)	wet	Landsat 5 (TM)	7	0%	L1T
P129 R45	2013.4.20 (110)	dry	Landsat 8 (OLI_TIRS)	9	19%	L1T
	2009.11.3 (307)	wet	Landsat 5 (TM)	7	0%	L1T
P128 R44	2013.3.20 (79)	dry	Landsat (ETM+)	9	18%	L1T
	2010.10.22 (295)	wet	Landsat 7 (ETM+)	9	0%	L1T
P128 R45	2010.2.8 (39)	dry	Landsat 7 (ETM+)	9	18%	L1T
	2010.10.22 (295)	wet	Landsat 7 (ETM+)	9	0%	L1T
P127 R45	2009.2.14 (45)	dry	Landsat 7 (ETM+)	9	34%	L1T
	2013.10.7 (280)	wet	Landsat 7 (ETM+)	9	0%	L1T
P127 R46	2009.2.14 (45)	dry	Landsat 7 (ETM+)	9	3%	L1T
	2013.10.7 (280)	wet	Landsat 7 (ETM+)	9	0%	L1T

from precipitation. To eliminate yearly fluctuations in rainfall, long-term precipitation data was considered with WorldClim (Hijmans et al., 2005), at an average of 50 years (1950-2000) with a resolution of about 900 m. Actual evapotranspiration was collected from MODIS16 ET, which has the most reliable evapotranspiration algorithm in grids of about 900 m (Mu et al., 2011). However, since MODIS16 ET data are only available from the years of 2000 to 2012, the 13 years of evapotranspiration were averaged to minimize fluctuations.

To estimate sediment retention, a module from InVEST (Tallis et al., 2013) was adopted that combines the USLE and retention efficiency. The USLE expresses potential soil erosion by multiplying the variables R(rainfall erosivity), K(soil erodibility), LS(topographic factor), C(land cover and management factor), and P(support practice factor) (Wischmeier and Smith, 1978). To estimate R (rainfall erosivity), the El-Swaify equation was adopted, as it is an appropriate estimator of rainfall erosivity in subtropical climate regions (Lee and Heo, 2011). The El-Swaify equation is expressed by the following formula:

$$R = 38.5 + 0.35P$$

where P is the annual mean precipitation.

K (soil erodibility) from the equation developed by Wischmeier and Smith (1978) is obtained from the following formula:

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

where m is soil characteristics, presented as (silt + sand) × (100 − clay); a is soil organic matter percentage, derived from the van Bemmelen factor (=1.724 × SOC), whereby SOC (soil organic carbon) is obtained from the World Harmonized Soil Database; b is soil structure; and c is profile permeability. The variables b and c were considered as default values, due to the lack of information in this region.

There are many equations for calculating LS in the USLE, and the equation used by Huang and Lu (1993) is considered appropriate for steep slopes (Tallis et al., 2013):

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

where λ is the flow direction value and *prct_slope* is the percent slope calculated from Digital Elevation Model (DEM).

C and P values were adopted from Ranzi et al. (2012) and Yang et al. (2003), which suggest values for each land cover type in Vietnam, and on a global scope, respectively. The sediment retention efficiency was adopted from Leh et al. (2013).

Finally, the hydrological ecosystem services were divided with a quantile classification that distributes same number of values into each class. The results were then overlapped exclusively for forest/shrub land cover.

IV. Result and Discussion

The land cover was classified into seven classes: evergreen forest/shrub, deciduous forest/shrub, grassland, cropland, bare land, built-up area, and water bodies (Figure 3). In this study, the land cover classification revealed some features in a finer resolution, such as the detection of small water bodies or newly developed croplands, and bare soils, which were previously classified as forests in GlobCover 2009 and Yu et al. (2013). Also north areas of the basin, where

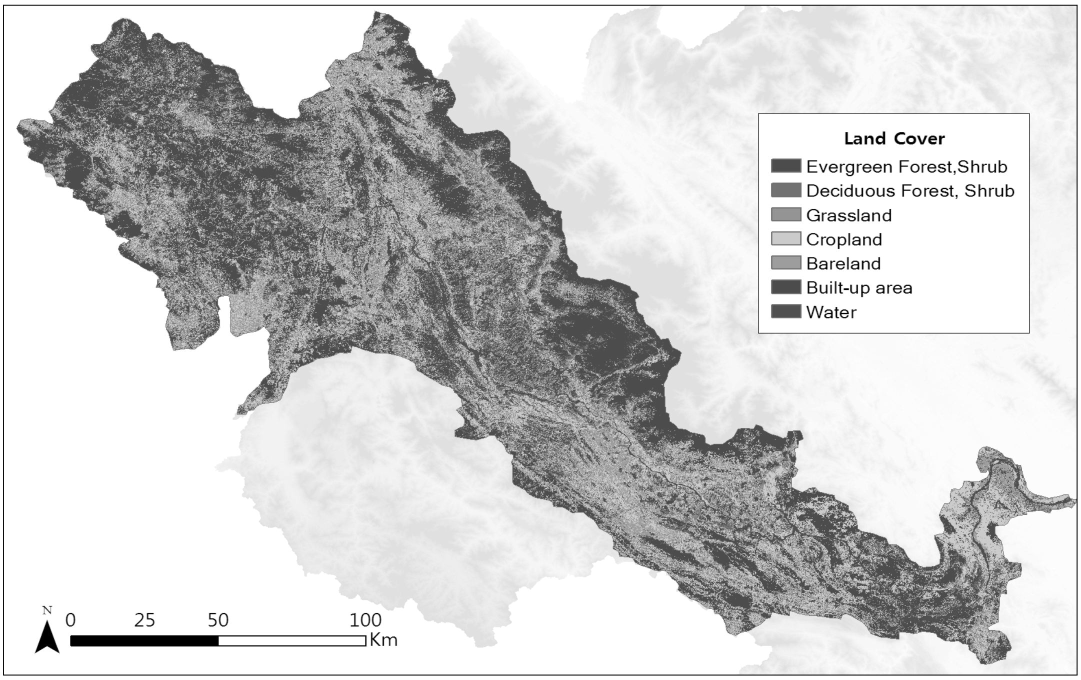

Figure 3. Land cover classification in Da river basin.

Table 2. Land cover composition in Da river basin.

Land cover classification			
#	Class	Area (km^2)	Area (%)
1	Evergreen Forest/shrub	10762.5	39.4
2	Deciduous Forest/shrub	3457.4	12.7
3	Grasslands	3670.1	13.4
4	Croplands	6259.7	22.9
5	Barelands	2378.7	8.7
6	Built-up areas	207.7	0.8
7	Water bodies	593.2	2.2
Total		27329.1	100.00

share borders with Lao PDR, showed poorer forest cover than previously known land covers.

The overall accuracy of the land cover map was 54.6%, showing that most of the errors were captured between forests in the reference map and other classes in this study. As a large number of pixels were overestimated as forests in the FROM-GLC-seg map, we can assume to be a result of limited Landsat data that only covered wet seasons (Yu et al., 2013; Appendix 1). For the forest/shrub class, the producer's accuracy was 58.6%, and the user's accuracy was 95.0% (Appendix 2), proving that the forest/shrub classes in this study are reliably

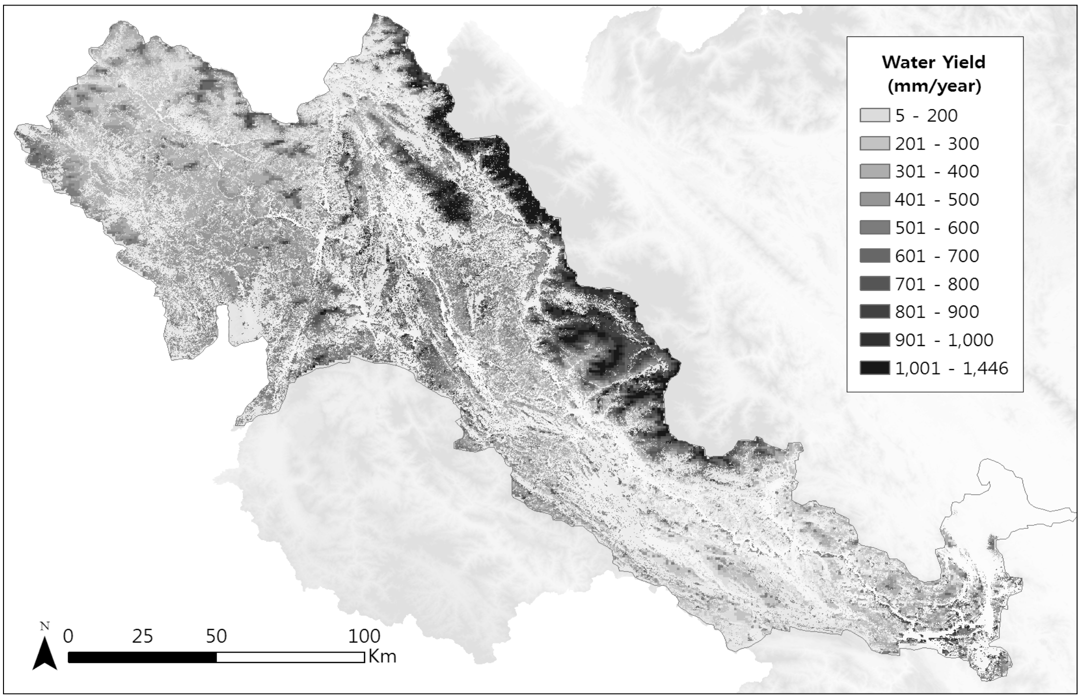

Figure 4. Water yield service from forests in Da river basin. Mt. Phu Luong (middle), Mt. Fanxipan (northern edge), Hoang Lien National Park (island-shaped) are shown as distinct water sources.

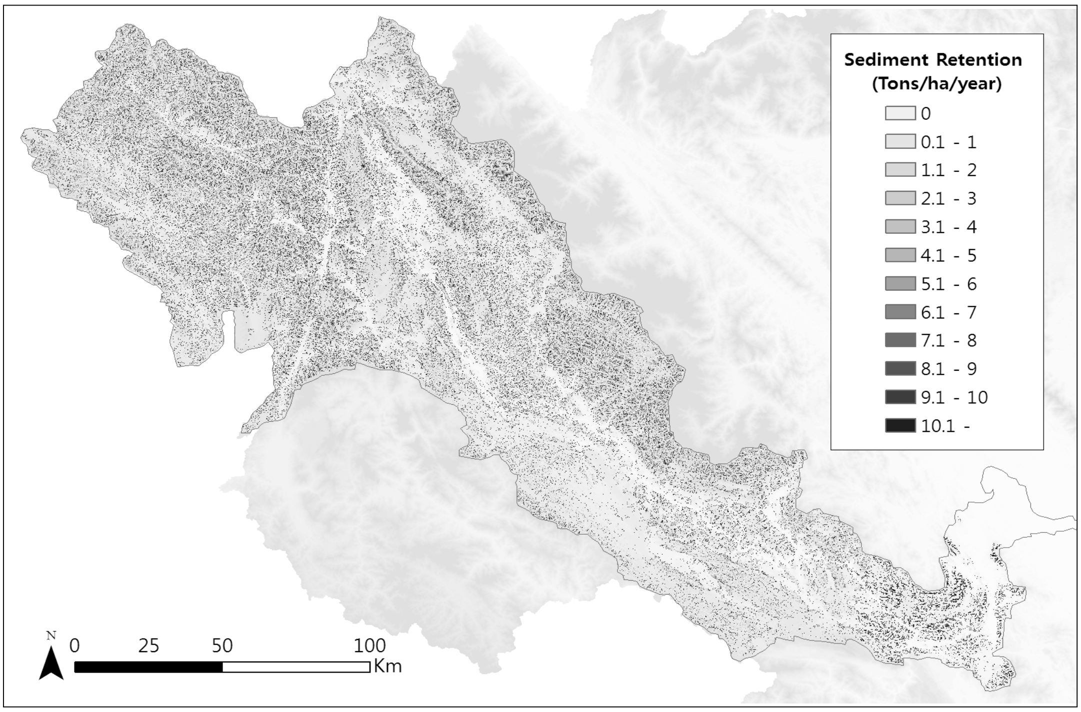

Figure 5. Sediment retention service from forests in Da river basin. The service is rather scattered due to randomly distributed sediment sources such as croplands.

predicted compared to the reference map. However, other classes showed low accuracy values and they need to be validated with actual field data and local experts' opinion on land cover classes.

Distributions of water yield and the sediment retention service from forests in the Da River basin were shown in Figures 4 and 5. Large amounts of water were supplied from Mt. Phu Luong, Mt. Fansipan, and Hoang Lien National Park. According to the quantile classification, the water yield service was divided into three classes: high, medium, and low. The results from the sediment retention service were randomly distributed, with about half of the forest area showing an absence of this service. This may be due to the randomly distributed location of croplands and bare lands, which are

Table 3. Composition of forest priority orders according to hydrological ecosystem services assessment in Da river basin (WY: water yield service, SR: sediment retention service).

Priority order		Area (km^2)	Area (%)
1	High WY and SR	4,071.4	32.5
2	Medium WY and SR	3,452.7	27.5
3	High WY only	2,639.5	21.0
4	Medium WY or SR only	2,360.1	18.8
5	No services	24.5	0.2

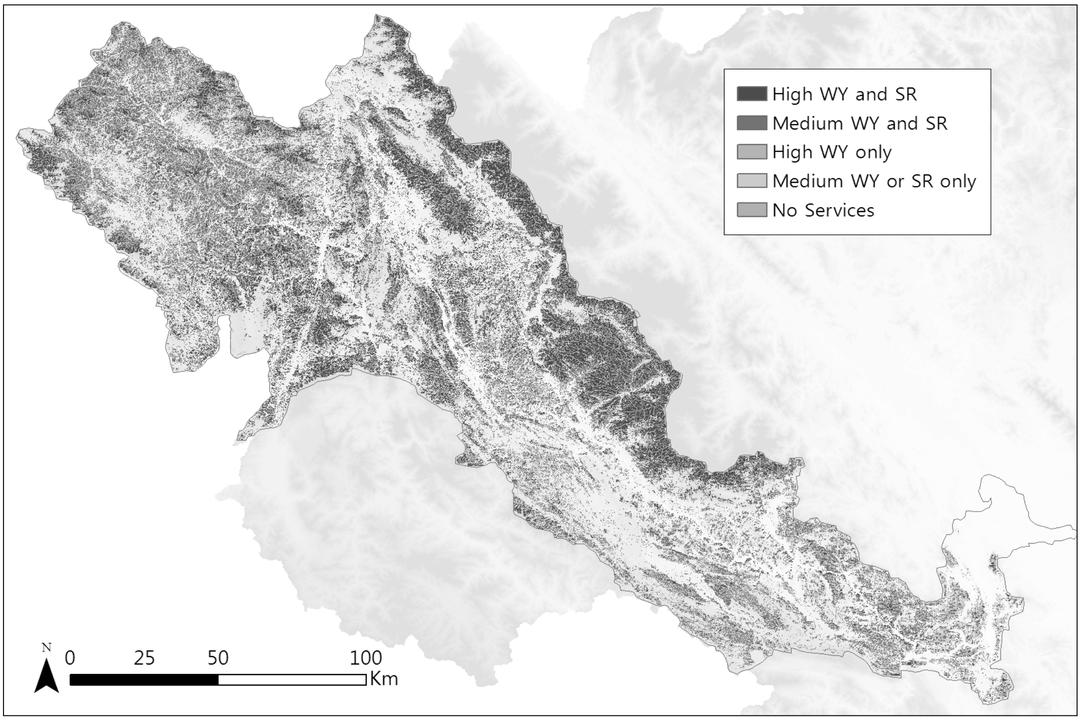

Figure 6. Priority forest area in implementing PFES policy in Da river basin, northern Vietnam.

major sources of soil loss. In other words, the amount of sediment retention service was highly affected by sediment source and inflow. For that reason, the sediment retention service was divided into two classes: service existence and no service.

By overlapping the two maps of hydrological ecosystem services in the forest areas, we suggested priority forest areas that provided a high level of ecosystem services for implementation of the PFES policy (Table 3, Figure 6). Forests with a high water yield and sediment retention service were identified from Mt. Phu Luong, Mt. Fansipan, and Hoang Lien National Park, and accounted for 32.5% of the Da River basin surface area.

V. Conclusion

One of major obstacles in implementing a payment scheme for ecosystem services is the uncertainty in ecosystem functions. Due to the ecosystem complexities, it is difficult to quantify the amount of provided services and to identify their spatial distributions for policy implementation (Chan et al., 2006; Fisher et al., 2008).

A spatially explicit quantification could enable local governors and forest managers to ascertain which regions should be managed first, and which landowner should be compensated for providing ecosystem services to meet a benefit sharing. In addition, it provides a logical ground to persuade enterprises who participate in the payment scheme to pay for these benefits. Currently in Vietnam, financial compensation through the PFES is limited to a few public enterprises and private companies. Therefore, estimating ecosystem services with a quantitative method in a spatially explicit way is of increasing significance for implementation of the PFES policy on a national scale for Vietnamese policy makers.

In this study, we suggested priority forest areas with two major hydrological ecosystem services, using a recent land cover map and a long-term averaged dataset in the Da River basin, northern Vietnam. The Da River basin is important because of its role as a major source of water to 5 million people living in Hanoi, but poor management is leading to the gradual degradation of the river basin. As it hosts two of the largest dams in the country, the Da River basin has a high potential for service payers in the PFES policy, such as water supply companies and hydroelectric plants (Nguyen et al., 2013). The results of this study showed that the distribution of ecosystem services varied even in the same forest areas, mainly due to the local topography, climate, and land cover. This research, thus, underlines the importance of identifying ecosystem service hot spots to effectively manage natural resources.

In addition, the highest priority areas that provide the two hydrological ecosystem services of concern in this study, such as Mt. Phu Luong and Hoang Lien National Park, are also areas of high biodiversity that possess primary forests and nature reserves. As well, Mt. Fansipan is one of the most famous eco-tourism spots in Vietnam. Therefore, other ecosystem services stated in the PFES law need to be assessed in order to estimate priority zones for the implementation of the PFES policy as a whole.

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Appendix 1. Landsat image used in FROM-GLC-seg (Yu et al., 2013).

Path / Row	Date of acquisition
129 / 044	2009.11.03
129 / 045	2009.11.03
128 / 044	2008.11.09
128 / 045	2006.11.04
127 / 045	2000.11.04
127 / 046	2000.09.17

Appendix 2. Producer’s accuracy and User’s accuracy.

	Producer’s accuracy	User’s accuracy
forest / shrub	58.61%	95.02%
grasslands	24.40%	15.10%
croplands	35.44%	2.33%
barelands	42.81%	17.05%
built-up lands	25.24%	1.00%
water bodies	50.04%	50.77%