Research article

Spatial Assessment of Land Cover Change and Ecosystem Services from a Case Study in Savannakhet Province, Laos

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Abstract Land use without proper land management may cause deforestation and other negative impacts on ecosystem services (ESs), as defined in the Millennium Ecosystem Assessment of 2005. In Laos, natural resource sectors have received many investments in the past decades, during which a loss of ESs occurred. The aims of this study were to assess impacts on the potential provisions of ESs caused by land cover changes. The Savannakhet province in Laos was selected for the case study. Land cover changes were investigated using Landsat satellite images from 1988. A land cover map for 2010 was obtained from the government. After classifying the image into five land cover types, spatial analyses of the ESs were conducted by utilizing the primary unit values of six ESs. The results indicated that forests were converted to agricultural areas. Most of the potential provisions of ESs decreased due to these conversions in the past two decades.

Keywords ecosystem services, land cover change, spatial analysis, Laos

INTRODUCTION

Land use without proper land management may cause deforestation and other negative impacts on ecosystem services (ESs) as defined in the Millennium Ecosystem Assessment (MA, 2005). Appropriate land use management practices are required to provide adequate ESs. Goldewijk and Ramankutty (2004) and Chase et al. (2000) determined that land cover change was a key driver of environmental and ES changes. Numerous studies have focused on the relationship between land cover changes and the loss of ESs (Kay Khaing Lwin et al., 2016). An understanding of the spatial patterns associated with ESs could be applied for developing effective environmental policies and for decision-making (Izquierdo and Clark, 2012). In Lao People's Democratic Republic, land use changes associated with potential development might cause negative impacts on ES provisions (USAID, 2015; Yoshida et al., 2010) and natural resource sectors such as agriculture and forestry have received many investments in the past decades (Saunders et al., 2014). In Laos, Savannakhet province located in the south of the country received eight percent of the total foreign direct investments from 2004 to 2010, two-thirds of which were provided to the agriculture and forestry sectors (IUCN and NERI, 2011). This may cause agricultural expansion and forest degradation in this province. There are few researches conducted in this province. Therefore, a study of the spatial impact assessment by land cover changes is needed, with a focus on the changes of ES potential provisions in Laos, especially in the province. The results of the ES study could be applicable to land use planning and other decision-making processes related to ES conservation in this area.

OBJECTIVE

The objective of the study is to assess impacts on the potential provisions of ESs caused by land cover changes in the past two decades in Savannakhet province, Laos. A spatial analysis of ESs was conducted based on comparing a 1988 land cover map with those of a 2010 map.

MATERIALS AND METHODS

Study Area

Savannakhet province is the largest province in area in Laos and is located in the southern part of the country (the Administration Office of the province: 16° 34′ 15.2″ N, 104° 45′ 48.3″ E) (Fig. 1). The average annual temperature was 26.2 ℃, and the average annual rainfall was 1,672.3 mm (Lao Statistics Bureau, 2013). The total population was 969,700 (Lao Statistics Bureau, 2015), and the area covers 21,774 km^2, 90 % of which is flat (IUCN and NERI, 2011). The elevation of this study area ranges from 62 m to 255 m, based on the ASTER GDEM (ASTER Global Digital Elevation Model: http://www.jspacesystems.or.jp/ersdac/GDEM/E/index.html)

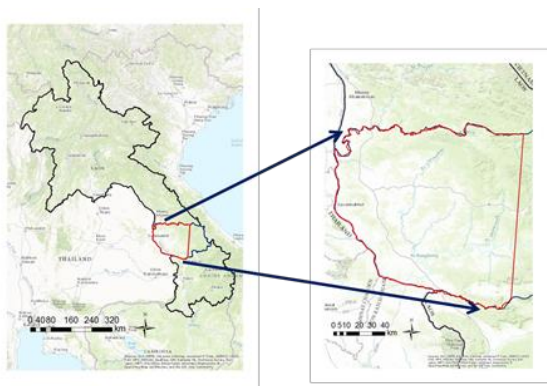


Fig. 1 Maps of Laos (on the left) and Savannakhet province (on the right)
Note: Black and red lines showed the country and the study area boundaries.

Research Process

The study consisted of three steps. The first step was the acquisition of satellite images and the development of a 1988 land cover map. Then we performed a reclassification of a 2010 land cover map provided from the Forest Inventory and Planning Center (FIPC), Government of Laos. The second step was an estimation of ES supply potentials by utilizing each ES unit value based on a literature survey, a land surface temperature calculation using band 6 (thermal band) of a Landsat 5 Thematic Mapper (TM) images, and the Universal Soil Loss Equation (USLE) analysis. Finally, after the normalization of the ES values by utilizing equal weights for each ES unit, a comprehensive analysis was conducted to understand the impacts on the ESs caused by land cover changes in the past two decades. ArcGIS 10.4.1 (ESRI) was used for the analysis.

1988 Land Cover Map Development and Reclassification of 2010 Land Cover Map

The following process was conducted for the development of a 1988 land cover map. Landsat 5 images for 1988 at 30 m x 30 m resolution were downloaded from the United States Geological Survey website *(http://landsat.usgs.gov)*. Four satellite images (WRS path/row 127049 and 127048 dated 16th March and 16th Feb. 1988, 126049 and 126048 dated 6th Feb. 1988) covered the study area. The images were subset to the study area located in the western part of the province, shown as a red line in Fig. 1. The images were classified into five types of land cover classes: forest, dry-forest, water, urban and bare land, and agriculture area. The normalized difference vegetation index (NDVI) and the normalized difference water index (NDWI) (McFeeters, 1996) were used to separate forest and water, respectively. For the classification of the remaining classes, namely, mixed-forest, dry-forest and grassland, urban and bare land, and agriculture area, supervised methods were used. Subsequently, the mixed-forest class was integrated into the forest class. Swamp areas were difficult to identify in the 1988 images; therefore, swamps were classified as "Other" together with clouds which were excluded from the ES analysis.

An accuracy assessment was conducted for the 1988 classification using ancillary data by creating approximately 100 random points for each land class, except urban and bare land class, which only 35 points were set due to the small ratio of urban area against the total area. Then the random points of the 1988 map were compared with 1988 Google Earth image and original satellite images as references. The result of the accuracy assessment was 0.853 by the kappa coefficient (Table 1). However, the resolution of the reference is not high. But we could not find any other reference for the old map.

We used a land cover map of 2010 provided by the FIPC, and reclassified the existing 22 land cover types into the same five land cover types used for the 1988 map (Table 2).

Table 1 Accuracy assessment of the 1988 land cover map

		1988 Google Earth image					Total
		Forest	Dry-Forest	Water	Urban and Bare land	Agriculture area	
Classified 1988 land cover map	Forest	90	10	0	0	0	100
	Dry-Forest	7	90	0	0	3	100
	Water	0	4	88	0	8	100
	Urban and Bare land	3	3	0	26	3	35
	Agriculture area	0	9	0	0	92	101
Total		100	116	88	26	106	436
Kappa coefficient		0.853					
Overall accuracy		86.7 %					

Table 2 Reclassification of the 2010 land cover map

National Level Classification System (NLCS) for Laos 2010 by FIPC	New category for this study by authors
11Evergreen Forest, 12Mixed Deciduous Forest, 14Coniferous Forest, 15Mixed Coniferous and Broadleaved Forest, 16Forest Plantation, 21Bamboo, 22Regenerating Vegetation	Forest
13Dry Dipterocarp Forest, 31Savannah, 32Scrub, 41Grassland	Dry-forest
81Water	Water
71Urban, 72Barren Land and Rock, 80Other Land	Urban and bare land
51Upland Crop, 61Rice Paddy, 62Other Agriculture, 63Agriculture Plantation	Agriculture area
42Swamp, 82Cloud, 83Cloud Shadow	Other

Note: Land cover numbers were defined under NLCS by FIPC

Table 3 shows the ES unit values based on a literature survey conducted by Kay Khaing Lwin et al. (2016) with several adjustments for this study, except temperature regulation and USLE estimation. The ES categories from the MA (2005) were used, including provisioning, regulating, and supporting services, except for cultural services. For supporting services, gross primary production (GPP) and carbon stock were selected. For regulating services, temperature regulation (land surface temperature estimation: LST), USLE and water infiltration were chosen. For provisioning services, only agricultural products (averaging per ha production of local products, namely, rice, vegetables, maize, soil bean, peanut, starchy roots from Lao Statistic Bureau (2013)) were used.

Table 3 Primary unit values of ESs

Types of ESs	Forest	Dry-Forest	Agriculture area	Urban and bare land	Water	Source
Supporting Services:						
GPP (t/ha/yr)[1]	30.7	4.585	12.093	0	0	Chen et al. (2013) and Hirata et al. (2013)
Carbon stock (t/ha)[2]	131.61	41.19	0	0	0	Forest Carbon (2015)
Regulating Services:						
Water infiltration (mm/h)[3]	100	280	38.5	2	0	Chaplot et al. (2002)
Temperature regulation (°C)	2.93	1.06	0.26	0	5.23	by authors*
Provisioning Services:						
Agriculture Products (t /ha)	-	-	4.00	-	-	Lao Statistic Bureau (2013)

Source: Kay Khaing Lwin et al. (2016) revised by the authors,
**: developed by using Landsat 5 as explained in the land surface temperature estimation section below.*
[1]: Data were attempted to collect in the study area or nearest location. GPP for forest was obtained from Hirata et al. (2013)' Thailand data which was close to this area, and Chen et al (2013) estimated in GPP of Asian region that were used for dry-forest and agriculture area.
[2]: Carbon stock unit values in Laos were presented in Forest Carbon (2015) which used biomass equations originally from Chave et al. 2005 and 2014. Then the unit values for forest and dry-forest in this paper were revised by taking into consideration the ratio of evergreen forest and deciduous forest areas in Savannakhet comparing 2000 and 2010 values (NLCS for Laos 2000 and 2010 by FIPC).
[3]: Water infiltration unit value of tree plantation from Chaplot et al. (2002) was used for those of forest unit value in this study, and the fallow and pastures unit values in the same paper were used for dry-forest in this study. For agriculture area, the averaged figures of cultivated (corn, vegetables) and cultivated (with conservation) in Chaplot et al. (2002) were used.

Land Surface Temperature (LST) estimation: LST for 1988 and 2010 were calculated by using the band 6 images of Landsat 5 TM. Four image scenes were used for making the 1988 land cover map, but only two scenes of Mekong River side where majority of urban areas situated, were utilized in this LST estimation for each year, which included enough urban area with other land cover types. Then, the following 16 images in separate eight years were collected: for 1988 LST estimation (Path/Row of 127/049: 16 Feb. 1988, 11 March 1989, 18 Feb. 1990, 10 April 1991; and those of 127/048: 16 March 1988, 11 March 1989, 19 Dec. 1990, 10 April 1991) and for 2010 LST estimation (Path/Row of 127/049: 5 March 2007, 24 April 2008, 25 Feb. 2010, 28 Feb. 2011; and those of 127/048: 1 Feb. 2007, 24 April 2008, 25 Feb. 2010, 28 Feb. 2011). These images were used to calculate LST as a shot of LST in different time in each year. Most of the images were captured around 10a.m. in Laos local time. The images were acquired in dry season from January to April or beginning of May to avoid the effect of clouds. The following processes as described by Kumar et al. (2012) originally from NASA (2004) were used to estimate LST. The first is Eq. (1).

$$L_{\gamma} = \left\{ \frac{L_{MAX} - L_{MIN}}{QCALMAX - QCALMIN} \right\} \times DN - 1 + L_{MIN} \tag{1}$$

Note: L_{MAX}=*the spectral radiance that is scaled to QCALMAX in* $W/(m^2 \times sr \times \mu m)$, L_{MIN}=*the spectral radiance that is scaled to QCALMIN in* $W/(m^2 \times sr \times \mu m)$, *QCALMAX=the maximum quantized calibrated pixel value* *(corresponding to L_{MAX}) in DN=255, QCALMIN=the minimum quantized calibrated pixel value (corresponding to L_{MIN}) in DN=1, DN=Digital Number*

Table 4 Parameter values of Landsat 5 TM

Satellite/Sensor	L_{MAX}	L_{MIN}	K_1	K_2
Landsat 5 TM	15.303	1.238	607.76	1260.56

Source: the Landsat 5 TM metadata file

The values for L_{MAX}, L_{MIN}, *QCALMAX*, and *QCALMIN* were obtained from the Landsat 5 TM metadata in Table 4.

After converting *DN* to $L\gamma$, the black body temperature T_B was calculated using Eq. (2) which is called Plank's inverse function (Kumar et al., 2012).

$$T_B = \frac{K_2}{\ln\left(1+\frac{K_1}{L_\gamma}\right)} \tag{2}$$

The values of K_1 and K_2 were obtained from the Landsat 5 TM metadata file in Table 4. T_B was converted to LST using Eq. (3) (Yue et al., 2007; Kumar et al., 2012).

$$LST = \frac{T_B}{1+\left(\gamma\frac{T_B}{\rho}\right)\ln\varepsilon} \tag{3}$$

Note1: *γ=the wavelength of emitted radiance (γ = 11.5 μm), $\rho = h\times c/\sigma$ p=1.438× 10^{-2} (mK), h=Plank`s constant (6.626 × $10^{-34}$ Js), c=the velocity of light (2.998× $10^{8}$ $ms^{-1}$), $\sigma$=Boltzmann`s constant (1.38× 10^{-23} JK^{-1}), ε=spectral emissivity (vegetation=0.95, non-vegetation=0.9, water=1.0 (Nichol 1996))*

Note2: LST results for 1988, 2007 and 2008 contained error points because of including little cloud part, the results were modified by excluding those parts out before adjustment by DEM data.

After converting the sea level elevation value for each pixel of the LST value by assuming as a constant of 6.5 /km lapse rate (a surface temperature decreases with an increase in altitude) (Minderet al., 2010), the LST values were averaged in each land cover type separately. Then the LST value differences were calculated based on the difference between the averaged LST value of urban areas and those of other land cover types in each year separately. Finally, the ES unit values for temperature regulation were estimated by averaging the LST value differences for eight years by each land cover category (Table 3).

USLE: USLE is based on a formula to estimate the quantity of soil erosion per unit area caused by surface water (precipitation) (USDA, United States Department of Agriculture: http://www.usda.gov /wps/portal/usda/usdahome). It was calculated using Eq. (4). The *R* value was calculated using Eq. (5) (Kobayashi et al., 2002). *A* in Eq. (5) used rainfall data from Savannakhet Meteorology Station by the years of 1990 and 2010. The *K* value was calculated by Eq. (6) to Eq. (10) (Wawer et al., 2005 originally by Williams, 1995) based on the soil map of Laos obtained from the FAO (Food and Agriculture Organization of the United Nations: http://www.fao.org/soils-portal/en/). The *L* and *S* values are topographical factors and were calculated in ArcGIS using the ASTER GDEM by a simple method, LS calculated just from the slope value in % using Eq. (11) (Mediavilla et al., 2017 originally by Ededo et al., 1995). The *C* value was obtained from Dubber and Hedbom (2008). The *P* factor was not considered. Hence, assuming that *P* = 1 (constant) when no soil conservation measures were practiced.

$$E = R\times K\times L\times S\times C\times P \tag{4}$$

$$R = 0.32 \times \left(\frac{A}{100} \right)^{2.5} \tag{5}$$

$$K = K_W = f_{csand} \cdot f_{cl-si} \cdot f_{orgc} \cdot f_{hisand} \tag{6}$$

$$f_{csand} = \left(0.2 + 0.3 \cdot \exp\left[-0.256 \cdot m_s \cdot \left(1 - \frac{m_{silt}}{100} \right) \right] \right) \tag{7}$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}} \right)^{0.3} \tag{8}$$

$$f_{orgc} = \left(1 - \frac{0.25 \cdot orgC}{orgC + \exp[3.72 - 2.95 \cdot orgC]} \right) \tag{9}$$

$$f_{hisand} = \left(1 - \frac{0.7 \cdot \left(1 - \frac{m_s}{100} \right)}{\left(1 - \frac{m_s}{100} \right) + \exp\left[-5.51 + 22.9 \cdot \left(1 - \frac{m_s}{100} \right) \right]} \right) \tag{10}$$

$$LS = \begin{cases} 0.009 \times p^2 + 0.0798 \times p, & p \leq 30\% \\ 0.2558 \times p + 3.248, & p > 30\% \end{cases} \tag{11}$$

Note: E: mean annual soil loss (t/ha/year), R: rainfall erosivity factor (MJ・mm/ha/h/year), K: soil erodibility factor (t・h/MJ/mm), L: slope length factor, S:slope steepness factor, C: crop management factor, P: erosion control practice factor, A: Annual rainfall (Savannakhet Meteorology station by statistic yearbook 2010), m_s: the sand fraction content (0.05-2.00 mm diameter) (%), m_{silt}: the sand fraction content (0.002-0.05 mm diameter) (%), m_c: the sand fraction content (<0.002 mm diameter) (%), p: slope (%), orgC: the organic carbon (SOC) content (%).

ESs Mapping

The land cover maps and the ES unit values were used to create maps for the potential provisions of ESs. A grid with a mesh size of 500 m × 500 m was created. A comprehensive analysis was conducted for the 1988 and 2010 maps by averaging each normalized ES score (0 to 1 scale). However, the USLE was converted to be a minus value before normalization because the original USLE value was high ES value in low USLE figure.

Table 5 Percent of land cover in 1988 and 2010

Land cover type	1988 (%)	2010 (%)
Forest	51.18	42.31
Dry forest	36.60	28.00
Water	1.33	2.06
Urban and bare land	0.05	0.42
Agriculture area	9.83	27.21

RESULTS AND DISCUSSION

Table 5 and Fig. 2 show the results of the land cover classifications. Forest and dry-forest areas decreased considerably and in contrast, agricultural area increased markedly from 1988 to 2010. In order to compare both maps, the areas of cloud and swamp parts which were classified as “Other” category in the 2010 map were excluded from the 1988 map as well. The results of the spatial analysis are shown in Fig. 3. Some ES supply potentials have decreased especially for carbon stock and GPP because of the decrease of the forest areas in general. As agricultural area increased, the provision of food production has also increased. Fig. 3c) and 3d) defined the change of soil erosion quantities, the red color of the USLE maps was identified the lowest annual soil loss which means soil loss of the 2010 map was smaller than that of the1988. Water area had the highest value with regard to temperature regulation service, followed by forests (Table 3). Surface temperatures changed considerably between 1988 and 2010 mainly because of the impact from land cover change especially for the center and southwest parts where the transformation from forest and dry-forest to agricultural area have happened, which had the higher potential provisions of its service in forest and dry-forest than agriculture area. As consequent, as shown in the Fig. 3g) and 3h) the temperature regulation service was decreased in general. Water Infiltration service was identified as water infiltration capacity which also affected from land cover changes. As shown in the Fig. 3i) and 3j), water infiltration service in the southwest part of the study area was declined due to the change from dry-forest to agricultural areas, followed by forest transformation to agricultural areas.

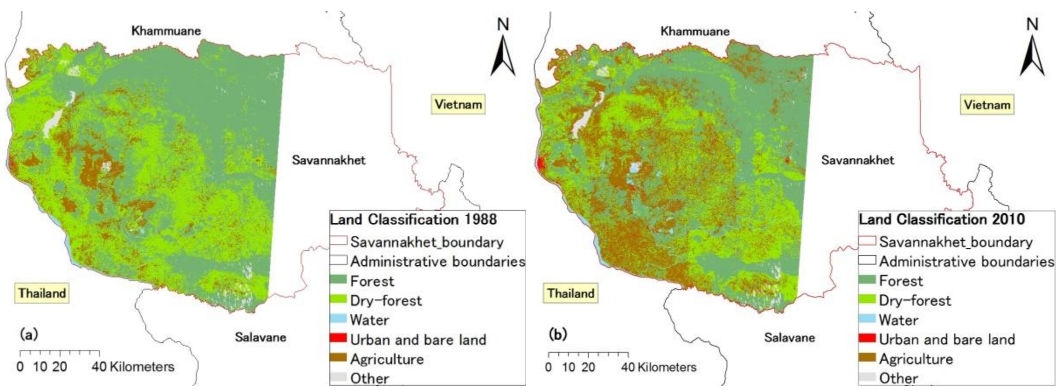


Fig. 2 Land cover classification (a) 1988 and (b) 2010

The results of comprehensive analysis were presented in Fig. 4(a) and 4(b) to prioritize ES conservation needs. The overall values of ES supply potentials were higher for 1988 than for 2010. Entirely, forest area had the highest importance of ES potential provisions in both maps. Therefore, the perspective of nature conservation, a land use policy sector should consider it properly for their future land use development policy, for example, land concession for industrial plantations which need the huge area of their cultivation. It will be one of the policy options to limit land use types, for example, introducing land use zoning policy, to protect forest area in order to avoid reducing the potential provisions of ESs.

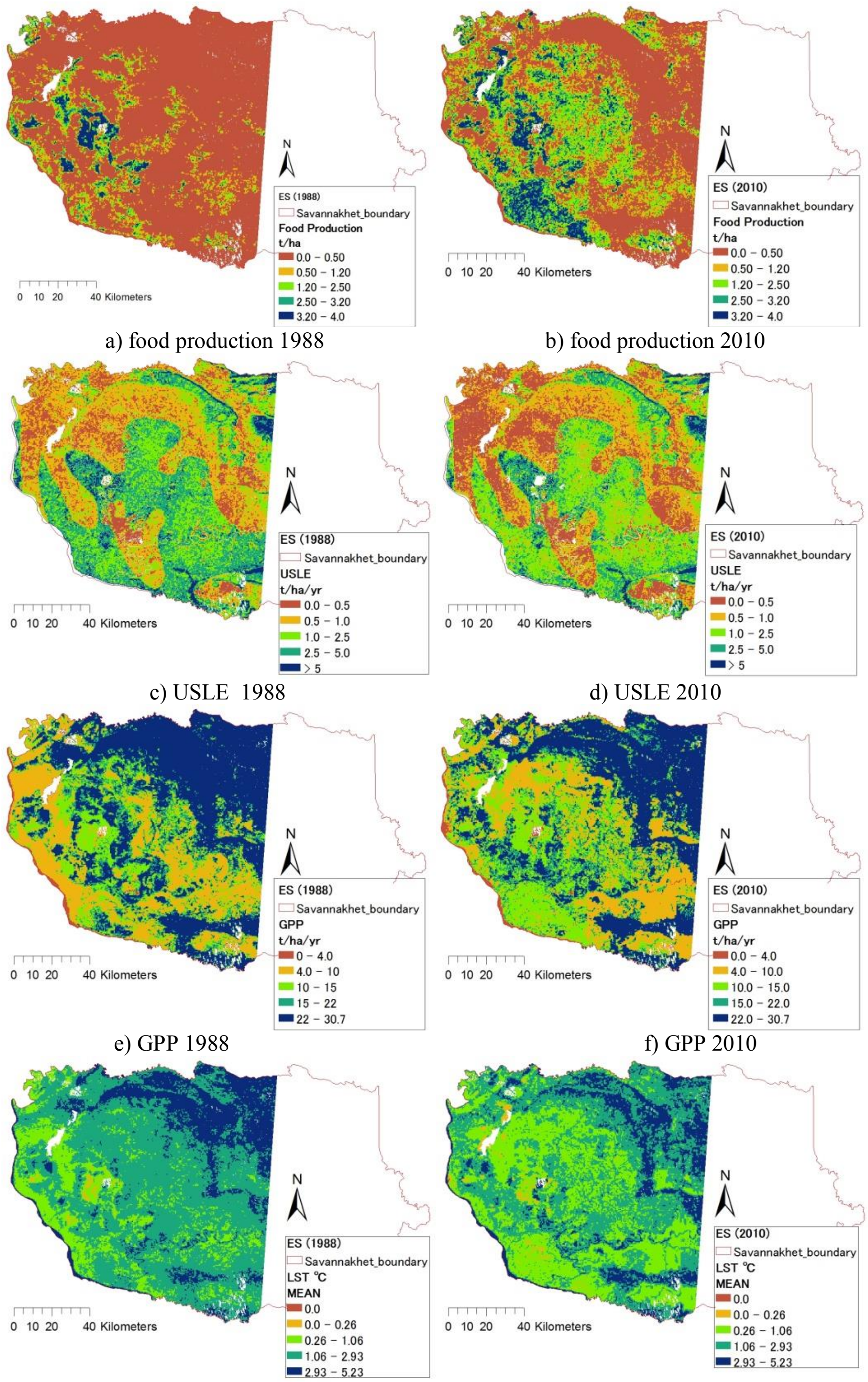
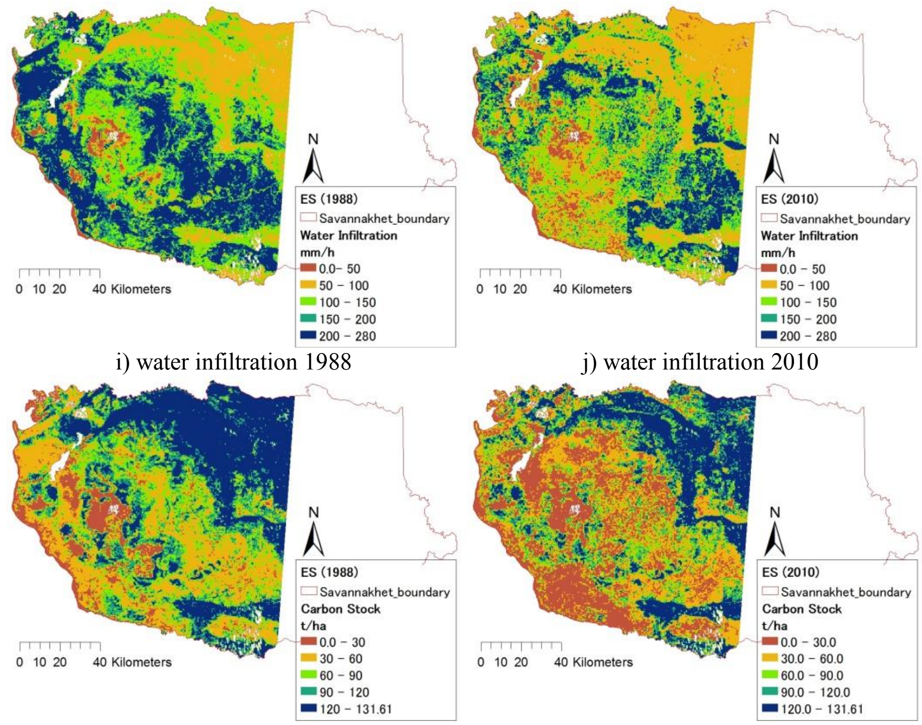


Fig. 3 Maps of ESs in the province for 1988 and 2010 [a) - h)]

Note: Map of USLE Fig. 3c) and 4d) were higher values in the blue color which means higher area of soil erosion quantities (this means low ES provision)



i) water infiltration 1988 j) water infiltration 2010

k) carbon stock 1988 l) carbon stock 2010

Fig. 3 cont. Maps of ESs in the province for 1988 and 2010

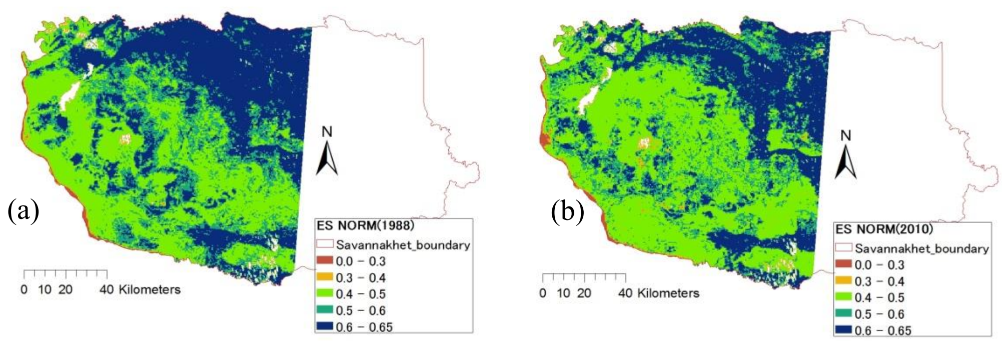


Fig. 4 Maps of comprehensive assessments for (a) 1988 and (b) 2010: 0 to 1 scale

CONCLUSION

A spatial analysis of potential provisions of ESs was conducted to understand the distributions of the ESs and to determine priority areas for conservation of the ESs. Forest area decreased considerably from 1988 to 2010 in contrast to agricultural area. Most of the changes in land cover type came from the transformation of forest and dry-forest to agricultural areas, and this might be the main cause for the changes in the potential provisions of ESs over two decades. Most of the potential provisions of ESs decreased due to these changes. The present study could be a useful tool for land use planning based on prioritizing conservation areas for ESs in this region. Our results illustrate the importance of considering ESs into land-use planning and land management policy. This approach could apply not only for this study area but also throughout nationwide and could probably be applicable for other developing countries. Future issues that require further study include the increased number of ESs, the collection of ES unit values for Laos, and the increase in the number of land cover classes. Culture services are also important in terms of social environment to understand the ES influence on their local livelihood activities.

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