AGRICULTURAL AND FORESTRY LANDSCAPE SUSTAINABILITY EVALUATION USING SUSTAINABILITY INDICATOR, LAMTAKHONG WATERSHED, NAKHON RATCHASIMA, THAILAND

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Abstract

Landscape sustainability plays a vital role in maintaining ecological security and promoting regional ecological sustainable development. The main objectives of the research are to classify and assess the landscape types and the changes to them and to evaluate agricultural and forestry landscape sustainability using sustainability indicators in the Lamtakhong watershed, Nakhon Ratchasima, Thailand. In this study, the extracted and predicted land use and land cover data during 1993 to 2025 were used to classify landscape types by the majority of land use and land cover. The derived landscape types were then applied for status and change assessment and sustainability evaluation. The results showed that during 1993 to 2025 the most dominant landscape was agricultural landscape and the least abundant landscape was miscellaneous landscape. Meanwhile, the development of landscape types indicated that urban, agricultural, and miscellaneous landscapes had continued to increase but forestry landscape had successively decreased. The overall sustainability level of the agricultural and forestry landscape during 1993 to 2025 was moderate. However, the sustainability of agricultural and forestry landscape had continuously declined in term of gains and losses in the past and would continue to do so into the future. With these results, it might be concluded that the sustainability of agricultural and forestry landscape in the Lamtakhong watershed will be decreased in the future. The findings of the study can be used as the basis for regular monitoring of the use of the land and can be a guide for biodiversity conservation and forest rehabilitation.

Keywords: Land use and land cover, landscape sustainability, sustainability indicator (SUSI), Lamtakhong watershed, Nakhon Ratchasima

Introduction

During the past decades, land use and land cover (LULC) in the Lamtakhong watershed was rapidly changed by human activities including urbanization, deforestation, and infrastructure development (Inkaew *et al.*, 2004). As a result there has been an increased demand for land over time and it directly affects the agricultural and forestry landscape

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sustainability.

LULC change is one ofthe main factors by which man influences the environment (Dale *et al*., 2000; Verburg and Chen, 2000; Hashim and Abdullah, 2005; Zhou *et al*., 2012). Changes in LULC are the most important socio-economic driving forces on global as well as local environmental change (Turner *et al*., 1990; Vitousek *et al*., 1997; Krausmann *et al*., 2003; Fu *et al*., 2006) and they play a major role in the dynamics and changes of landscapes (Kim *et al*., 2002.) In addition, improper land use practices or lack of appropriate land use planning adversely affects many natural processes that lead to soil erosion, land degradation, habitat destruction, and water pollution (Apan *et al*., 2000; Heshmati *et al*., 2011; Yanli *et al*., 2012).

Sustainability has become a central term in environmental planning and policy across the world since the late 1980s (Peterseil *et al*., 2004; Fu *et al*., 2006; Moldan *et al*., 2012). The Brundtland Report defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission for Environment and Development, 1987). Sustainable development is multi-dimensional involving social, economic, and environmental aspects (Commission of the European Communities, 2001; United Nation, 2007).

Changes in a landscape regarding the anthropogenic influence are a highly integrative indicator for sustainability (Peterseil *et al*., 2004; Helming *et al*., 2008). The removal of small biotopes or changes in the patch size of land use parcels to larger units can therefore be seen as an unsustainable development, at least in terms of ecological sustainability (Peterseil *et al*., 2004).

Hemeroby or a hemerobiotic state was based on the idea of describing ecological sustainability (Naveh and Liebermann, 1984; Peterseil *et al*., 2004). Theoretically, hemeroby is a measure of the intensity of human disturbance of a landscape or ecosystem and its state will be increased when human influence increases (Sukopp, 1976; Steinhardt *et al*., 1999). Peterseil *et al*. (2004) stated that hemeroby can be used as an indicator for sustainable landscape identification and a good overview to the distribution of sustainable land use at a local and regional level. Basically, the degree of hemeroby is measured by indicators such as the share of the neophytic and therophytic species, morphological and chemical soil features, and land use types (Steinhardt *et al*., 1999). In practice, land use intensity and landscape pattern changes of land use types can be attributed by the hemerobiotic state as a measure for naturalness or conversely of the human influence on the ecosystem (Wrbka *et al*., 2003; Peterseil *et al*., 2004). Therefore, hemeroby was here selected as the sustainability indicator to evaluate agricultural and forestry landscape sustainability because this approach was appropriate for the human impacts on the landscape in the Lamtakhong watershed based on the LULC types derived from remotely sensed data.The main objectives of the study are: (1) to classify and assess landscape types and their changes, and (2) to evaluate agricultural and forestry landscape sustainability using SUSI.

Materials and Methods

Study Area

The Lamtakhong watershed is one of the most important water resources for NakhonRatchasima province and the Northeast region of Thailand (Figure 1). It is situated between latitude 14° 22′ to 15° 4′ N and longitude 101° 16′ to 102° 15′ E, and covers an area of 3,315 km^2.

Data

The basic datasets for agricultural and forestry sustainability evaluation using SUSI were the classified LULC data from the LANDSAT data acquired in 1993, 2001, and 2009 and the predicted LULC in 2017 and

2025 using the CA-Markov model.

Methods

The research methodology framework of the study consisted of 2 main components: (1) landscape type assessment and change detection, and (2) landscape sustainability evaluation using SUSI (Figure 2).

Landscape Type Assessment and Landscape Change Detection

The Landsat-5 TM data in 1993 and 2001 and Landsat-7 ETM+ data in 2009 were, firstly, geometrically corrected using the image to image rectification method based on the color orthophotography in 2002. Herein, the second order of polynomial transformation for the spatial interpolation and the nearest neighbor re-sampling for the intensity interpolation were applied with the root mean square error less than 1 pixel (25×25 m). In this study, the Universal Transverse Mercator Zone 47 was applied for the map projection and the World Geodetic System 1984 was applied for the geodetic datum. The LULC data in 1993, 2001, and 2009 were firstly extracted from the Landsat TM and ETM+ data using the digital image processing with a hybrid classification algorithm (ISODATA and Maximum likelihood classifiers). From this, 8 LULC types were classified including (1) urban and built-up area, (2) paddy field, (3) field crop, (4) perennial trees and orchards, (5) pasture, (6) forest land, (7) water bodies, and (8) miscellaneous land. After that, extracted LULC data in 1993, 2001, and 2009 were used to predict the LULC data in 2017 and 2025 by the CA-Markov model. Then, the landscape types were classified according to the majority of the LULC type in a landscape cell with a size of 1×1 km^2 as a basic unit for watershed classification in Thailand (Chunkao, 1996). In this study, the 4 landscape types were urban landscape (ULT), agricultural landscape (ALT) which included paddy field, field crop, perennial trees, orchard, and pasture, forest landscape (FLT), and miscellaneous landscape (MLT) which consisted of water bodies and miscellaneous land. Finally, the landscape pattern change detection during 1993 to 2025, which was analyzed by means

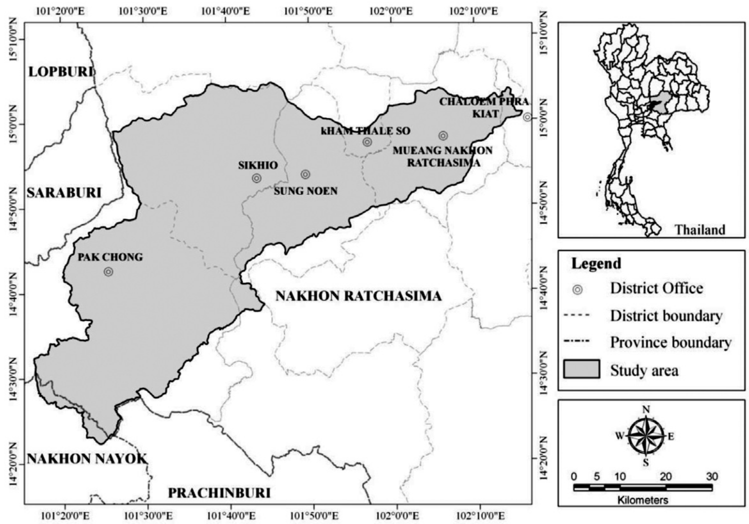


Figure 1. The study area in Lamtakhong watershed

of transition from 1 landscape to other landscape types (Abdullah and Nakagoshi, 2006), was extracted using the post classification comparison algorithm.

Landscape Sustainability Evaluation Using SUSI

Evaluation of landscape sustainability was here focused on the agricultural and forestry landscape. The hemeroby value of the agricultural and forestry landscape was firstly assigned for each LULC type according to the intensity of land use (Steinhardt *et al.*, 1999; Csorba and Szilárd, 2009). In this study, the hemeroby value and its value due to anthropogenic impacts on the LULC was assigned for each LULC type as shown in Table 1. Then, the hemeroby state of each landscape cell was calculated based on the hemeroby value of each LULC type and its proportional area in the landscape cell as:

$$[Hem\_LandCell] = \frac{\sum (x_{ij} \times a_i)}{\sum a_j} \quad (1)$$

where *Hem_LandCell* is the hemeroby state of the j^{th} landscape cell within the landscape

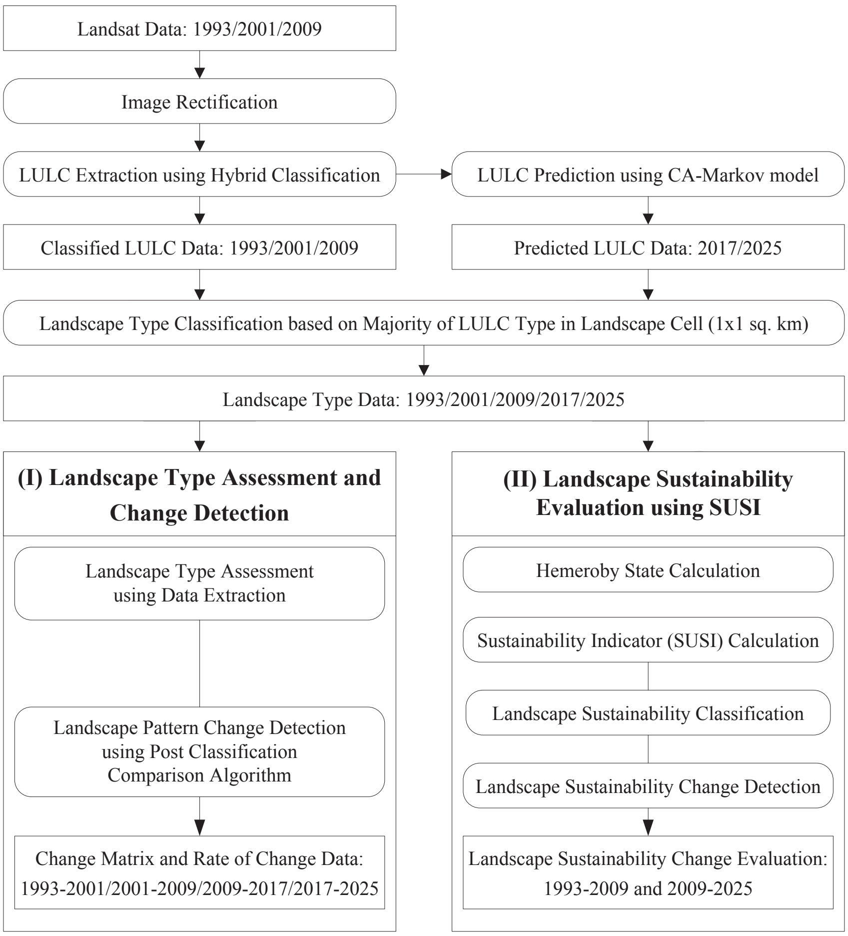


Figure 2. Workflow of research methodology

type, x_{ij} is the hemeroby value of LULC type i in the j^{th} landscape cell, and a_{ij} is the proportional area of each LULC type i in the j^{th} landscape cell.

After that the SUSI value of each landscape cell, which represents the deviation of the modeled hemeroby state of a certain landscape cell compared with the average hemeroby state for the whole landscape type (Peterseil *et al*. 2004), was calculated for the agricultural and forestry landscapes. In practice, the average values and standard deviation for each landscape type were firstly calculated and compared tothe hemeroby state of each landscape cell for the SUSI value as:

$$SUSI = \frac{[AvgHem\_LandType] - [Hem\_LandCell]}{StdDevHem\_LandType} \quad (2)$$

where *SUSI* is the sustainability indicator value of a landscape cell, *AvgHem_ LandType* is the mean of the hemeroby value for a specific landscape type, *StdDevHem_ LandType* is the standard deviation of the hemeroby value for a specific landscape type, and *Hem_LandCell* is the hemeroby value of a specific landscape cell in the landscape type. Then, the calculated SUSI values were further reclassified into 5 landscape sustainability levels as following.

1. Low sustainability (L), a SUSI value less than -2;
2. Low to moderate sustainability (L-M), a SUSI value between -2 and -1;
3. Moderate sustainability (M), a SUSI value between -1 and +1;
4. Moderate to high sustainability (M-H), a SUSI value between +1 and +2;
5. High sustainability (H), a SUSI value more than +2.

Finally, the landscape sustainability change was extracted in 2 periods, 1993-2009 and 2009-2025, using the transitional change matrix to explain the sustainability change in term of gains by the increasing sustainability and losses by the decreasing sustainability.

Results and Discussion

Landscape Type Assessment

Four landscape types including ULT, ALT, FLT, and MLT were classified based on the majority of the classified and predicted LULC type in 1993, 2001, 2009, 2017, and 2025 (Figure 3). Herein, the classified LULC type in 2009 was compared with the reference data derived from the field survey in 2009 for accuracy assessment (Table 2). The overall accuracy and Kappa hat coefficient for the LULC type classification were 90.53% and 0.87, respectively. Similarly the predicted LULC in 2009 derived from the CA-Markov

Table 1. Assignment of land use and land cover type for hemeroby levels and its value

Hemeroby level	Hemeroby value	Degree of naturalness	Land use land cover types
Ahemeroby	0	Natural	Absent in the study area
Oligohemeroby	1	Close to natural	Forest land
Mesohemeroby	2	Semi-natural	Perennial trees and orchards
β-euhemerobe	3	Relatively far from natural	Water body
α- euhemerobe	4	Far from natural	Paddy field, Field crop, Pasture
Polyhemeroby	5	Strange to natural	Miscellaneous land
Metahemeroby	6	Artificial	Urban and built-up land

Modified from Steinhardt et al. (1999)

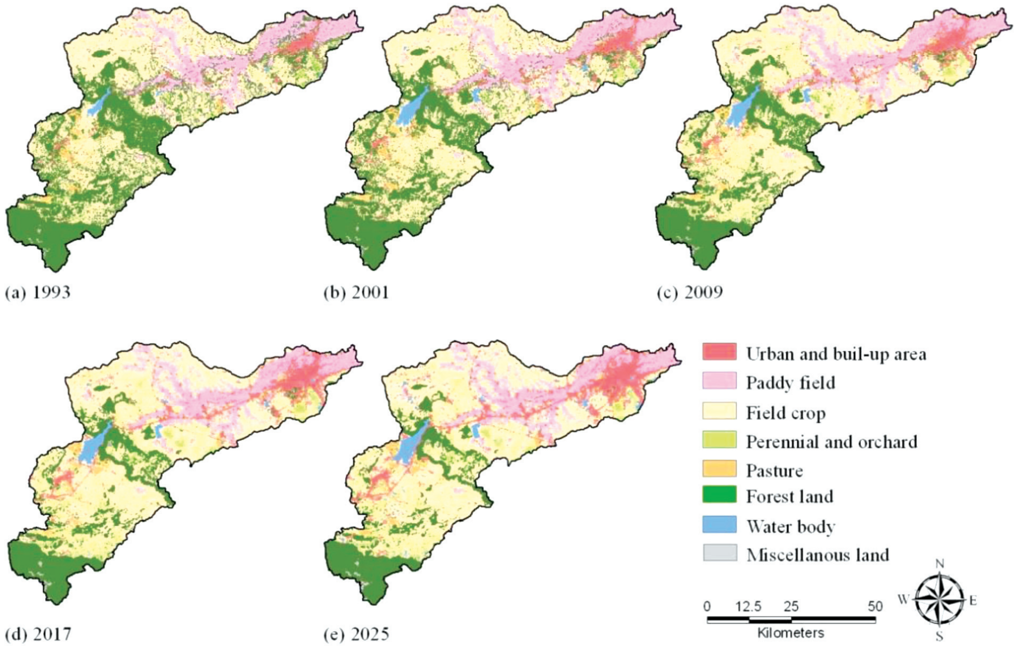


Figure 3. Distribution of LULC types in 1993, 2001, 2009, 2017, and 2025

Table 2. Confusion matrix and accuracy assessment for the classified LULC in 2009

Classified LULC in 2009	Reference data from field survey in 2009									
	U	PF	FC	PO	PS	F	W	M	Total	User's accuracy (%)
U	**36**	1	3					1	41	**87.80**
PF	1	**63**	2			1			67	**94.03**
FC	4	5	**242**	3	2	3	1	1	261	**92.72**
PO	2	3	3	**28**	1	3			40	**70.00**
PS			2	1	**9**				12	**75.00**
F			4	6		**126**			136	**92.65**
W							**9**		9	**100.00**
M	1							**3**	4	**75.00**
Total	**44**	**72**	**256**	**38**	**12**	**133**	**10**	**5**	**570**	
Producer's accuracy (%)	81.82	87.50	94.53	73.68	75.00	94.74	90.00	60.00		
Overall accuracy (%)	**=**	**90.53**								
Kappa coefficient	**=**	**0.87**								

Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial trees and orchards, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land model was also compared with the classified LULC type in 2009 for calibration and validation of the model. It was found that the overall accuracy of the predictive LULC in 2009 was 84.01% and the Kappa hat efficient was 0.77. During 1993 to 2025, the most dominant landscape was the ALT covered area at about 65.98 to 75.03% while the least dominant landscape was the MLT covered area at about 0.54 to 2.06% (Table 3).

As a result, it was found that during 1993 to 2025 the ULT and MLT had continuously increased and the FLT had continuously decreased. Meanwhile, the ALT had increased during 1993 to 2017 but it had decreased during 2017 to 2025. The spatial distribution of landscape type was presented in Figure 4, while the variation of the landscape type coverage with trend analysis as a simple linear equation during 1993-2025 was

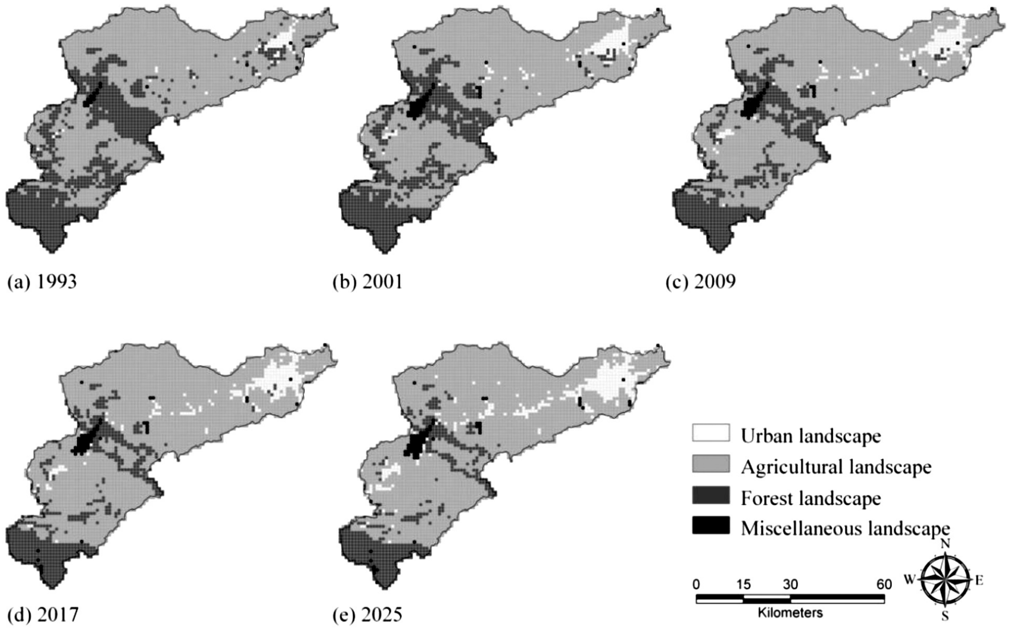


Figure 4. Distribution of landscape types in 1993, 2001, 2009, 2017, and 2025

Table 3. Area and percentage of landscape types during 1993 to 2025

Landscape type	1993		2001		2009		2017		2025	
	Area (sq. km)	%	Area (sq. km)	%	Area (sq. km)	%	Area (sq. km)	%	Area (sq. km)	%
ULT	62	1.75	128	3.61	170	4.79	224	6.31	302	8.51
ALT	2341	65.98	2431	68.52	2547	71.79	2662	75.03	2654	74.80
FLT	1126	31.74	941	26.52	781	22.01	602	16.97	519	14.63
MLT	19	0.54	48	1.35	50	1.41	60	1.69	73	2.06
Total	**3548**	**100.00**	**3548**	**100.00**	**3548**	**100.00**	**3548**	**100.00**	**3548**	**100.00**

presented in Figure 5. As result, it implies that the ALT and MLT areas slightly increase in the near future until they will be constant in the certain period as the logarithmic equation form (Figure 5(b) and 5(d)). In contrast, the FLT area slightly decreases in the near future and it will be constant in the certain time as the polynomial equation form (Figure 5(c)).

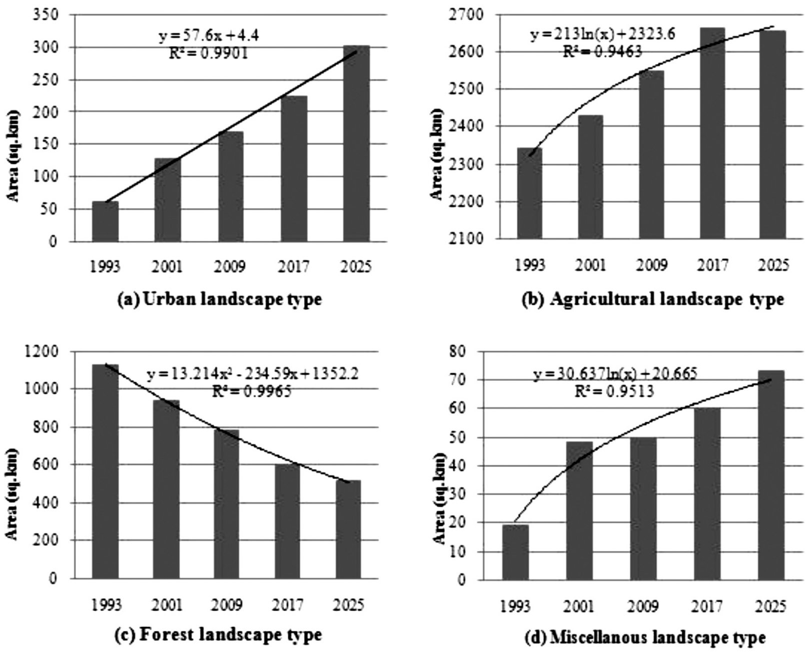


Figure 5. Variation of landscape types coverage in 1993, 2001, 2009, 2017 and 2025 and its tendency in the future: (a) Urban landscape type, (b) Agricultural landscape type, (c) Forest landscape type, and (d) Miscellaneous landscape type

Table 4. Transitional change matrix of landscape type in 4 periods

(a) Transitional change matrix between 1993 and 2001

Landscape type in 1993	Landscape type in 2001 (Sq. km)				
	ULT	ALT	FLT	MLT	Total
Urban landscape (ULT)	62	0	0	0	62
Agricultural landscape (ALT)	32	2282	0	27	2341
Forest landscape (FLT)	34	149	941	2	1126
Miscellaneous landscape (MLT)	0	0	0	19	19
Total	**128**	**2431**	**941**	**48**	**3548**
Area of change (sq. km)	66	90	-185	29	
Landscape change rate (%)	106.45	3.84	-16.43	152.63	
Annual rate of change (sq. km)	8.25	10.88	-23.13	3.63	

Table 4. Transitional change matrix of landscape type in 4 periods

(b) Transitional change matrix between 2001 and 2009

Landscape type in 2001	Landscape type in 2009 (Sq. km)				
	ULT	ALT	FLT	MLT	Total
Urban landscape (ULT)	126	2	0	0	128
Agricultural landscape (ALT)	31	2399	0	1	2431
Forest landscape (FLT)	13	146	781	1	941
Miscellaneous landscape (MLT)	0	0	0	48	48
Total	**170**	**2547**	**781**	**50**	**3548**
Area of change (sq. km)	42	116	-160	2	
Landscape change rate (%)	32.81	4.77	-17.00	4.17	
Annual rate of change (sq. km)	5.25	14.50	-20.00	0.25	

(c) Transitional change matrix between 2009 and 2017

Landscape type in 2009	Landscape type in 2017 (Sq. km)				
	ULT	ALT	FLT	MLT	Total
Urban landscape (ULT)	169	1	0	0	170
Agricultural landscape (ALT)	48	2495	0	4	2547
Forest landscape (FLT)	7	166	602	6	781
Miscellaneous landscape (MLT)	0	0	0	50	50
Total	**224**	**2662**	**602**	**60**	**3548**
Area of change (sq. km)	54	115	-179	10	
Landscape change rate (%)	31.76	4.52	-22.92	20.00	
Annual rate of change (sq. km)	6.75	14.38	-22.38	1.25	

(d) Transitional change matrix between 2017 and 2025

Landscape type in 2017	Landscape type in 2025 (Sq. km)				
	ULT	ALT	FLT	MLT	Total
Urban landscape (ULT)	224	0	0	0	224
Agricultural landscape (ALT)	64	2587	0	11	2662
Forest landscape (FLT)	14	67	519	2	602
Miscellaneous landscape (MLT)	0	0	0	60	60
Total	**302**	**2654**	**519**	**73**	**3548**
Area of change (sq. km)	78	-8	-83	13	
Landscape change rate (%)	34.82	-0.30	-13.79	21.67	
Annual rate of change (sq. km)	9.75	-1.00	-10.38	1.63	

However, the ULT area continuously increases in the near future without stopping as the linear equation form (Figure 5(a)).

Landscape Pattern Change Detection

The change of landscape pattern in the past and future during 1993 to 2025, which was quantified by the post classification comparison algorithm, was summarized as a transitional change matrix in Table 4, in which the area of change, landscape change rate, and annual rate of change in each specific period were presented.

It was found that the areas of ULT and MLT had increased in 4 periods with an irregular change rate. These increasing areas came from the ALT and FLT. On the contrary, the FLT had continuously decreased with a regular change rate in these periods. Meanwhile the ALT had increased with a regular change rate during 1993-2001, 2001-2009, and 2009-2017 but it initially decreased during 2017-2025. In addition, it revealed that the annual rates of change for all landscape types were unstable during 1993 to 2025.

Status of Agricultural Landscape Sustainability

During 1993 to 2025, most of the agricultural landscape was classified as having moderate sustainability and its area had increased from 1548 sq. km in 1993 to 2006 sq. km in 2025. This pattern could be observed for low and high agricultural landscape sustainability. Conversely, the area of the agricultural landscape which was classified as having low to moderate sustainability had decreased from 362 sq. km in 1993 to 257 sq. km in 2025. Similarly, this pattern could also be observed for the moderate to high agricultural landscape sustainability (Table 5 and Figure 6). As a result, it indicated that the overall sustainability level of the agricultural landscape according to the hemeroby state based on the LULC types during 1993 to 2025 was moderate with the hemeoby level at α- euhemerobe (far from natural).

Change of Agricultural Landscape Sustainability

According to the transitional change matrix of the agricultural landscape sustainability in the past and future, it was found that the overall sustainability of the agricultural landscape in the past (1993-2009) had decreased. In fact, the area of gained sustainability was 356 sq. km and area of lost sustainability was 430 sq. km while the unchanged sustainability was 1469 sq. km or about 65.14% of the landscape (Table 6). Meanwhile, the overall sustainability of the agricultural landscape in the future (1993-2009) had decreased more. The area of gained sustainability was 4 sq. km and area of lost sustainability was 466 sq. km while the

Table 5. Area and percentage of agricultural landscape sustainability

Landscape sustainability level	1993		2001		2009		2017		2025	
	Sq. km	%	Sq. km	%	Sq. km	%	Sq. km	%	Sq. km	%
L	6	0.26	10	0.41	10	0.39	21	0.79	22	0.83
L-M	362	15.46	144	5.92	169	6.64	222	8.34	257	9.68
M	1548	66.13	1871	76.96	1980	77.74	2021	75.92	2006	75.58
M-H	329	14.05	266	10.94	214	8.40	223	8.38	216	8.14
H	96	4.10	140	5.76	174	6.83	175	6.57	153	5.76
Total	**2341**	**100.00**	**2431**	**100.00**	**2547**	**100.00**	**2662**	**100.00**	**2654**	**100.00**

unchanged sustainability was 1956 sq. km or about 80.63% of the landscape (Table 7). In addition, a comparison between the gains and losses of the agricultural landscape sustainability level in the past (1993-2009) and in the future (2009-2025) was presented in Figure 7.

As a result, it can be stated that the agricultural landscape sustainability level according to the hemerobiotic state in the Lamtakhong watershed was moderate. However, the overall sustainability of the agricultural landscape had continuously declined in terms of gains and losses in the past and in the future. These findings implied that the degree of naturalness of the agricultural landscape will be changed from a semi-natural to a far from natural landscape in the near future.

Status of Forestry Landscape Sustainability

The forestry landscape sustainability consisted of 3 levels including low, low to moderate, and moderate. During 1993 to

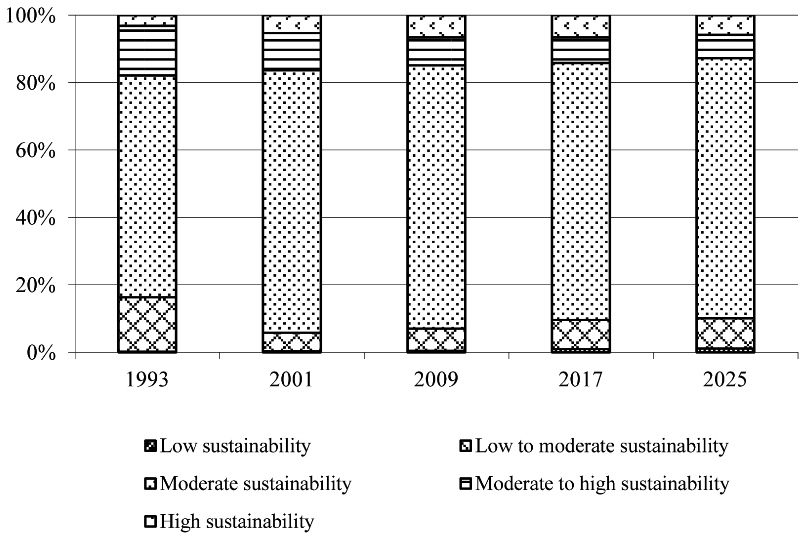


Figure 6. Percentage of agricultural landscape sustainability's level in 1993, 2001, 2009, 2017, and 2025

Table 6. Agricultural landscape sustainability change between 1993 and 2009

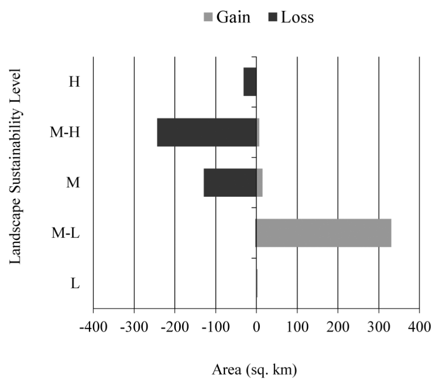
1993	2009 (sq. km)					Total
	L	L-M	M	M-H	H	
Low sustainability (L)	0	4	0	0	0	4
Low to moderate sustainability (L-M)	2	35	314	0	0	351
Moderate sustainability (M)	7	122	1326	25	2	1482
Moderate to high sustainability (M-H)	1	5	230	77	11	324
High sustainability (H)	0	1	31	31	31	94
Total	**10**	**167**	**1901**	**133**	**44**	**2255**

Note: Area of gains/losses sustainability were 356 and 430 sq. km, respectively

2025, most of the forestry landscape was classified as having moderate sustainability but its area had rapidly decreased from 894 sq. km in 1993 to 420 sq. km in 2025. This pattern could be also observed for the low and low to moderate forestry sustainability (Table 8 and Figure 8). As a result, it indicated that the overall sustainability level of the forestry landscape according to the hemeroby state based on the LULC types during 1993 to 2025 was moderate and its area had continuously decreased. In fact, the majority hemeoby level of the forestry landscape was at oligohemeroby (close to natural) and was located in the protected areas including the national park (Khao Yai) and the conservation zone of the national reserved forest.

Change of Forest Landscape Sustainability

For the forestry landscape sustainability change, the overall sustainability in the past (1993-2009) had decreased. The area of gained sustainability was none while the area of lost sustainability was 147 sq. km and the unchanged sustainability was 634 sq. km or about 81.18% of the landscape (Table 9). Similarly, the overall sustainability in the future (2009-2025) had continuously decreased with no gain sustainability. The area of lost sustainability was 98 sq. km and the unchanged



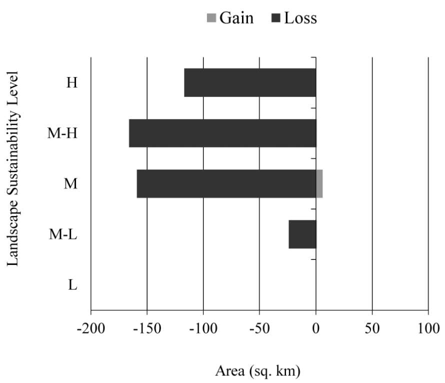


Figure 7. Comparison between gain and loss of agricultural landscape sustainability's level: (a) Agricultural landscape sustainability change between 1993 and 2009 and (b) Agricultural landscape sustainability change between 2009 and 2025

Table 7. Agricultural landscape sustainability change between 2009 and 2025

2009	2025 (sq. km)					Total
	L	L-M	M	M-H	H	
Low sustainability (L)	0	0	0	0	0	0
Low to moderate sustainability (L-M)	20	91	0	0	0	111
Moderate sustainability (M)	2	162	1760	3	0	1927
Moderate to high sustainability (M-H)	0	2	150	61	1	214
High sustainability (H)	0	0	52	78	44	174
Total	**22**	**255**	**1962**	**142**	**45**	**2426**

Note: Area of gains/losses sustainability were 4 and 466 sq. km, respectively sustainability was 421 sq. km or about 81.12% of the landscape (Table 10). In addition, a comparison between gains and losses of the forestry landscape sustainability level in the past (1993-2009) and in the future (2009-2025) was presented in Figure 9.

As a result, it may be concluded that the level of the forestry landscape sustainability according the hemerobiotic state in the study area was moderate and the overall sustainability of the forestry landscape had continuously declined without gain in the past and the future. These findings implied that forest land encroachment happened in the past, is still going on, and will go on in the future. Therefore, the responsible government agencies including the Royal Forest Department and the Department of National Parks, Wildlife, and Plant Conservation should set up a plan for forest rehabilitation, protection, and prevention.

Conclusions

Landscape types (ULT, ALT, FLT and MLT) and their changes were firstly assessed under GIS environment and the agricultural and forestry landscape sustainability in the Lamtakhong watershed was then evaluated using the SUSI. The results revealed that

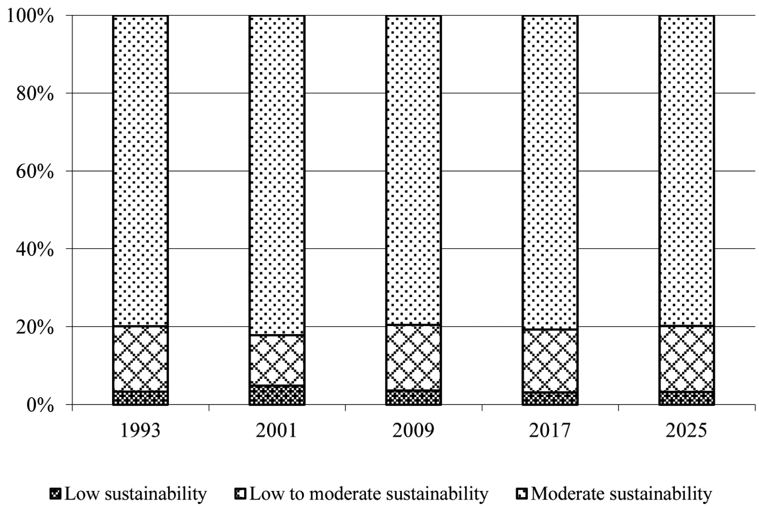


Figure 8. Forest landscape sustainability distribution in 1993, 2001, 2009, 2017, and 2025

Table 8. Area and percentage of forest landscape sustainability

Landscape sustainability level	1993		2001		2009		2017		2025	
	Sq. km	%	Sq. km	%	Sq. km	%	Sq. km	%	Sq. km	%
L	36	3.20	43	4.57	27	3.46	27	4.49	23	4.43
L-M	196	17.41	122	12.96	130	16.65	90	14.95	76	14.64
M	894	79.40	776	82.47	624	79.90	485	80.56	420	80.92
Total	**1126**	**100.00**	**941**	**100.00**	**781**	**100.00**	**602**	**100.00**	**519**	**100.00**

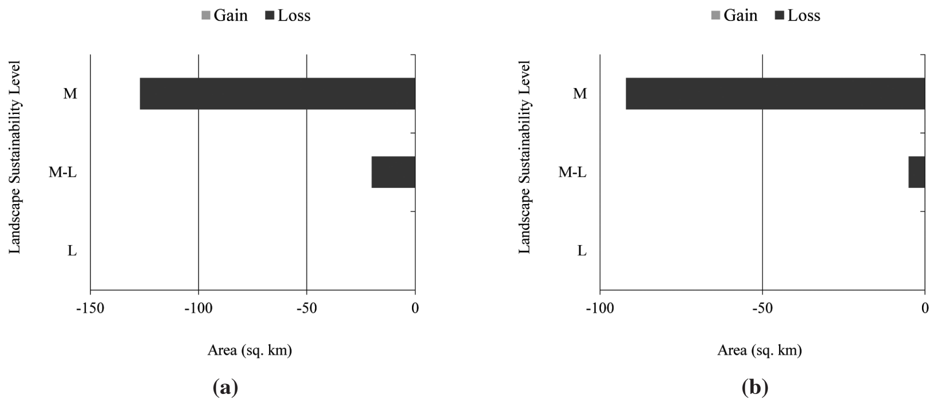


Figure 9. Comparison between gain and loss of forest landscape sustainability's level: (a) Forest landscape sustainability change between 1993 and 2009and (b) Forest landscape sustainability change between 2009 and 2025

Table 9. Forest landscape sustainability change between 1993 and 2009

2009	2017 (sq. km)			Total
	L	L-M	M	
Low sustainability (L)	2	0	0	2
Low to moderate sustainability (L-M)	20	8	0	26
Moderate sustainability (M)	5	122	624	753
Total	**28**	**132**	**621**	**781**

Note: Area of gain/loss sustainability were 0 and 147 sq. km, respectively

Table 10. Forest landscape sustainability change between 2009 and 2025

2009	2025 (sq. km)			Total
	L	L-M	M	
Low sustainability (L)	0	0	0	5
Low to moderate sustainability (L-M)	6	1	0	20
Moderate sustainability (M)	17	75	420	577
Total	**19**	**97**	**486**	**602**

Note: Area of gain/loss sustainability were 0 and 98 sq. km, respectively during 1993 to 2025 the most dominant landscape in the study area was the ALT while the least dominant was the MLT. At the same time, it was found that the man-made landscapes (ULT, ALT, and MLT) had continuously increased while the natural landscape (FLT) had continuously decreased. Further, in the future the ULT, ALT, and MLT will increase and the FLT will decrease based on the trend analysis.

For the agricultural and forestry landscape sustainability evaluation using the SUSI based on hemeroby, it was indicated that the overall sustainability level of the agricultural and forestry landscape during 1993 to 2025 was moderate. However, the overall sustainability of the agricultural and forestry landscape had continuously declined in terms of gains and losses in the past and would decline in the future. With these results, it may be concluded that the sustainability of the agricultural and forestry landscape in the Lamtakhong watershed will decrease in the future due to intensified use of the land. The results of this research can be used as a basis for regular monitoring of the use of the land and can be a guide for biodiversity conservation and forest rehabilitation for the Royal Forest Department, and the Department of National Parks, Wildlife, and Plant Conservation.

For future research, the evaluation of the landscape sustainability based on hemeroby should be integrated with regard to the environmental, economic, and social dimensions in the analysis. In addition, similar indices such as the index of naturalness by Machado (2004) or ecosystem health by Costanza and Mageau (1999) can be examined and compared with the hemerobiotic state.

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