Impact of Land Use and Land Cover Change on Ecosystem Service Values: A Case Study of Khon Kaen City, Thailand

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ABSTRACT

Land use and land cover change (LULCC) by unplanned and uncontrolled urban expansion have a significant effect on ecosystem service values (ESVs). Objectives of the study were (1) to extract LULC status and its change between 2006 and 2016; (2) to predict two different LULC scenarios in 2026 and; (3) to assess LULCC impact on ESVs. Herein, Landsat imageries in 2006, 2011 and 2016 were used to classify LULC types by object-based image analysis (OBIA) and the derived results were applied to predict LULC in 2026 of two scenarios by CLUE-S model and to assess the impact of LULCC on ESVs. Results revealed that paddy field and field crop notably decreased while urban and built-up areas and rangeland dramatically increased over the study periods whereas total ESVs declined from about 145 MM USD in 2006 to 132 MM USD in 2026 of Scenario II and the ESVs of three dominant ecosystem service functions (waste treatment, water supply, and climate regulation) continuously decreased. The impact of LULCC on ESVs remarkably differed among the LULC types. In conclusion, land use and city planners should try to minimize the effect of LULCC on ESVs during the planning process.

1. INTRODUCTION

One of the most important environmental pressures is land use and land cover change (LULCC) due to urbanization (Estoque and Murayama, 2013). The changes in LULC leads to changes in nature, destruction of green cover, and polluting the water resources (Al-shalabi et al., 2013). Accelerating urban growth and LULCC increases pressures on the natural environment and human welfare and have become a global concern (Turner and Meyer, 1994) with numerous relevant researches (Wu et al., 2013; Zhang et al., 2013; Camacho-Valdez et al., 2014; Showqi et al., 2014; Cai et al., 2016; Yirsaw et al., 2016; Tolessa et al., 2017), because these are believed to be responsible for ecological degradation such as habitat fragmentation and biodiversity loss (Bihamta et al., 2014). Rapid urban development usually happens at the expense of prime agricultural land, with the destruction of the natural landscape and public open space (Liu, 2009).

The concept of ecosystem services is defined as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Luederitz et al., 2015). Li et al. (2016) stated that ecosystems provide a multitude of services that are of fundamental significance to human well-being, livelihood, health, and survival. The importance of these services had stimulated considerable interest in their conservations by the publication of the Millennium Ecosystem Assessment, a monumental work involving over 1,300 scientists. One of the key results of the synthesis of Millennium Ecosystem Assessment was the finding that globally 15 of the 24 ecosystem services investigated were in a state of decline and this was likely to have a large and negative impact on future human welfare (MA, 2005). This situation called for further and more rigorous research on measuring, modelling and mapping ecosystem services and assessing changes in their delivery with respect to human welfare (Fisher et al., 2009).

MA (2005) categorized ecosystem services into 4 groups included (1) supporting services which are needed for the production of all other services such as nutrient cycling and soil formation; (2) provisioning services which are products from ecosystems such as food or timber; (3) regulating services which are benefits from the regulation of ecosystems such as purification of water, flood control, or regulation of the climate via carbon sequestration; and (4) cultural services which are benefits to people from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences. The function of ecosystem services with typical examples was explained in more detail in the report of TEEB (2010).

In the meantime, the method of ecosystem service valuation was broadly divided into three types: ecological, socio-cultural and economic value. In brief, the ecological, socio-cultural and economic value was evaluated based on ecological sustain-ability, equity, and cultural perceptions and efficiency and cost-effectiveness, respectively (De Groot et al., 2002). This study used a simple benefit transfer method, which is used to estimate economic values for ecosystem services by transferring available information from the previous study of Mamat et al. (2018) to the study area, because this method is a quicker and lower cost approach to estimating ecosystem valuation. Additionally, benefit values of different LULC types in term of ecosystem service was unavailable.

Currently, hundreds of projects and groups around the world are generating additional data on ecosystem services and on improving modeling, mapping, valuation, and management techniques such as Shoyama and Yamagata (2014), Chuai et al. (2016), Yi et al. (2017), Bryan et al. (2018), Fei et al. (2018), Ye et al. (2018), and Juanita et al. (2019).

This study aimed to apply geoinformatics technology and land use and land cover change model to assess the impact of LULCC on ESVs at Khon Kaen City, Khon Kaen Province, Thailand. It is one of the most intense urbanization cities in Thailand. The acceleration of the city's growth has been driven by internal and external driving forces. The Thai government adopted a policy that focused on distributing growth distribution among regional cities by applying the "Growth poles" theory to develop Khon Kaen as a core of economic growth (Glassman and Sneddon, 2003). Meanwhile, the globalization driving forces via economic cooperation, Greater Mekong Subregion, ASEAN, and Ayeyawady Chao Phraya Mekong Economic Cooperation Strategy earmark Khon Kaen as a logistics hub of the Greater Mekong Region and East-West Economic Corridor linking the western and eastern regions of Myanmar to Vietnam (Dhabhalabutr, 2016). As result, it creates many problems (e.g., motorization, congestion, air and water pollution, municipal waste, suburban sprawl, flooding) related to social and environmental sustainability in the city (Kikuchi et al., 2014).

The objectives of this study were (1) to extract LULC status and its change between 2006 and 2016; (2) to predict two different scenarios in 2026; and (3) to assess LULCC impact on ecosystem services between 2006 and 2026. The expected results will be useful for city planning, environmental impact study, and policy decision making for sustainable use of urban landscape in the future.

2. METHODOLOGY

2.1 Study area

Khon Kaen City situates in the central part of Khon Kaen Province and covers an area of 953.4 km^2 with a total of 417,046 persons. The elevation of the study area ranges approximately from 100 m to 200 m above mean sea level (Figure 1). The main landform is flood plain along Chi River and its terrace, where urban and built-up area and agricultural land are mostly situated. The main river flows from West to East. The area is characterized by a tropical savanna, Aw (Köppen climate classification) with winter that is dry and very warm. The annual mean, maximum and minimum temperatures between 2007 and 2016 were 32.2 °C, 42.0 °C, and 9.5 °C, respectively. The highest total rainfall occurred in 2008 was 1,780.66 mm with 122 rainy days while the lowest total rainfall was in 2013 was 934.10 mm with 109 rainy days (Khon Kaen Municipality, 2017).

2.2 Research methodology

Research methodology workflow consisted of 3 components included (1) LULC status assessment; (2) LULC scenarios prediction; and (3) ecosystem services evaluation (Figure 2).

2.2.1 LULC status assessment

The historical and recent LULC in 2006, 2011 and 2016 were firstly classified from Landsat-7, 7 and 8 imageries dated on 11 April 2006, 11 December 2011 and 15 November 2017, respectively under the eCognition software. Herewith, the multiresolution segmentation algorithm was applied to segment image objects with six multispectral bands of Landsat images (blue, green, red, near infrared, shortwave infrared 1 and 2) based on the criteria of relative homogeneity with predefined optimum values for scale, shape and compactness of 30, 0.1, and 0.5, respectively. Then, training samples were selected for

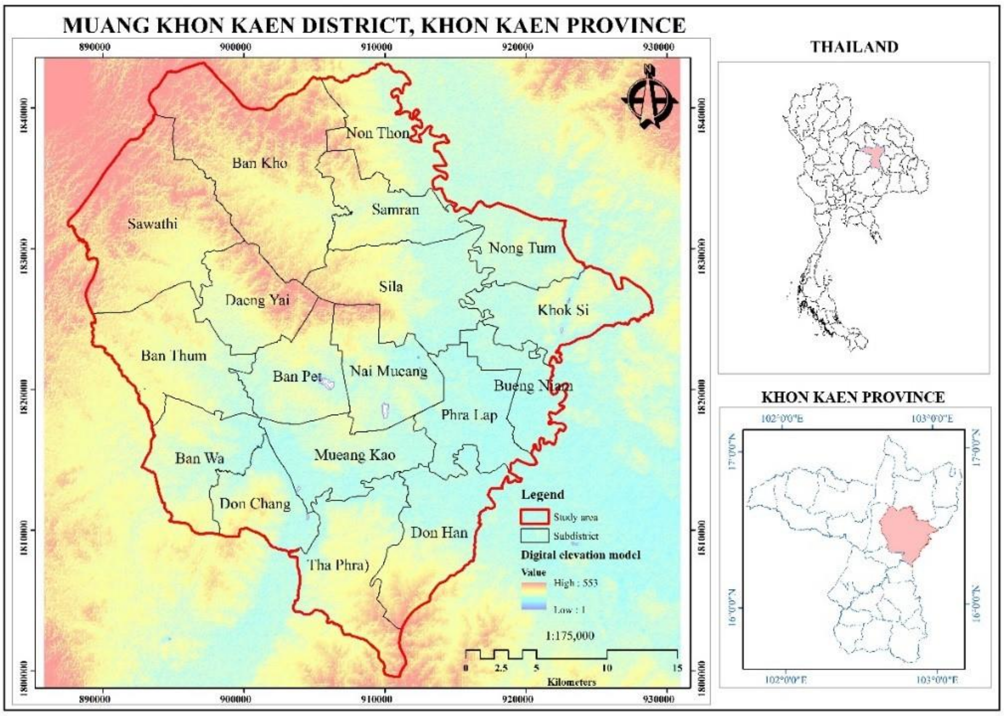


Figure 1. Location map of the study area

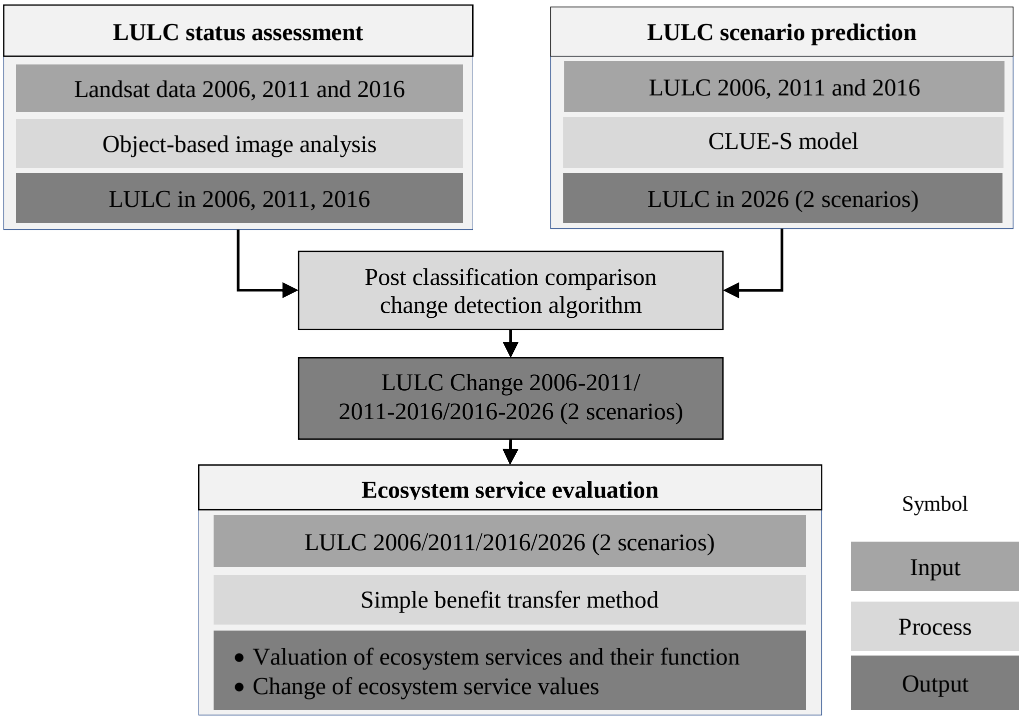


Figure 2. Workflow of research methodology

LULC classification with the standard nearest neighbor classifier based on optimized object features as suggested by Qian et al. (2015) with modification (Table 1). Most of the selected object features for LULC classification, namely mean value, standard deviation, brightness, and max. diff., were automatically created from six multispectral bands after image segmentation except for three spectral indices

(NDVI, NDWI, and LWM) which were generated as arithmetic object feature using corresponding equations (See Table 1). The NDVI, NDWI, and LWM were applied to quantify vegetation cover, wetness distribution, and land and waterbody in the study area, respectively.

Table 1. Object features used for the LULC classification.

Object feature	Description
Mean value	Mean value of a specific band of an image object
Standard deviation	Standard deviation of an image object
Brightness	Mean value of the six multispectral bands
Max. diff.	Maximum intensity difference of the six multispectral bands
NDVI	Normalized difference vegetation index: (NIR-Red)/(NIR+Red)
NDWI	Normalized difference water index: (Green-NIR)/(Green+NIR)
LWM	Land and water mask: (SWIR1/Green) *100

Modified from Qian et al. (2015) by adding LWM.

In this study, the LULC classification system, which was modified from the standard land use classification system in Thailand by the Land Development Department, was applied to classify LULC types under the eCognition software. They were comprised of (1) urban and built-up area; (2) paddy field; (3) field crop; (4) forest land; (5) water body; (6) marsh and swamp; (7) rangeland; and (8) unused land (abandoned land, bare land, pits and landfill).

After that, the accuracy assessment of thematic LULC data in three years was performed using overall accuracy and Kappa hat coefficient based on very high spatial resolution images of Google Earth in 2006, 2011 and field survey in 2017. In this study, 757 sample points based on the multinomial distribution theory with the desire a level of confident of 95% and a precision of 5% for the LULC class and the stratified random sampling were applied to assess accuracy (Congalton and Green, 2009).

Finally, the post-classification comparison changes detection algorithm (Jensen, 2015) was applied to detect LULCC between 2006 and 2016.

2.2.2 LULC prediction

The LULC data in 2011 with transitional LULC change matrix from 2006 to 2011 and driving factors on LULC change (elevation, slope, distance to existing urban area, distance to road network, distance to stream, average income per capita at subdistrict, land value in each land value zone, and population density at subdistrict) were firstly applied to predict LULC data in 2016 and its result was compared with the classified LULC in 2016 for CLUE-S model validation by using wall-to-wall accuracy assessment. If the Kappa hat coefficient is equal to or more than 80%, the derived configuration of the CLUE-S model is validated and further uses to predict two LULC scenarios. Based on Fitzpatrick-Lins (1981), the Kappa hat coefficient of more than 80% represents strong agreement or accuracy between two maps.

Characteristics of two scenarios, which were transformed based on reviewing relevant policy and plan of Khon Kaen province and discussed with stakeholders within the city, were proposed to define land requirement as the following.

Scenario I: Historical land use development, the land requirement for each LULC type in 2026 was based on the annual change rate of each LULC type from the transitional area matrix between 2011 and 2016 under the Markov Chain model.

Scenario II: Planning and policy, the existing urban planning map of Khon Kaen City from the Khon Kaen Public Works and Town and Country Planning Office (2017) and urban policy from the National Housing Authority (2012) were reviewed and transformed into a land requirement.

Finally, LULC status and its change were assessed again to describe LULC change between 2016 and 2026 of 2 scenarios.

2.2.3 Ecosystem service evaluation

The derived LULC data between 2006 and 2026 of 2 scenarios were used to calculate ESVs based on the simple benefit transfer method (Costanza et al., 1997) as:

$$\text{ESV}= \sum (\text{A}_k \times \text{VC}_k) \quad (1)$$

Where, ESV denotes the total value of ecosystem service, while A_k and VC_k represents the area and coefficient value for proxy LULC type ‘k’, respectively (Table 2).

Finally, ESV change was assessed by comparing the values of one dataset with the corresponding value of the second dataset in each period. Herein, the contribution ESV changes were calculated (Kindu et al., 2016) as:

$$\text{ESV change} = \left[\frac{\text{ESV final year} - \text{ESV initial year}}{\text{ESV initial year}}\right] \quad (2)$$

Where, positive values suggest an increase whereas negative values imply a decrease in the amount of USD, and the ESV changes are presented in percent.

Table 2. Coefficient value for different LULC types for ESV estimation

Ecosystem services category	Ecosystem services function	Ecosystem service value of each LULC type (USD/ha/year)							
		Urban and built-up area	Paddy field	Field crop	Forest land	Water body	Marsh and swamp	Range land	Unused land
Regulating services	1) Gas regulation	0	74.7	74.7	299.4	0	268.9	104	4.2
	2) Climate regulation	0	133.0	133	282.1	68.7	2,554.7	108	9.0
	3) Waste treatment	0	245.0	245	119.2	2,719.0	2,716.0	91.5	18.0
Supporting services	1) Soil formation	0	218.1	218.1	278.6	1.5	255.5	155	11.8
	2) Biodiversity protection	0	106.1	106.1	312.6	372	373.5	130	27.7
Provision services	1) Water supply	0	89.6	89.6	283.5	3,047.7	2,315.6	105	4.8
	2) Food production	0	149.4	149.4	22.9	14.9	44.8	29.8	1.4
	3) Raw materials	0	14.9	14.9	206.5	1.5	10.5	25	2.8
Cultural services	1) Recreation and culture	12.7	1.5	1.5	144.2	648.4	829.2	60.3	16.6
Total		12.7	1,032.3	1,032.3	1,949.0	6,873.7	9,368.7	808.6	96.3

Source: Modified from Mamat et al. (2018).

3. RESULTS AND DISCUSSION

3.1 Historical and recent LULC status and its change

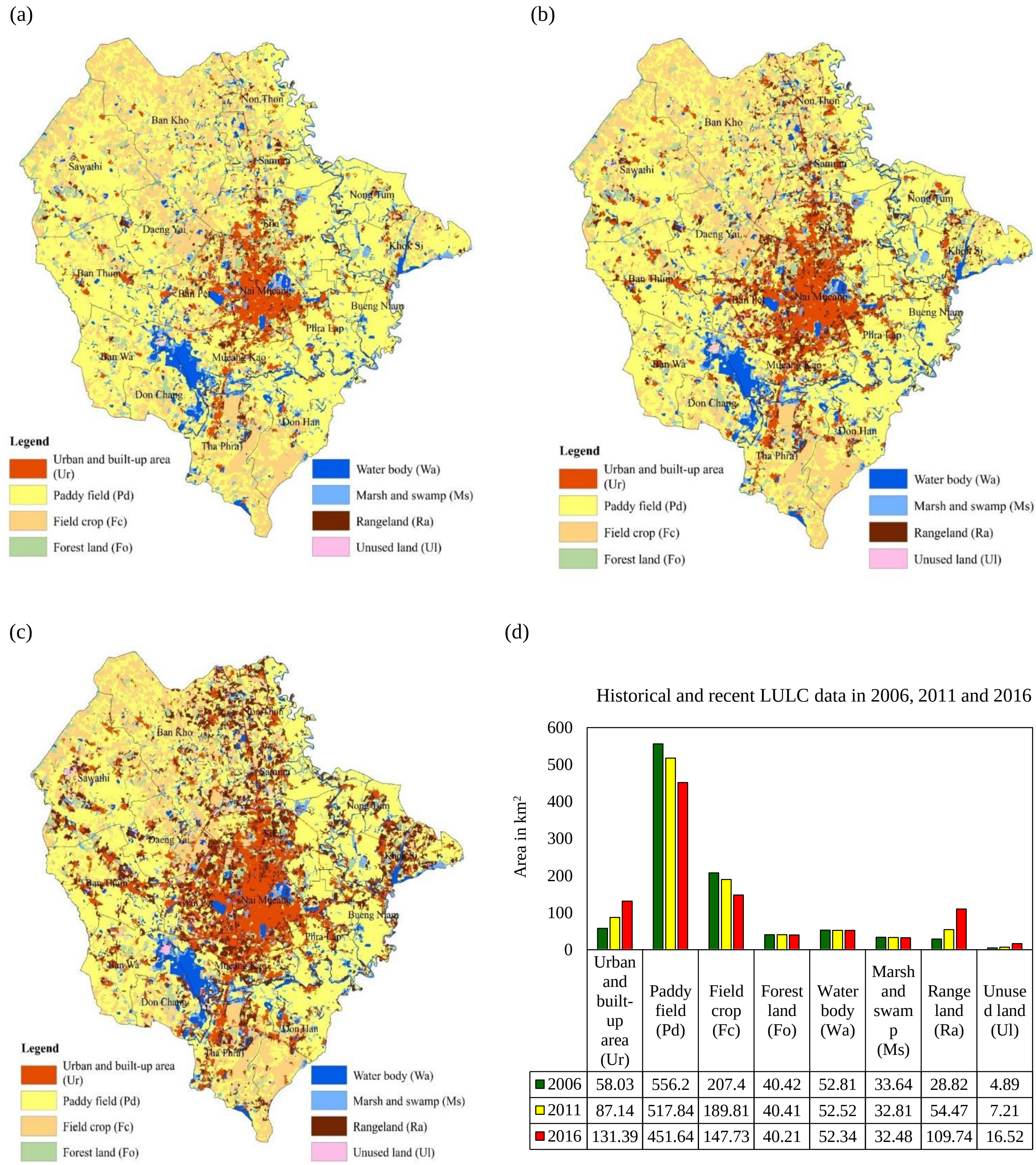
In 2006, 2011 and 2016, the top three dominant LULC types were paddy field, field crop and urban and built-up areas and covered 83.66%, 80.91%, and 74.44% of the total area, respectively (Figures 3(a)-(c)). In these periods, urban and built-up areas extraordinarily increased from 58.03 km^2 in 2006 to 131.39 km^2 in 2016 but paddy field and field crop notably decreased from 763.60 km^2 in 2006 to 599.37 km^2 in 2016 (Figure 3(d)). The derived overall accuracy and Kappa hat coefficient of the classified LULC maps in three years varied from 81.24% to 85.34% and 72.56% to 80.24%, respectively.

The transitional change matrix of LULC between 2006 and 2016 (Table 3) indicated that approximately 47 km^2 of paddy field and 22 km^2 of field crop in 2006 were converted to urban and built-up areas in 2016. This result shows transfiguration activity from rural to urban society in the city. This finding agreed with the study of Ninh and Waisurasingha (2018), who found that most of the agricultural lands were converted to urban and built-up areas between 1990 and 2015. In the meantime, paddy field (50 km^2) and field crop (32 km^2) in 2006 were altered to rangeland in 2016 because they were sold to businessmen and they abandoned them for high return in the future. This observation was consistent with the previous study of Phatchaney and Chamaratana (2018), who found agricultural lands in suburb areas of the city were sold to landlords.

3.2 Validation of CLUE-S model

The Kappa hat coefficient of the predicted

LULC in the 2016 map by the CLUE-S model when it was compared with the classified LULC in the 2016 map by OBIA was 81.51% (Table 4). As a result, the accurate value is more than 80% as required. Therefore, the CLUE-S model with the predefined parameters (land use type conversion matrix, land use type resistance) was accepted for LULC prediction in 2026 of 2 scenarios.



	Urban and built-up area (Ur)	Paddy field (Pd)	Field crop (Fc)	Forest land (Fo)	Water body (Wa)	Marsh and swamp (Ms)	Range land (Ra)	Unused land (Ul)
2006	58.03	556.2	207.4	40.42	52.81	33.64	28.82	4.89
2011	87.14	517.84	189.81	40.41	52.52	32.81	54.47	7.21
2016	131.39	451.64	147.73	40.21	52.34	32.48	109.74	16.52

Figure 3. Spatial distribution of LULC data in (a) 2006, (b) 2011, (c) 2016 and (d) comparison of LULC area in 2006, 2011, and 2016

Table 3. Land use and land cover change matrix between 2006 and 2016

LULC type in 2006	LULC type in 2016								
	Ur	Pd	Fc	Fo	Wa	Ms	Ra	Ul	Total
Urban and built-up area (Ur)	57.98	0.00	0.00	0.00	0.02	0.00	0.00	0.02	58.03
Paddy field (Pd)	47.15	451.36	0.01	0.00	0.05	0.01	50.08	7.54	556.20
Field crop (Fc)	22.07	0.00	148.02	0.00	0.01	0.00	32.07	5.22	207.40
Forest area (Fo)	0.10	0.00	0.00	40.21	0.10	0.00	0.00	0.00	40.41
Water body (Wa)	0.04	0.02	0.01	0.00	52.20	0.00	0.00	0.55	52.81
Marsh and swamp (Ms)	0.07	0.00	0.00	0.00	0.06	32.30	0.00	1.20	33.64
Rangeland (Ra)	2.22	0.00	0.00	0.00	0.00	0.00	26.60	0.00	28.82
Unused land (Ul)	2.12	0.00	0.00	0.00	0.00	0.00	0.49	2.28	4.89
Total	131.75	451.39	148.04	40.21	52.45	32.32	109.24	16.82	982.21
Area change (km^2)	73.72	-104.80	-59.36	-0.21	-0.37	-1.33	80.42	11.93	-
Annual change rate (km^2)	7.37	-10.48	-5.94	-0.02	-0.04	-0.13	8.04	1.19	-

Table 4. Error matrix for accuracy assessment for CLUE-S model validation

	LULC type	Predicted LULC in 2016 by CLUE-S model (number of pixel)								
		Ur	Pd	Fc	Fo	Wa	Ms	Ra	Ul	Total
Classified LULC in 2016 by	Urban and built-up area (Ur)	36,190	9,391	3,823	43	1	-	2,891	212	52,551
	Paddy field (Pd)	1,975	174,411	178	-	4	2	3,574	405	180,549
	Field crop (Fc)	364	-	58,095	-	4	1	686	47	59,197
	Forest land (Fo)	-	-	-	16,008	-	-	-	-	16,008
	Water body (Wa)	232	15	4	35	20,791	24	2	-	21,103
	Marsh and swamp (Ms)	313	3	-	-	2	12,610	-	-	12,928
	Rangeland (Ra)	2,036	12,617	8,448	-	-	1	20,674	6	43,782
	Unused land (Ul)	453	1,977	1,424	-	116	165	255	2,312	6,702
	Total	41,563	198,414	71,972	16,086	20,918	12,803	28,082	2,982	392,820
	Kappa hat coefficient in %	81.51	-	-	-	-	-	-	-	-

3.3 Future LULC status and its change

The logistics regression analysis, which was performed to identify LULC type location preference according to the driving force on LULC change in 2026 is summarized in Table 5. The most dominant driving factor for LULC type allocation, except unused land was a distance to the road network. On the contrary, land value factor was insignificant for each LULC type allocation because it was mostly evaluated based on road networks. The derived multiple linear equations for LULC type allocation provided area under the curve (AUC) values varied from fair to good fit between the predicted and real LULC transition (Pontius and Schneider, 2001). In the case of unused land, there was poor fit (AUC=0.60) because the unused land randomly occurs in the landscape, and it does not require specific conditions.

As a result, the top three dominant LULC types in 2026 of two scenarios were paddy field, urban and built-up area, and rangeland and covered of 75.23% and 75.49% of the total area, respectively (Figure 4(a) and 4(b)). In fact, the land requirement of each predictive LULC type in 2026 under Scenario I was estimated from the annual transitional area of LULC change between 2011 and 2016 by the Markov Chain model. In contrast, the trend of historical LULC development from 2011 to 2016 was modified for land requirement under Scenario II by updating the urban development area of the National Housing Authority and conservation agriculture area from the city plan of DTP. Van Asselen and Verburg (2013) stated that land requirement dictates the final area of each LULC type in the future under the CLUE-S model. The deviation values between the required and predicted areas of each LULC type both scenarios were very small and varied from -0.45 km^2 (underestimation) to 0.86 km^2 (overestimation). This finding confirms that the CLUE-S model can provide a good result for LULC prediction.

In addition, the major decreased LULC classes of both scenarios between 2016 and 2026 were paddy field and field crop with an annual rate of 10.88, 5.70 km^2, and 10.93, 5.74 km^2, respectively. On the other hand, the main increased LULC classes in the same period were urban and built-up areas, rangeland, and unused land with an annual rate of 8.59, 6.90, 1.26 km^2, and 9.26, 6.53, 1.23 km^2, respectively (Table 6 and Table 7). The increase of urban and built-up areas mainly came from the paddy field, field crop, and rangeland.

Table 5. Identified driving force for each LULC type allocation and multiple linear equations

No.	LULC type	Multiple linear equation	AUC
1	Urban and built-up area	$\text{Log}\left(\frac{P_i}{1-P_i}\right)$ = -4.35838+0.00448X_1-0.00081X_3-0.00375X_4+0.00028X_5+ 0.00001X_6+0.0031X_8	0.821
2	Paddy field	$\text{Log}\left(\frac{P_i}{1-P_i}\right)$ = 376717 -0.02119X_1-0.07755X_2+0.00015X_3+0.00101X_4 - 0.00019X_5-0.00256X_8	0.814
3	Field crop	$\text{Log}\left(\frac{P_i}{1-P_i}\right)$= -7.04349 +0.03491 X_1+0.07137 X_2+0.00017 X_3-0.00024 X_4+0.00075X_5-0.00891X_8	0.852
4	Forest land	$\text{Log}\left(\frac{P_i}{1-P_i}\right)$= -6.27343+0.01847$X_1$+ 0.06303$X_2-0.00082X_4$	0.638
5	Rangeland	$\text{Log}\left(\frac{P_i}{1-P_i}\right)$= -3.49416+0.05407$X_2-0.00031X_3-0.0013X_4$+0.00001$X_6$	0.779
6	Marsh and swamp	$\text{Log}\left(\frac{P_i}{1-P_i}\right)$= 2.25337-0.03215 X_1+0.00031X_3+0.00089X_4-0.00124X_5	0.708
7	Water body	$\text{Log}\left(\frac{P_i}{1-P_i}\right)$ = 3.02175-0.03635X_1-0.05361X_2+0.00034X_3+0.00163X_4- 0.00219X_5	0.659
8	Unused land	$\text{Log}\left(\frac{P_i}{1-P_i}\right)$= -5.1179+0.0580$X_2$	0.600

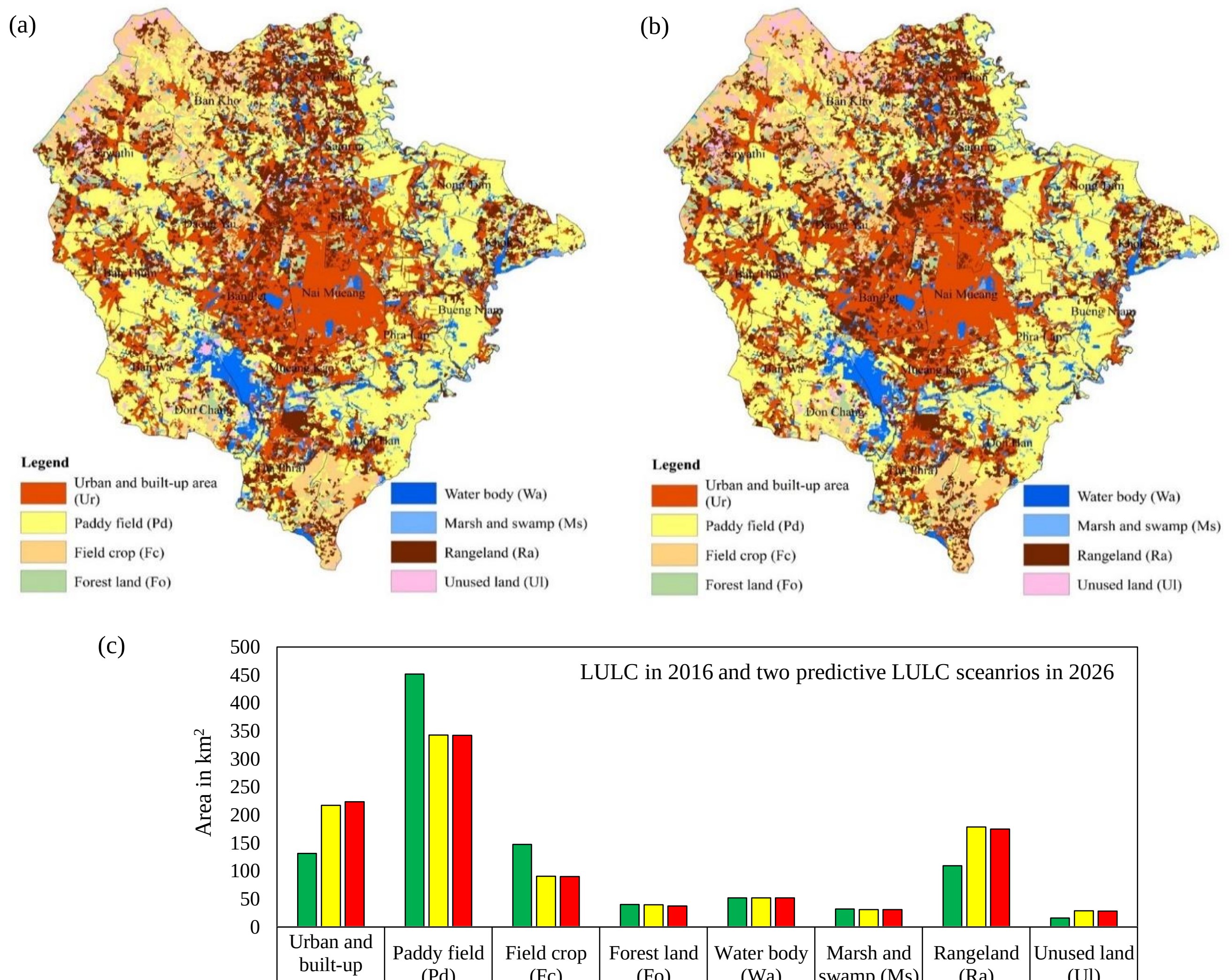
Note: X_1 is elevation (m), X_2 is slope (%), X_3 is distance to the existing urban area (m), X_4 is distance to road network (m), X_5 is distance to streams (m), X_6 is average income per capita at sub-district level (baht/year), X_8 is population density at sub-district level (persons/km^2).

Table 6. Land use and land cover change matrix between 2016 and 2026 of Scenario I

LULC type		LULC 2026 Scenario I: Area in km^2								
		Ur	Pd	Fc	Fo	Wa	Ms	Ra	Ul	Total
LULC 2016	Urban and built-up area (Ur)	114.95	3.95	0.53	1.3	1.34	1.05	7.38	0.89	131.39
	Paddy field (Pd)	65.25	319.29	4.78	2.43	4.31	3.19	43.21	9.18	451.64
	Field crop (Fc)	14.25	5.3	83.45	1.01	0.58	0.51	35.79	6.84	147.73
	Forest land (Fo)	2.2	1.47	0.52	33.23	0.38	0.21	1.93	0.27	40.21
	Water body (Wa)	2.57	3.94	0.2	0.26	42.22	1.07	1.62	0.46	52.34
	Marsh and swamp (Ms)	2.36	2.86	0.14	0.21	1.46	24.34	0.96	0.15	32.48
	Rangeland (Ra)	12.73	5.01	0.94	1.41	1.38	0.82	86.39	1.06	109.74
	Unused land (Ul)	2.96	1.02	0.14	0.18	0.4	0.15	1.42	10.25	16.52
Total		217.27	342.84	90.7	40.03	52.07	31.34	178.7	29.1	982.05
Area change (km^2)		85.88	-108.80	-57.03	-0.18	-0.27	-1.14	68.96	12.58	
Annual change rate (km^2)		8.59	-10.88	-5.70	-0.02	-0.03	-0.11	6.90	1.26	

Table 7. Land use and land cover change matrix between 2016 and 2026 of Scenario II.

LULC type		LULC 2026 Scenario II: Area in km^2								
		Ur	Pd	Fc	Fo	Wa	Ms	Ra	Ul	Total
LULC 2016	Urban and built-up area (Ur)	115.51	4.43	0.52	1.25	1.34	1.06	6.54	0.74	131.39
	Paddy field (Pd)	60.82	313.81	4.73	2.29	4.31	3.2	48.54	13.94	451.64
	Field crop (Fc)	19.47	7.29	83.16	1	0.58	0.51	31.77	3.95	147.73
	Forest land (Fo)	2.89	2.55	0.51	31.53	0.38	0.21	1.9	0.24	40.21
	Water body (Wa)	2.58	3.98	0.2	0.21	42.28	1.08	1.68	0.33	52.34
	Marsh and swamp (Ms)	2.13	3.06	0.14	0.2	1.47	24.43	0.97	0.08	32.48
	Rangeland (Ra)	16.65	5.44	0.92	1.28	1.37	0.84	82.23	1.01	109.74
	Unused land (Ul)	3.94	1.77	0.15	0.18	0.4	0.15	1.36	8.57	16.52
Total		223.99	342.33	90.33	37.94	52.13	31.48	174.99	28.86	982.05
Area change (km^2)		92.60	-109.31	-57.40	-2.27	-0.21	-1.00	65.25	12.34	-
Annual change rate (km^2)		9.26	-10.93	-5.74	-0.23	-0.02	-0.10	6.53	1.23	-



	Urban and built-up area (Ur)	Paddy field (Pd)	Field crop (Fc)	Forest land (Fo)	Water body (Wa)	Marsh and swamp (Ms)	Rangeland (Ra)	Unused land (Ul)
2016	131.39	451.64	147.73	40.21	52.34	32.48	109.74	16.52
2026 of Scenario I	217.27	342.84	90.7	40.03	52.07	31.34	178.7	29.1
2026 of Scenario I	223.99	342.33	90.33	37.94	52.13	31.48	174.99	28.86

Figure 4. Spatial distribution of predictive LULC data in 2026: (a) Scenario I, (b) Scenario II and (c) comparison area of LULC in 2016 and 2026 of Scenario I and II (cont.).

3.4 Estimation of ecosystem service values

The estimation of ESVs according to LULC types (Table 8) revealed that in the past periods, the top four dominant LULC types (paddy field, water bodies, marsh and swamp, and field crop) contributed ESVs in 2006, 2011, and 2016 about 93.42%, 91.82% and 88.29% of total ESVs, respectively. Meanwhile, in the future time, the top four dominant LULC types contributed for ESVs in 2026 of two scenarios were water bodies, paddy field, marsh and swamp and rangeland which accounted for 86.64% and 86.84% of the total ESVs, respectively. Subsequently, the high rate of decline of LULC types has considerably negative ESVs in the study area.

Table 8. Estimation of ecosystem service values according to LULC type

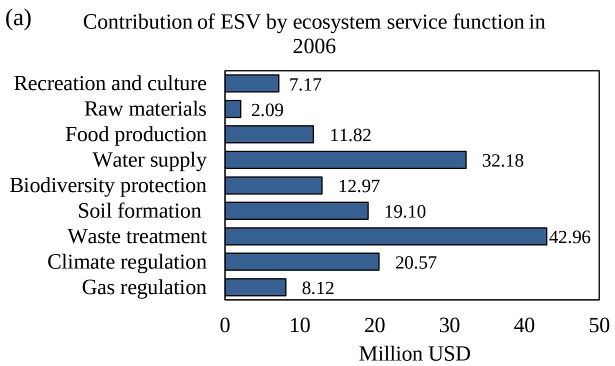
ESVs in MM USD

LULC type	2006		2011		2016		2026 of Scenario I		2026 of Scenario II	
	ESV	%	ESV	%	ESV	%	ESV	%	ESV	%
Urban and built-up area	0.07	0.04	0.11	0.07	0.17	0.12	0.28	0.21	0.28	0.21
Paddy field	57.42	36.58	53.46	35.09	46.60	32.09	35.39	26.67	35.34	26.76
Field crop	21.41	13.64	19.59	12.86	15.28	10.52	9.37	7.06	9.32	7.06
Forest land	7.88	5.02	7.88	5.17	7.84	5.40	7.80	5.88	7.39	5.60
Water bodies	36.30	23.12	36.10	23.70	36.05	24.83	35.78	26.96	35.82	27.12
Marsh and swamp	31.52	20.08	30.74	20.18	30.28	20.85	29.36	22.12	29.49	22.33
Rangeland	2.33	1.48	4.40	2.89	8.83	6.08	14.45	10.89	14.16	10.72
Unused land	0.05	0.03	0.07	0.05	0.16	0.11	0.28	0.21	0.28	0.21
Total	156.98	100	152.35	100	145.21	100	132.71	100	132.08	100

In addition, the contribution of ESVs by ecosystem service functions (ESFs) over the study period revealed that the top three dominant ESFs were waste treatment, water supply, and climate regulation but ESVs of these functions continuously decreased, because areas of paddy field and field crop which plays a significant role in these functions continuously decreased (Figures 5(a)-(e)). For instance, ESVs of waste treatment declined from 42.96 MM USD in 2006 to 35.42 in 2026 under Scenario II. Likewise, ESVs of water supply dropped from 32.18 MM USD in 2006 to 29.98 in 2026 under Scenario II.

3.5. Changes in ecosystem services values

The changes in ESVs discovered a significant decrease in the total ESVs over the study period (Table 9). The total amount of changes of ESVs from 2006 to 2011 was 4.63 MM USD or 2.95% of the total value in 2006 and it further decreased from 2011 to 2016 with an amount of 7.14 MM USD or 4.69% of the total value in 2011. Meanwhile, the changes in ESVs of Scenario I from 2016 to 2026 was 12.50 MM USD or 8.61% of the total value in 2016 whereas the changes in ESVs of Scenario II was 13.13 MM USD or 9.04% of the total value in 2016. This finding indicated the effect of LULCC under Scenario II (based on the existing plan and policy) on ESVs is higher than Scenario I (based on historical land use development).



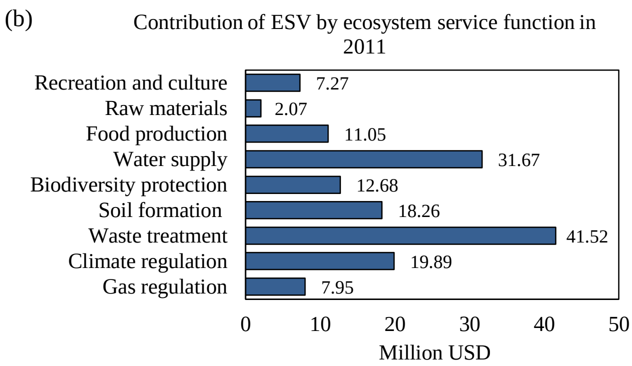


Figure 5. Contribution of ecosystem service value between 2006 and 2026 (2 scenarios) by its function and category.

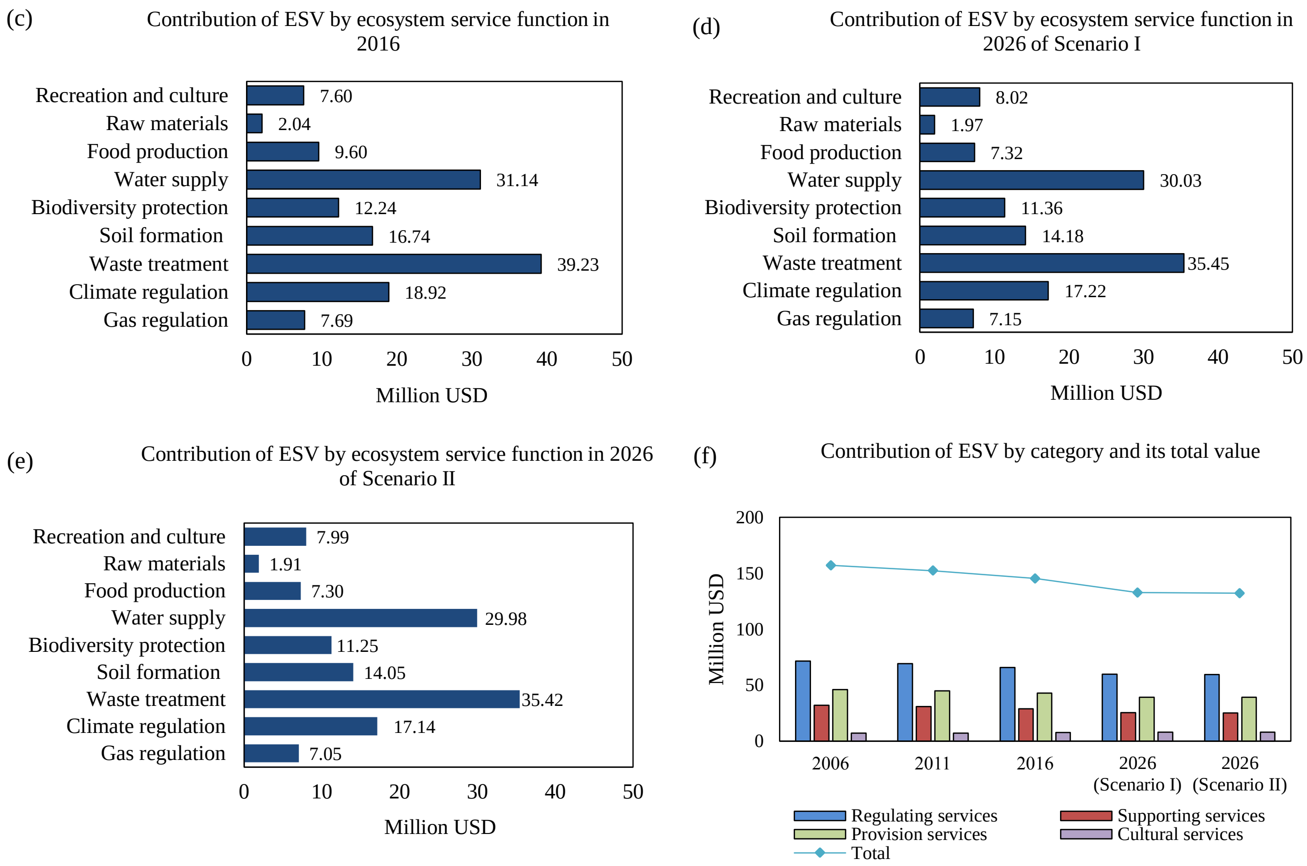


Figure 5. Contribution of ecosystem service value between 2006 and 2026 (2 scenarios) by its function and category (cont.).

Table 9. Changes in ecosystem services values in the historical, recent and future periods

LULC type	2006-2011		2011-2016		2016-2026 of Scenario I		2016-2026 of Scenario II	
	MM USD	Proportion (%)	MM USD	Proportion (%)	MM USD	Proportion (%)	MM USD	Proportion (%)
Urban and built-up area	0.04	57.14	0.06	54.55	0.11	64.71	0.11	64.71
Paddy field	-3.96	-6.90	-6.86	-12.83	-11.21	-24.06	-11.26	-24.16
Field crop	-1.82	-8.50	-4.31	-22.00	-5.91	-38.68	-5.96	-39.01
Forest land	0.00	0.00	-0.04	-0.51	-0.04	-0.51	-0.45	-5.74
Water bodies	-0.20	-0.55	-0.05	-0.14	-0.27	-0.75	-0.23	-0.64
Marsh and swamp	-0.78	-2.47	-0.46	-1.50	-0.92	-3.04	-0.79	-2.61
Rangeland	2.07	88.84	4.43	100.68	5.62	63.65	5.33	60.36
Unused land	0.02	40.00	0.09	128.57	0.12	75.00	0.12	75.00
Total	-4.63	-2.95	-7.14	-4.69	-12.50	-8.61	-13.13	-9.04

In addition, the changes in ESVs revealed a significant decrease or increase in ESVs from diverse LULC types in different periods (see Table 9). The decrease of ESVs between 2006 and 2011 is mostly represented by paddy field, field crop and marsh and swamp that accounted for 6.29 MM USD while the increase of ESVs in the same period characterized by rangeland, urban and built-up area and unused land that accounted for a total of 2.13 MM USD. Similarly, the decrease of ESVs was mostly represented by paddy field, field crop, and marsh and swamp between 2011 and 2016, while the increase of ESVs was characterized by rangeland, unused land, and urban and built-up area in the same period. Likewise, the decrease of

ESVs between 2016 and 2026 of two scenarios is also represented by paddy field, field crop, and marsh and swamp, whereas the increase of ESVs is also characterized by rangeland, unused land and urban and built-up areas.

Furthermore, the changes in ESVs by ESFs exposed a significant decrease of almost all functions except recreation and culture under cultural service in all periods (Table 9). As a result, waste treatment under regulation service had considerably decreased from 1.44 MM USD in the period of 2006-2011 to 3.81 MM USD in the period of 2016-2026 (Scenario II). Likewise, soil formation under supporting service had significantly decreased from 0.84 MM USD in the period of 2006-2011 to 2.69 MM USD in the period of 2016-2026 (Scenario II) and food production under provision service had significantly decreased from 0.76 MM USD between 2006 and 2011 to 2.30 MM USD between 2016 and 2026 (Scenario II). On the contrary, recreation and culture under cultural service had slightly increased from 0.10 MM USD in the period of 2006-2011 to 0.41 MM USD between 2016 and 2026 (Scenario I).

3.5 Impact of LULCC on ecosystem service values

The impact of LULCC on ESVs noticeably differed among the LULC types as observed in the contributions of the area and ESV for each LULC type over the study periods (Figure 6). In particular, the paddy field declined about 556 km^2 (56.63%) in 2006 to 342 km^2 (34.86%) in 2026 under Scenario II and field crop declined from about 207 km^2 (21.12%) in 2006 to 90 km^2 (9.20%) in 2026 under Scenario II. (See Figures 3(d) and Figure 4(c)). Consequently, the total ESVs significantly decreased over the study periods. The ESV of paddy field decreased from 3.96 MM USD in 2006 to 11.26 MM USD in 2026 under Scenario II. Similarly, the ESV of field crop dropped from 1.82 MM USD in 2006 to 5.96 MM USD in 2026 under Scenario II.

The change in the agriculture ecosystem (paddy field and field crop) significantly affected the changes in the total ESVs during the entire study period. Herein, the total ESVs of agriculture ecosystem declined by 17.22 MM USD from 2016-2026 of Scenario II while the total ESVs in the study landscape decreased by 13.13 MM USD (Table 10). On the contrary, areas of urban and built-up areas and rangeland constantly increased over the study periods. Particularly, areas of urban and built-up areas and rangeland significantly increased about 58 km^2 (5.91%) and 29 km^2 (2.94%) in 2006 to 224 km^2 (22.81%) and 175 km^2 (17.83%) in 2026 under Scenario II, respectively. (See Figures 3(d) and Figure 4(c)). However, the corresponding ESV of urban and built-up areas and rangeland showed only a slight increase from 2.4 MM USD in 2006 to 14.44 MM USD in 2026 under Scenario II compared to the area expansion of both land use types. Consequently, based on the simple benefit transfer method of Costanza et al. (1997) with the modified coefficient of ESVs from Mamat et al. (2018), the overall trends of ESVs as a result of LULC changes were similar (Figure 6).

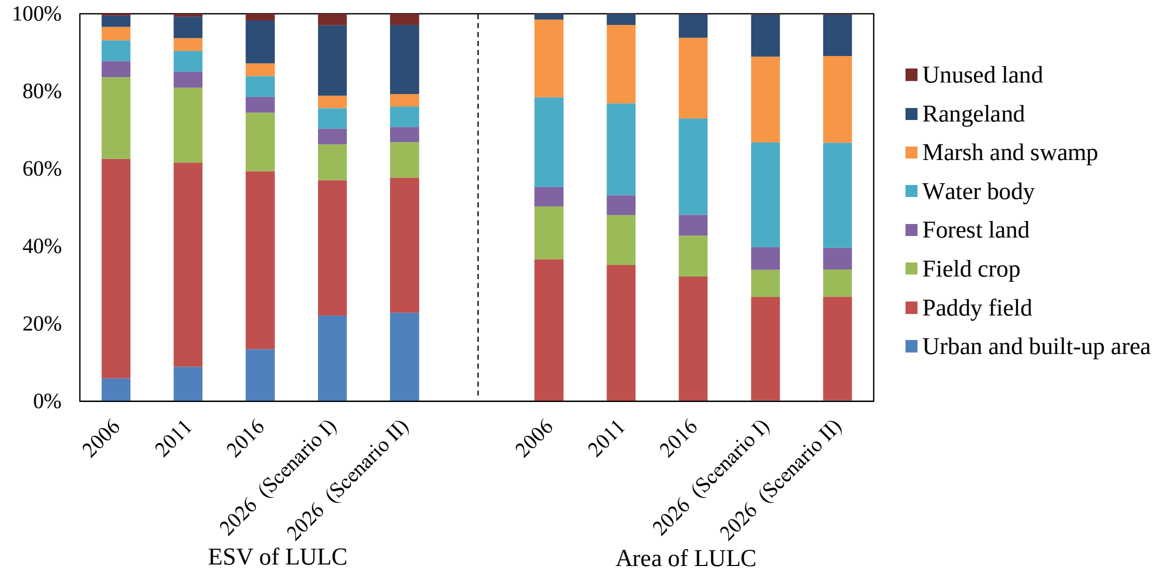


Figure 6. Area and ecosystem services value contribution of LULC types in different years.

Table 10. Changes in ecosystem services values by ecosystem service function and categories in different periods

Ecosystem services categories	2006	2011	2016	2026 SC-I	2026 SC-II	2006-2011	2011-2016	2016-2026 SC-I	2016-2026-SC-I	2006-2011	2011-2016	2016-2026 SC-I	2016-2026 SC-II
Ecosystem services function	MM USD	MM USD	MM. USD	MM USD	MM USD	MM USD	MM USD	MM USD	MM USD	%	%	%	%
Regulating services													
Gas regulation	8.12	7.95	7.69	7.15	7.05	-0.17	-0.25	-0.54	-0.65	-2.13	-3.19	-7.06	-8.41
Climate regulation	20.57	19.89	18.92	17.22	17.14	-0.68	-0.97	-1.70	-1.78	-3.30	-4.88	-9.00	-9.40
Waste treatment	42.96	41.52	39.23	35.45	35.42	-1.44	-2.29	-3.78	-3.81	-3.34	-5.51	-9.64	-9.71
Supporting services													
Soil formation	19.10	18.26	16.74	14.18	14.05	-0.84	-1.52	-2.56	-2.69	-4.41	-8.31	-15.27	-16.06
Biodiversity protection	12.97	12.68	12.24	11.36	11.25	-0.30	-0.44	-0.88	-1.00	-2.28	-3.44	-7.19	-8.13
Provision services													
Water supply	32.18	31.67	31.14	30.03	29.98	-0.51	-0.53	-1.10	-1.16	-1.59	-1.68	-3.54	-3.73
Food production	11.82	11.05	9.60	7.32	7.30	-0.76	-1.46	-2.27	-2.30	-6.46	-13.16	-23.70	-24.00
Raw materials	2.09	2.07	2.04	1.97	1.91	-0.02	-0.03	-0.08	-0.13	-0.94	-1.27	-3.67	-6.30
Cultural services													
Recreation and culture	7.17	7.27	7.60	8.02	7.99	0.10	0.34	0.41	0.38	1.39	4.66	5.44	5.06
Total	156.97	152.35	145.21	132.71	132.09	-4.62	-7.14	-12.50	-13.13	-2.94	-4.69	-8.61	-9.04

4. CONCLUSION

The use of geoinformatics technology and land use and cover change model were successfully applied to classify and predict LULC for assessing LULCC impact on ESVs in the study area. The impact of LULCC on ESVs noticeably differed among the LULC types according to area and ESVs for each LULC type over the study periods. The study revealed that areas of paddy field and field crop declined from about 763 km^2 (77.75%) in 2006 to 432 km^2 (44.06%) in 2026 under Scenario II. On the contrary, areas of urban and built-up areas and rangeland significantly increased from about 57 km^2 (8.85%) in 2006 to 399 km^2 (40.64%) in 2026 under Scenario II. Consequently, the total ESVs significantly decreased over the study periods. The change in the agriculture ecosystem (paddy field and field crop) greatly affected the changes in the total ESVs in the study area during the entire study period. The ESV of paddy field and field crop declined by about 17 MM USD, while the total ESVs in the study landscape decreased by about 13 MM USD. The impact of LULCC under Scenario II on ESVs is higher than Scenario I even though the conservation agriculture area of 65 km^2 was protected under Scenario II. Subsequently, land use and city planners should try to minimize the effect of LULCC on ecosystem service functions during the planning process. This research framework is expected to serve as a guideline for land use and city planners to allocate an optimum LULC scenario for balancing the economic development and ecosystem health in the future. Additionally, the local coefficient value of ecosystem services should be examined in more detail for each LULC type when ESVs were estimated based on the simple benefit transfer method.

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