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Monitoring the land use/land cover changes and simulation by using the CA-Markov model-a case study in Bang Lamung district, Pattaya city, Chon Buri province, Thailand

Wiboonwatchara, B. [1,2*], Shu, H.[2] and Soytong, P.[1]

[1]Faculty of Geoinformatics, Burapha University, Chon Buri Campus, Saen Sook, Mueang, Chonburi, Thailand; [2]State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing (LIESMARS) Wuhan University, Wuhan 430079, China.

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Abstract The land use/land cover (LULC) changes in Bang Lamung District by using a Cellular Automata-Markov (CA-Markov) model was investigated. The results showed that the first scenario is shown to be spontaneous in LULC change. There has been increased in the built-up areas over the past few decades, with the highest growth since 2009-2032 in the built-up areas with an average annual change of 94.83%. The agriculture areas have been steadily decreasing with an average annual change of -46.41%. The second scenario is shown to be the green area improvement. The study found that the green area would be remained sufficient for the population in 2027 and 2032. However, the annual change rate of green area per population tended to decrease, especially in the areas of Pattaya City such as Nong Pa Lai Sub-district, Bang Lamung Sub-district, and Na Kluea Sub-district. The third scenario is shown to be the area comprehensive town plan. A comparison of the simulation results of the LULC map in 2027 and 2032 with the current Bang Lamung Town Plan found that the urban expansion area has changed according to the overall town plan. The results indicated that the built-up area is expected to increase by an annual change of 13.10%, while the area used for agriculture is expected to decrease by an annual change of -55.99%. The distribution of controlled and protected areas is revealed inconsistent with the town plan due to the inefficiency of government officials. These land use changes will be useful in planning the urban administration and management of Bang Lamung City to accommodate the growth of the EEC project.

Keywords: Land use/land cover changes, CA-Markov model, EEC, Pattaya City

Introduction

Urbanization and industrialization have become key issues affecting the land use/land cover (LULC) system. LULC has a widespread influence in many fields, not only in urban planning but also in transportation, environment, policy, and economy (Wang *et al.,* 2018). For developed and developing countries,

* **Corresponding Author:** Wiboonwatchara, B.; **Email:** bawonluck.8@gmail.com

LULC is divided into two categories, i.e. urban redevelopment and urban growth (Barney, 2006). Compared with developing countries, the trend of LULC changes in industrialized countries is more important in creating a green and fertile environment and enhancing comprehensive competitiveness in the world (Pielke *et al*, 2011). The Urbanization and industrialization transformative process, which represents the shift from 'rural' to 'urban' is rapidly changing the face of Thailand. Bangkok's recent transformation from a sprawling metropolitan region to the Eastern Seaboard of Thailand as the "Eastern Economic Corridor" (EEC) is a developing economic region.

EEC is the enhancement of the former Eastern Seaboard (ESB). This massive investment is Thailand's Special Economic Zone (SEZ) and is currently the leading economic zone in ASEAN attracting multinational companies to invest, especially in the automotive, petrochemical, and electronics industries. Leading to the establishment of 30 industrial estates and over 5,000 factories. With this highly successful development of the area, exports in the Eastern Seaboard area have increased from 7% to 12% and the industry in the area has grown 12% over the past 20 years (Eastern Economic Corridor (EEC) Office, 2019).

Bang Lamung is a district which is a coastal area located in Chonburi Province. In the recent decade, we have witnessed the rapid growth of Bang Lamung City and the surrounding region initiated by EEC allocation and development for new urban planning, industrial parks, tourism, and the main logistics connection model in the region. In addition, Pattaya city is one of the potential centers for tourism, services, and foreign investment that promoted by the government. Moreover, the government continues to focus on roadmaps for technological transformation into smart cities, creating a hub for the activities of economy, investment, and tourism in this area. These are growing urbanization which puts pressure on green spaces due to the demand for green environments and comfort of living (Waddell, 2002). To maintain the balance, the LULC change is therefore an important task for governments and city planners to formulate policies to regulate the land use development.

LULC change has been recognized as one of the most important indicators for global and regional eco-environmental changes (Alam *et al.*, 2021). Remote Sensing and GIS approaches combined with multispectral satellite data have been commonly used for the acquisition of LULC information (Singh *et al*, 2016). Using remote sensing and GIS techniques can be utilized for the measurement of LULC change detection (Aburas *et al*, 2016). The simulation of LULC has become one significant application in urban studies involving spatial modeling.

The combination of remote sensing data and CA-Markov models can be used to build a model of LULC, which is an important tool for evaluating and managing the land use policies (Yulianto *et al.,* 2018). The CA-Markov model is combined with the cellular automata model and the Markov model. The Markov model is a statistical model that computes the probability matrix of the transition between two states by using the transition probability matrix. The state of future time periods can be simulated from the state of previous time periods (Arsanjani *et al*, 2013). The LULC simulation would be considered three scenarios: spontaneous, green area improvement, and area comprehensive plan scenarios. This research can serve the municipal office for developing the land use planning and provide information about the LULC change situation in Bang Lamung district.-The purpose of research finding was to analyse the dynamics and trends of LULC, especially in industries and settlements. The situation of LULC in Bang Lamung District are proved to simulate using the Cellular Automata Markov (CA-Markov) models.

Materials and methods

ALOS remote sensing images (AVNIR-2) and Sentinel 2A and 2B were used for LULC base map generation. To ensure the accuracy of the extracted LULC maps, all acquired images are cloud-free (<10%) and taken in the same season in 2009, 2011, 2017, and 2022. In pre-processing stage followed by the atmospheric and radiometric corrections are performed. For geometric correction, all data from ALOS (AVNIR-2) and Sentinel -2 have been already geometrically resolved. Techniques for classifying images come in several forms. The satellite image is digitized to create LULC maps based on the researcher's knowledge of the study area. To analyze the dynamics of LULC, the classification of LULC is categorized into major classes and sub-classes. The major classes are grouped into 3 types following three major types of Bang Lamung city plan. The sub-classes are grouped into 5 types of land use such as built-up, agriculture, open space, forest, and water bodies. This sub-class is based on the Land Development Department (LDD), Thailand. The details of LULC classes are described in Table 1.

The accuracy assessment process is taken to classify the LULC 2022 map which derives from the satellite image compared to the same area in the field. The sample ground truth is 200 points. In this study, the method of accuracy assessment is based on ground truth in order to derive the accuracy of classification images and calculate the error matrix. The result of the accuracy assessment provides overall accuracy, user's accuracy, and producer's accuracy of the LULC map.

Table 1. Land use/land cover class details

Major class	Sub-class name	Class Description
Urbanization area	Built-up	Includes artificial constructions (e.g., concrete, urban areas, industrial areas) including golf course
Control area	Agriculture	Cultivated agriculture including crops, farms, and orchards.
	Open space	Bare soils, bushes, dry land, and meadows including grass along the river and canal
Protect area	Forest	Forest and nation park
	Water bodies	Includes both natural and artificially created water bodies such as rivers and ponds.

The cellular automata-Markov (CA-Markov) model is composed of the cellular automata model and the Markov model. The Markov model is a statistical model for calculating the transition probability matrix between two states. By combining the cellular automata model and the Markov model, the spatiotemporal distribution of LULC can be simulated (Gong *et al*, 2013). The component of a CA-Markov model is a Markov model. A Markov LULC model takes into consideration temporal transitions through a Markovian process. In a Markovian process, the status of a cell in period t + 1 is characterized by its status in the previous period. The change from one period to another is defined by the transition probability matrix (Hyandye and Martz, 2017) which can be described in a matrix as follows formula (1).

$$P = P_{ij}, \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Here P_{ij} denotes the probability of changing from a status i to a status j. The probability has the following formula (2) and (3).

$$\sum_{j=1} P_{ij} = 1, \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$0 \leq P_{ij} = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Therefore, a Markov model has the following formula (4).

$$P_{(N)} = P_{(N-1)}P_{ij} = P_{(0)}{P_{ij}}^{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

For the model validation, the simulated LULC 2022 is compared to the actual LULC 2022 by using the Kappa Indices of Agreement and related statistics (Landis and Koch, 1977) for calibration. After the model is validated, it will be

used to simulate LULC for the years 2027 and 2032. The LULC of 2022 is simulated by using the 2011 and 2017 LULC maps to measure the agreement between two images: the "comparison" map (simulated LULC 2022 map) and the "reference" map (actual LULC 2022 map). The comparison map is generated by the CA-Markov model, which must be validated against the reference map representing reliability.

Results

Study area

Bang Lamung is a district in Chonburi province which is located in the eastern region of Thailand and approximately 142 kilometers away from Bangkok. Bang Lamung District covers an area of 524.87 sq.km. The coordination of the study area is between 701000 E to 728000 E and 1412000 N to 1447000 N in WGS 84/ UTM zone 47N (Figure 1). The study area has a total population of 328,961 people (2022) and a population density of approximately 626 people/ sq.km, which is classified as a big-sized city (Pattaya City) according to the Criteria and Standards of Town Planning (DPT) 2006 of Thailand. Bang Lamung is divided into eight sub-districts.

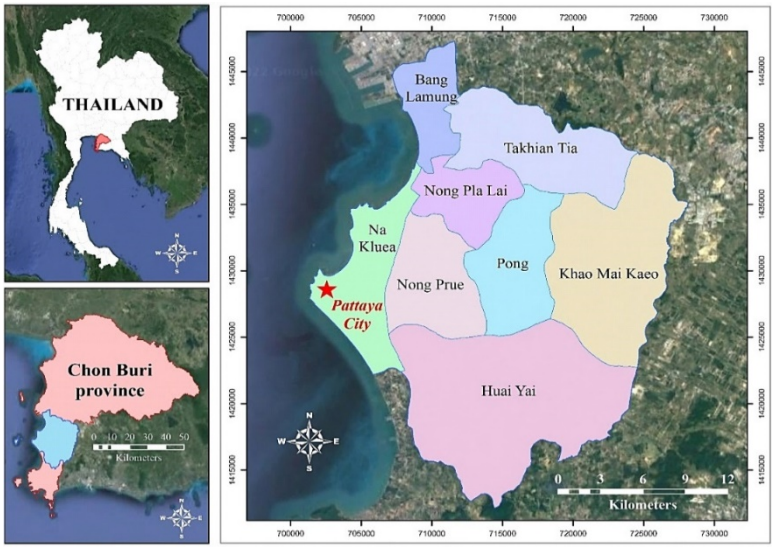

Figure 1. The location of Bang Lamung district.

Pattaya City is a special municipality in Bang Lamung District that is considered a Special Administrative Region just like Bangkok as an Autonomous

Region located in the eastern part of Thailand. Pattaya City is planned to be a growth center for the central area of Bang Lamung District.

Land Use/Land Cover Classification

The LULC maps from the study are classified into 5 categories: built-up, agriculture, open space, forest, and water bodies. ALOS (AVNIR-2) and Sentinel 2 images are used to extract classified LULC maps from 2009 to 2022. In this study, the LULC classified maps of 2017 and 2022 are used to generate a transition map, which is then input into the CA-Markov model to simulate LULC in 2027 and 2032. The simulations are conducted for analysing under 3 scenarios as follows:

The spontaneous scenario

The spontaneous scenario describes a historical situation in which the observed LULC trend between 2017 and 2022 is stable through 2027 and 2032. The simulation results presented in Figure 2 show that the coastal areas consist mainly of built-up areas, with some visible urban development in the west inland areas by 2027 and 2032.

The result presented for the LULC map simulation in 2027 and 2032 is shown in Table 2. As of 2022, the built-up area accounted for 42.25% (221.78 sq. km) of the district area and increased by 48.13% (252.63 sq. km) and the built-up area is expected to be 52.30% (274.51 sq. km) in 2027 and 2032, respectively. On the contrary, the proportion of agriculture area is expected to decrease by 27.04% (141.95 sq. km) and 22.56% (118.42 sq. km) in 2027 and 2032, respectively. These simulation results showed that with normal LULC change, agriculture areas can be replaced by built-up areas. The highest projected growth is highlighted from 2009 to 2032 in the built-up areas with an average annual change of 94.83% as shown in Table 3. However, agriculture areas and open spaces are expected to decline at an average annual change of -46.41% and -25.29%, respectively. In addition, forest areas and water bodies are also projected to experience slight decreases at an annual average change of -5.41% and -4.52%, respectively.

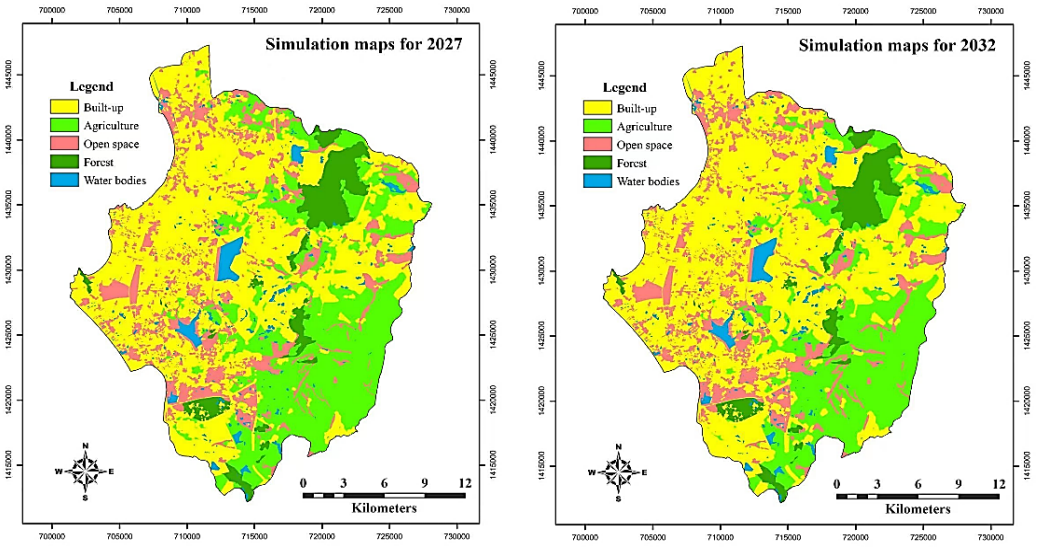

Figure 2. The simulation LULC map of 2027 and 2032 in Bang Lamung district

Table 2. The simulated LULC areas for 2027 and 2032 under the spontaneous scenario

Land use Class	2022		2027		2032	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
Built-up	221.78	42.25	252.63	48.13	274.51	52.30
Agriculture	175	33.34	141.95	-27.04	118.42	-22.56
Open space	79.57	15.16	80.36	-15.31	84.09	16.02
Forest	32.15	6.13	33.98	6.47	32.02	-6.10
Water bodies	16.37	3.12	15.94	-3.04	15.83	-3.02
Total	524.87	100	524.87	100	524.87	100

Table 3. The distribution of LULC in square kilometers in 2009 - 2032

Land use class	2009	2011	2017	2022	2027p	2032p	Annual % change
Built-up	140.9	157.62	178.87	221.78	252.63	274.51	94.83
Agriculture	220.99	207.84	198.02	175.00	141.95	118.42	-46.41
Open space	112.55	110.25	99.28	79.57	80.36	84.09	-25.29
Forest	33.85	32.23	32.44	32.15	33.98	32.02	-5.41
Water bodies	16.58	16.93	16.26	16.37	15.94	15.83	-4.52

The green area improvement scenario

The scenario analysis is involved open spaces, agricultural areas, and forests as green areas. The green area in the city is primarily related to the population size. The standardization of the ratio of green area to population size as a benchmark is an important tool to help prevent the reduction of green areas. As calculated, it is found that the population will increase in 2027 and 2032, which will affect the future demand for green area. In this study, the number of people in each sub-district was used to analyze the ratio of green area to population size (Table 4).

Table 4. The population projection in 10 years in each sub-district

Sub-district	Population (people)		
	2022	**2027**	**2032**
Na Kluea	128,774	162,400	204,800
Nong Prue	87,985	111,000	140,000
Huai Yai	31,150	39,300	49,600
Ta Khian Tia	24,927	31,400	39,600
Nong Pla Lai	24,777	31,200	39,300
Bang Lamung	12,751	16,100	20,300
Pong	10,818	13,600	17,200
Khao Mai Kaew	7,779	9,800	12,400
Total	328,961	414,800	523,200

Note: The calculation does not include the non-registered population.

The analysis of green areas is divided into 8 sub-districts, as shown in Figure 3. The study found that green space decreased in 2027 and 2032. Most of the open space is found in downtown Pattaya and the central area with bare soil, bushes, dry land, and grassy meadows along the canal. Most of the agricultural areas are concentrated in the Khao Mai Kaew and Huai Yai sub-districts, while forest areas are found in Takhian Tia, Khao Mai Kaew, and Huai Yai sub-districts.

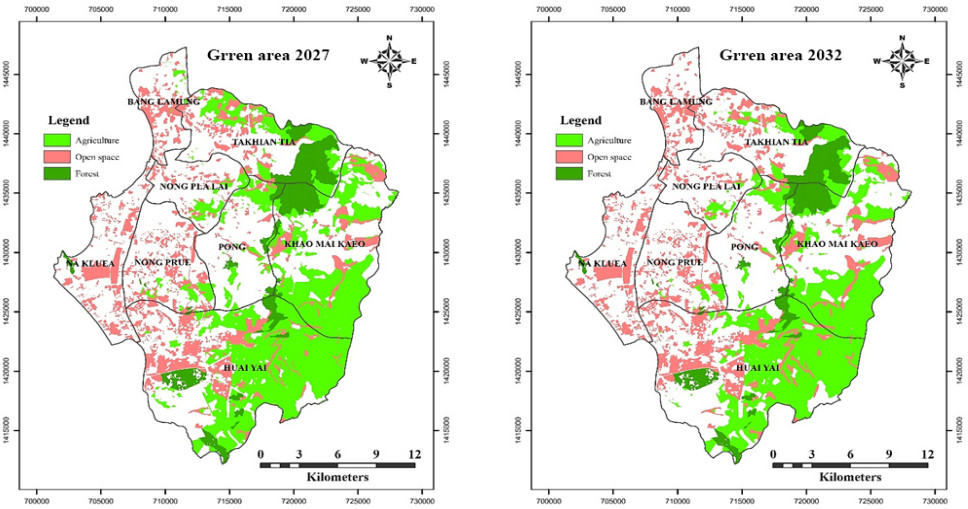

Figure 3. Simulated map of green area in Bang Lamung (2027 and 2032)

The amount of green space per person in each subdistrict is shown in Table 5. For analysis, the research was taken the urban planning criteria set by the Department of Public Works and Town Planning, which was an area of 8 square meters per person. It is important to note that the Department's definition of green areas only encompasses open spaces designated for recreational and environmental conservation purposes, except those found in agricultural and forestry areas. In this study, the researcher counted all green areas, including open spaces, agricultural areas, and forest areas to be the total green areas due to the current situation of all green areas in Bang Lamung district.

However, when considering the green area per person in each sub-district area, it found that the sub-district with the highest green area per person is expected in Khao Mai Kaew, with approximately 6,355.62 and 4,543.56 sq.m/ person in 2027 and 2032, respectively, followed by Huai Yai sub-district with approximately 2,604.37 and 1,958.98 sq.m/ person in 2027 and 2032, respectively. It can be seen that Khao Mai Kaew and Huai Yai are mostly forest and agriculture areas, while the green area in Nong Prue Sub-district is expected to be approximately 120.29 and 89.24 sq.m/ person in 2027 and 2032, respectively. Lastly, the green space in Na Kluea Sub-district, which covers Pattaya City, is expected to decrease approximately 79.75 and 63.14 sq. m / person in 2027 and 2032, respectively.

It is noted that the green area in city area such as Nong Pa Lai, Bang Lamung and Na Kluea Sub-district, which cover Pattaya City and consists mostly of open space, is decreased in average annual of green area per person around -60.74%, -55.63%, and -48.31% respectively. Moreover, Pong, Ta Khian Tia, and

Khao Mai Kaew sub-district which mostly is forest and agriculture areas, are also expected to decrease in average annual of green area per person over than -50%.

Table 5. The simulated green area per person in 2027 and 2032

Sub-district	*Population			**Green area (sq.m)/person			Annual % change
	2022	2027p	2032p	2022	2027p	2032p	
Na Kluea (cover Pattaya)	128,774	162,400	204,800	101.33	79.75	63.14	-37.69
Nong Prue	87,985	111,000	140,000	172.67	120.29	89.24	-48.31
Huai Yai	31,150	39,300	49,600	3,500.85	2,604.37	1,958.98	-44.04
Ta Khian Tia	24,927	31,400	39,600	1,665.93	1,192.63	802.16	-51.85
Nong Pla Lai	24,777	31,200	39,300	398.34	235.85	156.38	-60.74
Bang Lamung	12,751	16,100	20,300	765.59	469.13	339.72	-55.63
Pong	10,818	13,600	17,200	1,565.70	954.98	627.48	-59.92
Khao Mai Kaew	7,779	9,800	12,400	9,170.06	6,355.62	4,543.56	-50.45
Total	328,961	414,800	523,200	871.60	617.86	448.26	-48.57

Note: * Population from DOPA
** Green area in this research covers open space, agriculture, and forest area counted in square meter

The area comprehensive plan scenario

The study was divided land use into 3 major groups based on Bang Lamung city plan. These groups were urbanization areas which referred to the residential and commercial areas including in the city plan promoted by the government for urbanization, the control area which referred to the agricultural and open space areas in the city plan, and protect area which referred to the areas where urbanization is prohibited, such as forest conservation areas and national parks, as compared to the current city plan.

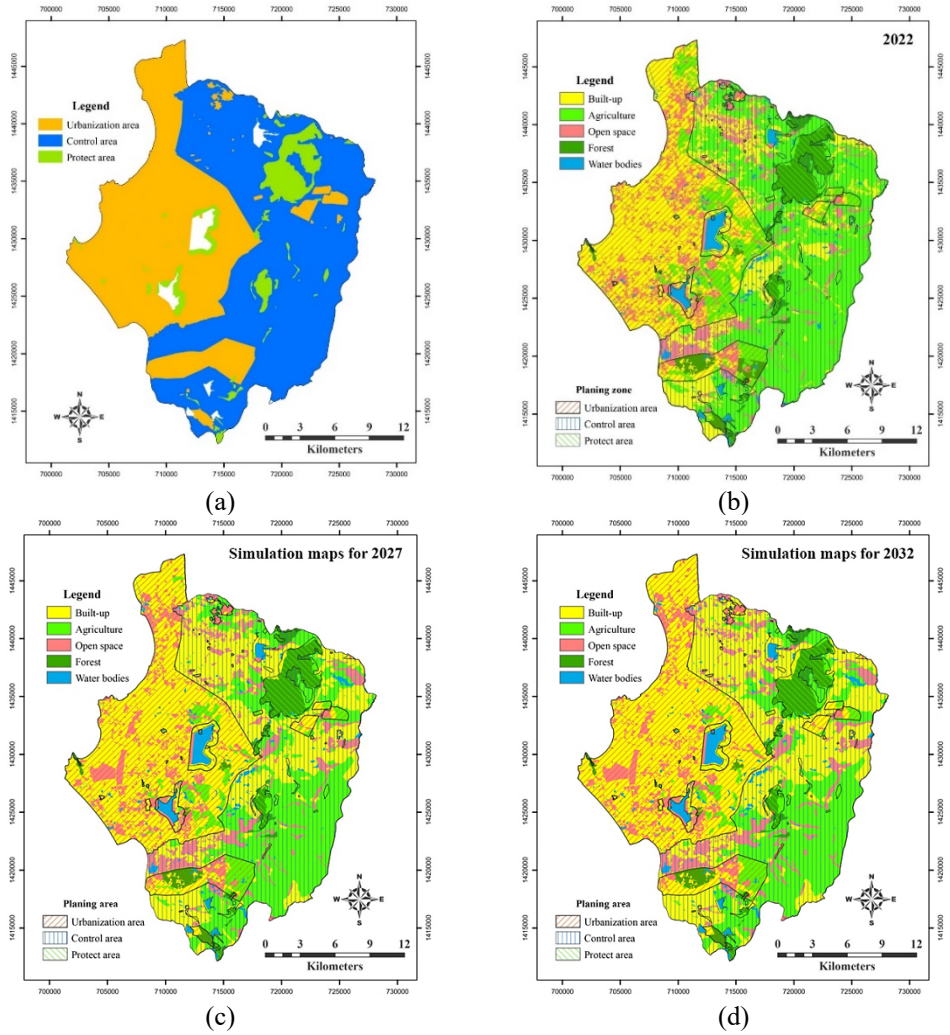

Figure 4. The 3 major groups based on the Bang Lamung city plan (a), land use in 2022 (b), simulated land use in 2027 (c), and simulated land use in 2032 (d)

The built-up area is expanded to the east (Figure 4). In 2027 and 2032, a significant portion of agricultural areas converted into urban areas. Therefore, it is evident that the expansion of the built-up area is not expected in accordance with the boundary set by the current Bang Lamung city plan which determined in the urbanization area. The results of the annual changes in the simulated LULC for 2027 and 2032 under the area coverage plan scenario are presented in Table 6.

Table 6. The distribution of simulated LULC in square kilometers in 2027 and 2032 under the area comprehensive plan

Area comprehensive plan	Land use class	2022	2027p	2032p	Annual % change
Urbanization area	Built-up	129.19	140.28	146.11	13.10
	Agriculture	31.29	19.95	13.77	-55.99
	Open space	40.12	40.56	41.03	2.27
	Forest	6.20	6.12	6.05	-2.42
	Water bodies	3.24	3.13	3.09	-4.63
	Total	210.04	210.04	210.04	
Control area	Built-up	85.42	104.62	119.86	40.32
	Agriculture	138.19	117.36	99.82	-27.77
	Open space	32.60	35.9	39.1	19.94
	Forest	7.95	6.60	5.75	-27.67
	Water bodies	5.11	4.81	4.74	-7.24
	Total	269.27	269.27	269.27	
Protect area	Built-up	6.12	6.59	7.25	18.46
	Agriculture	4.10	4.35	4.67	13.90
	Open space	2.49	2.51	2.58	3.61
	Forest	22.00	21.27	20.21	-8.14
	Water bodies	0.39	0.38	0.38	-2.56
	Total	35.10	35.10	35.10	

The research showed that the model is simulated the growth of built-up areas in areas which designated for urbanization areas, with an average annual growth of 13.10% between 2022 and 2032. However, all built-up areas remain in the Bang Lamung city plan. Meanwhile, in the control area is expected average annual decline in agriculture areas by -27.77% between 2022 and 2032. In the protected area of forestry is expected to decline on the average annual rate of -8.14% between 2022 and 2032. As a result, the controlled and protected areas are not concerned in accordance with the Bang Lamung General Town Plan.

Discussion

The study on LULC in Bang Lamung District was analyzed by using the satellite image classification (Sentinel 2 and ALOS (AVNIR-2) data). The spatial resolution is one of the factors affecting the satellite image classification accuracy. Free satellite image data were used with similar spatial resolution (10 m) and recorded satellite images from the past to the present. In addition, image classification techniques used image interpretation which useful for complex areas such as Bang Lamung District. The development of a wall-to-wall land cover monitoring system was not an easy task in the cases of large, diverse, and complex countries (Mas *et al.*, 2017). Therefore, the satellite image of Bang Lamung District is digitized to create LULC maps based on the knowledge of the researcher of the study area.

It should be accurated the base maps and estimations of the LULC dynamics consistent with Soytong *et al*. (2019) and Chonburi Land Use Classification Report (2017) which classified to 9 categories, the highest being agriculture/livestock, which accounted for 56.67%, followed by the community and city areas at 16.14 percent, forest/wetland area at 11.14%, and others at 5.40%. It was considered to be the independent growth of the city. Results can be seen that the built-up areas in Bang Lamung District would continue to expand until all vacant land is transformed into the built-up areas, especially in the eastern part of the district, which is mostly agricultural area. The annual growth of construction between 2002 and 2032 is estimated to be averaged of 94%. At the same time, it is evident that the agricultural areas and open spaces decreased significantly (Department of Public Works and Town Country Planning, 2019), with an average annual decline rate of -46% and -25%, respectively. According to the research, it was evident that the highest growth rates of construction occurred between 2017 and 2022.

The green area improvement in Bang Lamung District is analyzed by dividing into sub-districts to determine the amount of green area per person, by using the standard criteria of the Department of Public Works and Town Country Planning (Guidelines for Green Area Management and Green Area Ratio Standards for Urban Communities in Thailand, 2017). However, the study provided an overall of green areas similar to the result of green area in Bang Lamung District classified by land use type. It was found that most of the sub-district areas are covered the agricultural area of 293.32 sq. km., representing 50.93 percent followed by other areas of urban areas and wasteland areas of 204.28 sq. km. representing 35.47 percent, forest and perennial areas of 61.87 sq. km. representing 10.74 percent, the area of water resources in the amount of 8.64

sq. km. representing 1.5 percent and golf course area of 7.85 sq. km. representing 1.36 percent, respectively (Soytong *et al*., 2019). The green areas included the open spaces which are designated for public use, such as parks and recreation areas. Finally, forests are the pristine green areas that are essential to the ecosystem and must be appropriately preserved.

The area comprehensive plan scenario was considered for analysing the future LULC of Bang Lamung District by comparing them with the current city plan of Bang Lamung (Department of Public Works and Town country planning, 2019). It showed that the built-up area increased in designated urbanization areas, and some built-up areas spreaded outside the boundaries of urbanization areas, but all built-up areas remained in the Bang Lamung city plan. Agriculture and open space areas are controlled areas to conduct the research project. The controlled areas did not match the Bang Lamung city plan boundaries due to the ineffective enforcement problem of the comprehensive plan. The forest areas and water sources did not match the boundary of the Bang Lamung city plan because the satellite images were taken in January which is a dry winter in Thailand. During this period, the phenomenon of shedding leaves and the amount of water in the water resources is decreased. These affected the classification of image classification.

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