

# GIS MODELING FOR INDUSTRIAL-AGRICULTURAL LANDUSE PLANNING: A CASE STUDY OF PHRA NAKHON SI AYUTTHAYA PROVINCE, THAILAND

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*Received: July 29, 2012; Revised: September 28, 2012; Accepted: October 03, 2012*

## Abstract

The main objective of this research is to develop GIS-based modeling of land allocation for industrial-agricultural land-use planning. To achieve the ultimate goal, 2 main processes were integrated as a chain. They were (1) land suitability assessments and (2) the land allocation process. Phra Nakhon Si Ayutthaya Province in Thailand was selected to be the study area because of the presence of conflicts among various high potential types of development within it. The results of the land suitability assessment showed that almost 80% of the study area was suitable for agriculture whereas about 70% of the area was suitable for industry. Unavoidably, there was considerable spatial overlap within the study area. Therefore, the land allocation process was able to designate which should be the agricultural or industrial areas. The results were collated to the study area for 4 different land-use scenarios under different policies, which were the promotions of agriculture, industries, and their combinations with an orientation towards either one. These scenarios were scenario I: maximizing the agricultural area; scenario II: maximizing the industrial area; scenario III: optimizing the industrial-agriculture (I-A) area with an agricultural orientation; and scenario IV: optimizing the I-A area with an industrial orientation. These results were shown in 4 maps of the scenarios.

**Keywords:** Land suitability assessment, land allocation model, land-use planning, GIS modeling

## Introduction

Land is a limited resource on which human activities often conflict with one another in making use of it. In developing countries, increasing land demand always leads to landuse conflict and becomes a major problem. Depending on the population, economics, and industrial growth, agricultural land is constantly

being converted into urban built-up and industrial areas without consideration of the land's suitability and sustainability.

By nature, the land-use conflict is unavoidable. The growth of the industrial sector is definitely one of the key factors indicating progress in economics and the

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standard of living whereas the growth in the agricultural sector indicates the adequacy of food to maintain the basic quality of living. However, as a consequence, the growth of the industrial sector will cause more pollution to the environment than that caused by the agricultural sector. Thus, industrial promotion should be planned carefully while agriculture promotion should not be neglected.

In the past, the economic structure of Thailand was mainly characterized by the agricultural sector. Since the late 1980s the economic structure of Thailand has changed dramatically with rapid industrialization. The share of the agricultural sector in the GDP has fallen from 23.2% in 1980 to less than 10% in 2000. On the contrary, the ratio of the GDP increased in the manufacturing, commercial, and service sectors. In 2007 Thailand's economic structure came from agriculture 12.3%, industry 44%, and services 43.7% (Economy Watch, 2010).

Alongside rapid economic growth, urbanization, and industrialization, Thailand is facing various social and environmental challenges such as experiencing industrial pollution, an unsanitary urban environment, and destruction of the natural environment. Major air pollutants in Thailand are particulate matters. One of the emission sources of those pollutants is factories. The central region of Thailand accounts for 60-70 % of all industrial emissions. As well as air pollution, poor water quality and waste disposal problems come from industries (Pollution Control Department, 2010).

Because of these conflicts relevant to land use, land should be allocated in a proper way, particularly relying on its suitability, so that its future sustainability can be optimized. The ultimate goal of this study is, therefore, to develop an integrated Geographic Information System (GIS)-based model of land allocation for industrial-agricultural land-use planning in Phra Nakhon Si Ayutthaya Province as a case study.

### **Concept of Land Allocation**

The term land allocation in this study

was defined as the process to assign an area for a particular land-use such as industry or agriculture based on land suitability and policy by using various GIS techniques. There have been many studies which have tried to allocate land into appropriate uses in order to increase overall land efficiency. However, they have focused mainly on the suitability of a specific land use such as for agriculture, forestry, and even more specifically for several alternative crops. The results of these studies could not be the overall answer for land allocation and could not be adequate to ensure the whole sustainable development of the land. In practice, a decent land-use planning requires the consideration of land suitability for agriculture and industry simultaneously.

Multi-Objective Decision Analysis (MODA) has been a widely used technique in the land allocation process. Multi-objective decision problems refer to problems that have a very large number of feasible alternatives, where the objectives and constraints are functionally related to the decision variables (Malczewski, 1999), such as the revenue from each crop in a parcel of land. Multi-site Land-use Allocation Problems (MLUAs) which refers to the problem of allocating more than 1 land-use type in an area is an example of a generic class of multi-objective decision problems (Eldrandaly, 2010). Land-use planning always deals with spatial decision making problems which are multi-faceted challenges. Solutions for these problems involve highly complex spatial data analysis processes successfully operated using the GIS. Eldrandaly (2010) presented Gene Expression Programming which integrated the Artificial Intelligence techniques with GIS for solving MLUA problems. Liu *et al.* (2007) presented an integrated GIS-based analysis system (IGAS) for supporting land-use management of lake areas in urban fringes in China. The IGAS consists of modules of land-use suitability assessment and change/demand analysis, and land evaluation and allocation. Multi-criteria analysis and system dynamics techniques are used to assess land-use suitability and forecast potential land-use varia-

tion, respectively.

Considering these previous works, MODA techniques, MLUAs, IGAS and other techniques have been effective for land allocation in a small scale area such as in farm management but they are not fit for the macro or provincial level which are lacking detailed data such as the revenue and rate of return needed for an objective function including the conditions of the particular land-use types. The results of these studies may not be the overall answer for land allocation which can ensure complete sustainability in macro land-use planning. In this study, therefore, the land suitability assessments of both industry and agriculture in Phra Nakhon Si Ayutthaya were prepared before land allocation was established through the Land Suitability Combination Matrix (LSCM). To develop the allocation model techniques in GIS, spatial multi-criteria decision analysis (SMCDA) was employed in the study.

### Study Area

Phra Nakhon Si Ayutthaya province (Figure 1), the study area, is located in the central region of Thailand only 75 km from Bangkok. It is composed of 16 districts covering a total area of 2556.60 km<sup>2</sup> or 1597900 rai. (1 rai is equal to 1600 m<sup>2</sup>). The population was 751636 in January 2007 while the Gross Provincial Product (GPP) was 345549 million Baht (454026 Baht/person) in 2007 which had increased from 53973.169 million Baht in 1994 (Phra Nakhon Si Ayutthaya Provincial Office, 2007). The important economic sectors of the area are agriculture and industries. In 2007, about 287244 and 7011 million Baht of GPP came from the industrial and agricultural sectors, respectively. Based on the economic structure, land use of the area can be classified into 3 major types which are agricultural land, industrial land, and other land. From the total area of 1597900 rai, the agricultural area was 1126459 rai in 2006. Rice is the major crop, covering an area of 1074861 rai. Lat Bua Luang, Wang Noi, Bangsai, Ayutthaya, Sena, Bang Pa-in, Bangban, and Uthai districts have been declared to be in the agricultural land

reform area since 2001. According to the industrial promotion policy, Phra Nakhon Si Ayutthaya Province is in the second zone of industrial promotion set up by the Broad of Investment. In 2006, there were 3 industrial estates in the province and 1581 factories with an investment value of 263407.32 million Baht and 211455 workers.

Phra Nakhon Si Ayutthaya Province was selected to be the study area because of the presence of conflicts among various high potential types of development within it. Apart from the provincial capital being very famous historically and archeologically as a world heritage site, the province is also a well-known center of rice cultivation and an industrial expansion overflow area from Bangkok. According to the 9<sup>th</sup> (2002-2006) and 10<sup>th</sup> (2007-2011) national economic and social development plan of Thailand (National Economic and Social Development Board, 2007), the goals of national development have concentrated more on the sustainability concern together with the strategic planning for the province which aims at promoting the area to be a center for commerce, investment, and tourism as well as rice production (Phra Nakhon Si Ayutthaya Provincial Office, 2010). A balance for land development is required



Figure 1. Map of the study area, Phra Nakhon Si Ayutthaya Province

and should be carried out by selectively allocating potential areas for promising development simultaneously.

**Methodology**

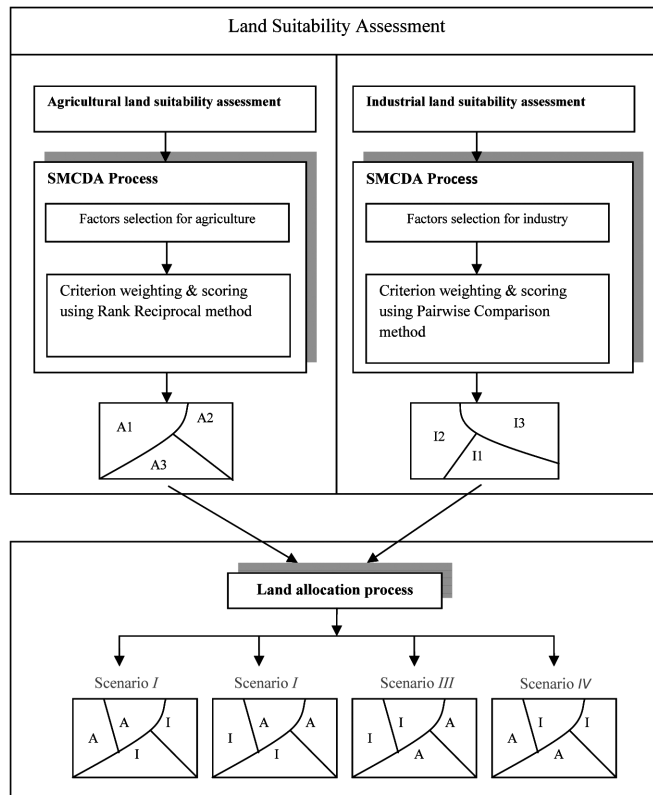
The study framework can be divided into (1) the land suitability assessment of the area for agriculture and industry and (2) the land allocation process to assign where should be promoted to be an agricultural or industrial area in different policy scenarios. The conceptual framework of the study is illustrated in Figure 2.

**Land Suitability Assessment**

The assessment processes of both sectors, agriculture and industry, were paralleled using SMCDA and GIS techniques. They included criteria selection, scoring, and weighting and were incorporated in land suitability maps

(Figure 3). The suitability maps of agriculture and industry were then taken into the allocation process.

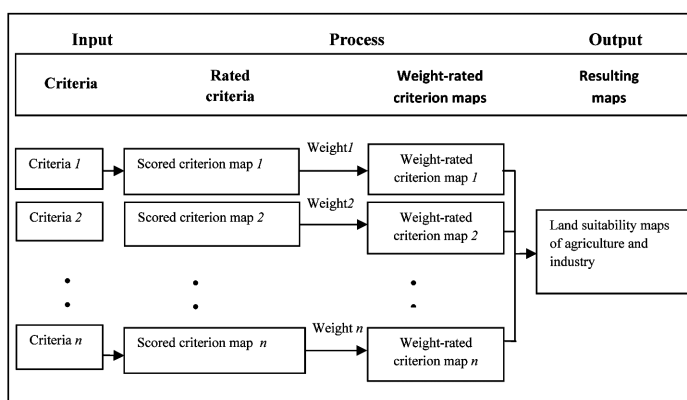
The criteria used in land suitability for agriculture were adapted from previous studies such as the FAO (1976) and Shrestha (1999). Soil nutrient is one of the basic factors to be considered as well as temperature, rainfall, and topography. Irrigation, water bodies, and flooding conditions are the accompanying factors required. Since the main crop in Phra Nakhon Si Ayutthaya has been rice, the criteria of paddy field suitability were referred for assessment. Due to the characteristics and scale of the study area, the variation in temperature, rainfall, and topography is so small that it becomes stable for the analysis. Therefore, the main influencing factors used in this study were soil quality, distance from a water body, irrigation, and flood hazard. These criteria were generated in the form of



**Figure 2. Conceptual framework of the study**

criterion maps. For example, the soil quality map was generated from 12 characteristics, contained in the soil series, including soil drainage, soil texture, soil depth, soil salinity, soil pH, nitrogen, phosphorus, potassium, organic matter, jarosite, cation exchange capacity, and base saturation. The flood frequency map was developed by observing

the incidence of flooding on many dates during the years 2000-2006 using overlay analysis. The criterion scoring, as shown in Table 1, was operated following the FAO guidelines (FAO, 1976) and the opinion of the Land Development Department experts. The rank reciprocal method, feasible for a small number of criteria, was applied to the weight



**Figure 3. The Spatial Multi-criteria Decision Analysis (SMCDA) of agricultural and industrial land suitability assessment**

**Table 1. Scores of criteria in the agricultural land suitability assessment**

Criteria	Range of measurement	Score	Weight
Soil quality*	Highly suitable (S1)	4	0.480
	Moderately suitable (S2)	3	
	Marginally suitable (S3)	2	
	Not Suitable (N)	1	
Distance from water body (m)	<=250	4	0.120
	>250-<=750	3	
	>750-<=1,000	2	
	>1,000	1	
Irrigation zone	Irrigation	1	0.160
	Non-irrigation	0	
Frequency of flooding	Never	4	0.240
	Seldom	3	
	Often	2	
	Very often	1	

\*From the FAO guidelines (FAO, 1976)

determination of each criterion. The total indexes were calculated using the Simple Additive Weighting method (SAW) and classified into 4 classes, according to the FAO guidelines, as highly, moderately, marginally, and not suitable.

For the industrial suitability assessment, the factors affecting the industrial location

were selected based on theories and previous researches. Theories and concepts about industrial location have been developed since 1875 when J. H. Von Thunen attempted to incorporate a location into the general framework of economics. A book about industrial location theory was published by Alfred Weber in 1909. Recently, many studies have

**Table 2. Scores of criteria in the industrial land suitability assessment**

Factors	Criteria	Range of measurement	Score	Weight
Accessibility	Distance from road (m)	<=500	4	0.299
		>500<=1,000	3	
		>1,000-<=1,500	2	
		>1500	1	
Electricity	Distance from electricity line (m)	<=500	4	0.222
		>500-1,000	3	
		>1,000-1,500	2	
		>1500	1	
Labor	Distance from village (m)	<=1,000	4	0.091
		>1,000-2,000	3	
		>2,000-3,000	2	
		>3000	1	
Facility	Distance from urban area or municipality	<=1,000	4	0.116
		>1,000-2,000	3	
		>2,000-3,000	2	
		>3000	1	
Agglomeration	Distance from existing industrial area (m)	<=1,000	4	0.095
		>1,000-2,000	3	
		>2,000-3,000	2	
		>3000	1	
Land price	Land price zone (bath/rai)	<=400,000	4	0.070
		>400,000-2,000,000	3	
		>2,000,000-4,000,000	2	
		>4000000	1	
Flood hazard	Frequency of flooding	Never	4	0.107
		Seldom	3	
		Often	2	
		Very often	1	

suggested that the significant factors are both physical and socioeconomic such as accessibility, infrastructure and facilities, labor availability, land price, topography, and flooding, etc. (Chobpattana, 1989; Weerakoon, 1996; Xu, 1996; Piracha, 2001; Tianpajeegoon, 2001; Panjarongkha, 2003). In this study the factors used were recommended by 10 experts from the Industrial Estate Authority of Thailand. The factors included 1) accessibility, 2) electricity, 3) labor, 4) facilities, 5) agglomeration, 6) land price, and 7) flood hazard. Their scoring and weighting were synthesized and prepared as scored criterion maps as listed in Table 2.

The weights were obtained from 30 entrepreneurs by questionnaire and interview. The pairwise comparison method was used in the weighting of the criterion maps. The GIS local operation which is the summation of the weight-score products of all the criterion maps was performed to serve the SAW decision rule. The industrial land suitability ranking of the area was achieved as a map with 4 classes, namely highly, moderately, marginally, and not suitable.

**Land Allocation Process**

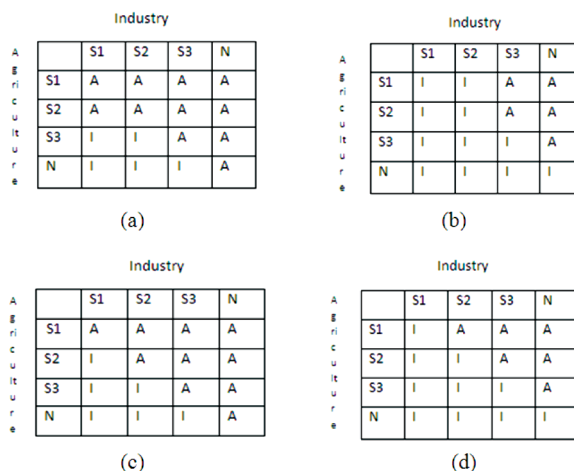
With the interest in the impact of land-use policies on agricultural and industrial

sectors, there could be set up 4 possible scenarios, i.e. I: maximizing the agricultural area; II: maximizing the industrial area; III: optimizing the industrial-agricultural area with an agricultural orientation; and IV: optimizing the industrial-agricultural area with an industrial orientation.

In the first possible scenario, which aimed at maximization of the agricultural area, the land was allocated for agriculture according to its suitability as much as possible. Conversely, the second scenario aimed at maximization of the industrial area so the land was allocated for industry if it was feasibly suitable. Compromisingly, the third and the fourth scenarios sought the optimized land allocation for agricultural and industrial sectors by comparing their suitability.

The rules for land allocation were set up by comparing the land suitability for agriculture and industry in the same area in the form of the matrix called Land Suitability Combination Matrix (LSCM). This process was a raster-based local operation with a grid size 20x20 m.

The LSCM was generated to specify that a grid cell should be either agriculture or industry particularly relying on the policy and the advantage of its land suitability. Four LSCMs were developed according to the 4 scenarios (Figure 4). Each cell was reassigned



**Figure 4. Land Suitability Combination Matrix (LSCM) for (a) scenario I: maximizing agricultural area, (b) scenario II: maximizing industrial area, (c) scenario III: optimizing I-A with agricultural orientation, and (d) scenario IV: optimizing I-A with industrial orientation**

to be agriculture or industry based on its higher suitability preference. A cell with equivalent suitability was reassigned to be agriculture or industry depending on the orientation of the policy. For example, for scenario I which aimed at maximizing the agricultural area, the land was allocated to agriculture as much as possible. Cells with S1 and S2 of agricultural suitability were reassigned to be suitable for agriculture. Cells with S3 and N were regarded as similar to the industrial suitability. If the agricultural suitability of the same cells was less than the industrial suitability, they were reassigned to be industrial land; otherwise they were agricultural land. In scenario II which aimed at maximizing the industrial land, the land was allocated to industry as much as possible by using the same concept but with the opposite reassignment for cell allocation as for scenario I. Scenarios III and IV sought for allocation optimization between agriculture and industry. Therefore, cells were reassigned to be suitable for agriculture or industry according to their dominant suitability. Cells with equivalent suitability were reassigned to be agricultural land or industrial land depending on the policy orientation.

## Results and Discussion

### Agricultural Land Suitability Assessment

The land suitability map for agriculture was generated as shown in Figure 5(a). The area cover of each suitability class is tabulated in Table 3. The urban areas, roads, and rivers were excluded from the suitability map. The results showed that almost 80% of the study area was moderately or highly suitable for agriculture. The highly suitable area (S1), covering about 4 %, was located in the upper central and the northeast of the province due to the high quality of soil and marginal flood hazard. The marginally suitable areas (S3) were located in the west of the province due to the presence of a flood hazard and the long distance from a water body. The not suitable class area was not found as Phra Nakhon Si Ayutthaya has been a prosperous cultivation area since historical times.

### Industrial Land Suitability Assessment

The land suitability map for industry was generated as shown in Figure 5(b). Since the urban areas have seldom changed, they were excluded from the map. The map shows

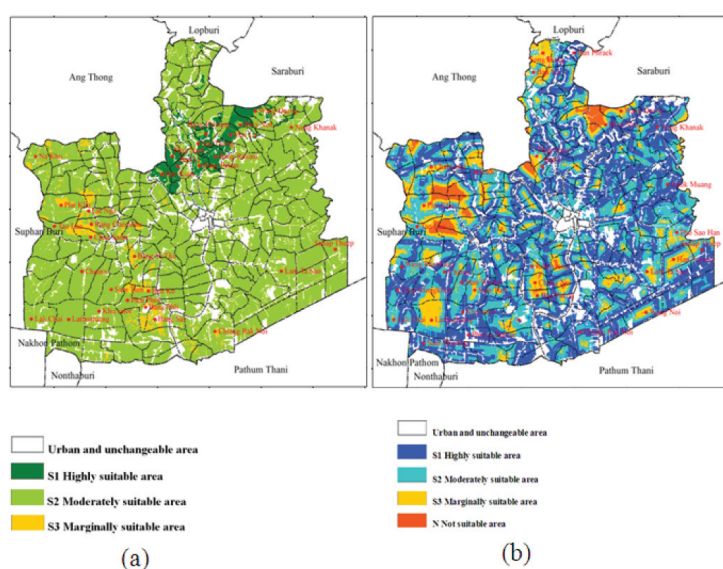


Figure 5. Land suitability for (a) Agriculture (b) Industry

the areas with 3 different levels of suitability which are highly suitable, moderately suitable, and marginally suitable. About 70% of the area was suitable for industry. It was found that 35.59% and 33.14% of the total area were classified as highly and moderately suitable for industry, respectively. Only a few percent

of the total area was classified as marginally and not suitable for industry (Table 4). The results revealed that the most suitable areas were more likely to be located near to the main roads and electricity lines. The most suitable area appeared to be in the east covering Nakhon Luang, Bang Pahan, Uthai,

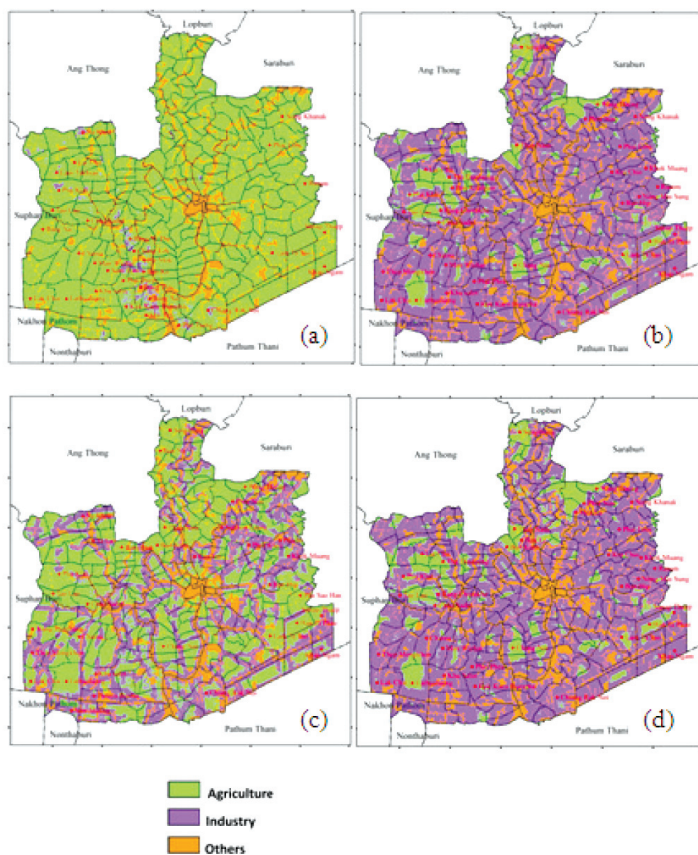


Figure 6. Land allocation of (a) scenario I, (b) scenario II, (c) scenario III, and (d) scenario IV

Table 3. Area coverage on classified land suitability for agriculture

Land suitability classification	Area (Sq. km)	Area (Rai)	Area (%)
Highly suitable area (S1)	105.84	66,151	4.21
Moderately suitable area (S2)	1891.12	1181948	75.28
Marginally suitable area (S3)	75.73	47328	3.02
Other area	439.43	274640	17.49
<b>Total</b>	<b>2512.12</b>	<b>1570067</b>	<b>100.00</b>

**Table 4. Area coverage on classified land suitability for industry**

Land suitability classification	Area (Sq. km)	Area (Rai)	Area (%)
Highly suitable area (S1)	893.40	558372	35.59
Moderately suitable area (S2)	831.66	519787	33.14
Marginally suitable area (S3)	283.87	177420	11.31
Not suitable area (N)	61.54	38462	2.45
Other area	439.55	274717	17.51
<b>Total</b>	<b>2510.02</b>	<b>1568758</b>	<b>100.00</b>

**Table 5. Comparison of existing agricultural and industrial areas in 2007 and the results of land allocation in scenarios I, II, III, and IV**

	Agricultural area		Industrial area		Other area		Total	
	Rai	Percent	Rai	Percent	Rai	Percent	Rai	Percent
2007	1163249	74.09	29153	1.86	377677	24.05	1570079	100
Scenario I	1269845	80.88	24448	1.56	275786	17.56	1570079	100
Scenario II	202626	12.90	1091637	69.53	275816	17.57	1570079	100
Scenario III	747562	47.61	546516	34.81	276001	17.58	1570079	100
Scenario IV	221711	14.12	1072540	68.31	275828	17.57	1570079	100

and Wang Noi Districts due to the advantage of accessibility, electricity, labor, facilities, and agglomeration in the area.

### Industrial-Agricultural Land Allocation

The resulting maps of the land allocation processing for particular scenarios, namely scenarios I, II, III, and IV, were generated as shown in Figure 6. Existing agricultural and industrial areas in 2007 and the allocated land use in the scenarios were compared in Table 5.

In scenario I, almost all of the study area (80.88%) was suitable for agricultural land. Only 1.56% was allocated to be industrial land (Figure 6(a)). In scenario II, 69.53% of the area was allocated to be industrial land and only 12.90% to be agricultural land (Figure 6(b)). In scenario III, almost half of the land (47.61%) was allocated to be agricultural land and 34.81% to be industrial land (Figure 6(c)). In scenario IV, more land was allocated to be suitable for industry than

for agriculture, with 68.31% of the study area being allocated to be industrial land and only 14.12% to be agricultural land (Figure 6(d)). In fact, the existing land use in 2007 was more similar to scenario I than the other scenarios. Hence, it could be concluded that the existing land use in 2007 was more likely to be traditionally maximizing the agricultural area. It was interesting to note that the area allocated for agriculture in a sub-district could be as high as 98.97% in Rasom which is part of Phachi district and the area allocated for industry in a sub-district could be as high as 93.50% as found in Kok Kaeo Burapha which is part of Bang Sai district.

### Conclusions

The objective of the study was to develop the GIS modeling for industrial-agricultural landuse planning. To achieve the ultimate goal, 2 main processes were integrated as a chain.

They were (1) land suitability assessments and (2) land allocation. The result maps for the first part showed the potential of the land for agriculture and industry. For the land allocation, the result maps indicated where the agricultural and the industrial areas should be via the LSCMs, which established the rules for determining suitability based on 4 different scenarios of the land-use policies. However, these results may not be the overall answer for the land-use planning and may not be adequate to ensure the whole sustainability of the land use. The LSCMs specified the land use depending only on the suitability of the land ; and the impacts of these scenarios in economic, social, and environmental terms were not taken into account. Therefore, an additionally sustainable assessment should be considered for further study to evaluate these impacts in order that the land-use planner can choose appropriate scenarios that meet the objective of sustainable development.

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