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Analysis of Integrated Expert Geographic Information Systems for Secured Landfill Sites

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Abstract: Siting of secured landfill is difficult because of the complexity of technical and social aspects. Technically, the appropriate tool for secured landfill sites analysis should be applied in the siting procedure. This study aims at developing a comprehensive tool to facilitate the analysis of secured landfill sites. It integrates Geographic Information System (GIS), Expert System (ES) and Analytic Hierarchy Process (AHP) into a packaged tool. The GIS represents spatial data, ES represents a knowledge base about secured landfill siting, AHP was applied for ranking of candidate sites and a user interface was developed to make this tool a user-friendly graphical system. The use of this tool was illustrated by identifying suitable sites for secured landfill in Khon Kaen Province, Thailand.

Key words: Geographic information system, expert system, analytic hierarchy process, secured landfill

INTRODUCTION

The improper management of hazardous waste may pose a serious threat to human health and environment (soil, air, water). Typically, hazardous waste management consists of collection, transportation, treatment and disposal of waste. Disposal of the waste is the final process and a key issue in overall hazardous waste management programs (Millano, 1996). There are several methods used for ultimate disposal of hazardous waste such as incineration, immobilization, landfill and off-shore and underground storage. Landfill is the option used in many countries and a major portion of wastes is disposed of through this rustic method. It is also technologically considered as an unsophisticated disposal method (Visvanathan, 1996). However, siting of landfills has become increasingly difficult since communities typically respond to plans to build a secured landfill or other hazardous waste disposal facilities with the view of Not in My Back Yard (NIMBY) or Locally Unwanted Land Uses (LULUs). It means that in general, a new facility for treating or disposing hazardous waste is desirable, but at the same time every community refuses to accept the facility (Minehart and Neeman, 2002).

There are two basic approaches to facility siting: open and closed. Closed siting approach often fails because social and political considerations are not given adequate attention, not because of environmental or technical mistakes. The open approach supports more effective public involvement and shares decision-making power (Kuhn and Ballard, 1998). In order to achieve the open approach, the appropriate tool for siting analysis should be applied in the siting procedures. In addition, this tool should be effective and easy to use for the general public, planners and decision makers. Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) such as Analytic Hierarchy Process (AHP) have been used in a number of studies in site selection (for example, Lindquist, 1991; Siddiqui *et al.*, 1996; Koa *et al.*, 1997; Lin and Koa, 1998; Badri, 1999; Badri *et al.*, 2001; Chuang, 2001; Kontos *et al.*, 2003). However, the research about the integration between GIS and MCDA as a public participation tool is still needed (Higgs, 2006). An Expert System (ES), a computer program which comprises a software technology that can replicate

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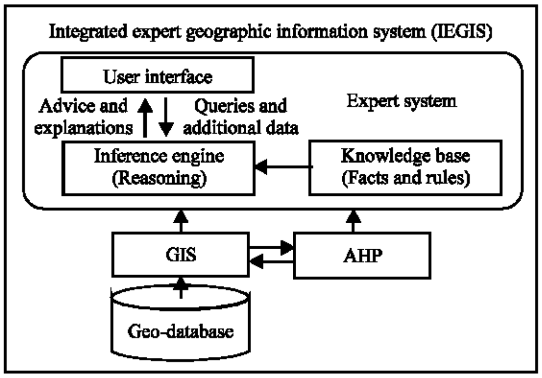


Fig. 1: Components of the integrated expert geographic information system

certain aspects of expertise and can manipulate both qualitative and quantitative knowledge, has also been indicated as a tool in site selection by various authors (Arentze *et al*., 1995; Eldrandaly *et al*., 2003; Way, 2005). The basic components of expert systems include (1) user interface which allows users to communicate with the system and to provide necessary data to the system (2) an inference engine, which solves given problems using input data from users and knowledge from a knowledge base, through its own reasoning methods and (3) a knowledge base, which contains the knowledge obtained from a domain expert, including facts and rules (Kim *et al*., 1990). Even though the GIS, MCDA and ES are useful for siting analysis there has been no attempt to integrate all of them for the comprehensive of secured landfill sites analysis. Therefore, the aim of this study is to develop a comprehensive tool to facilitate the analysis of secured landfill sites. It integrates ES, GIS and AHP into a packaged tool, called an Integrated Expert Geographic Information System (IEGIS).

The components of IEGIS are shown in Fig. 1. The developed system was used to identify the suitable sites for secured landfill in Khon Kaen Province located in the Northeast region of Thailand and there is no licensed hazardous waste disposal site in the region.

MATERIALS AND METHODS

This study was conducted at Khon Kaen University, Khon Kaen Province, Thailand during June 2006 to August 2007.

Materials: The computer used in this study is a standard Windows computer with ArcMap 9, Microsoft Visual Studio.Net 2003, Microsoft Excel 2003 and Visual Basic for Application (VBA).

Developing an Expert System for siting of secured landfill analysis: The ES for siting of secured landfill analysis was developed by using Microsoft Visual Studio. Net 2003. The system has capability to provide the information and suggestions about siting of secured landfill sites taking into account relevant laws, regulations and technical knowledge and allowing users to specific data layers for GIS analysis based on data they have in hand.

Integrating the GIS and ES: The integration of GIS and ES was developed by using Microsoft Visual Studio.Net 2003. It enables the data flow between the ES and the GIS to move back and forth flexibly based on users needs. The system has capacity to allow users to create their own buffer area according to relevant laws, regulations and technical knowledge. The outputs of this step are the suggestion about screening criteria which should be used in the GIS analysis, optimum size of secured landfill and candidate sites.

Integrating the GIS and AHP: Microsoft-Excel and Visual Basic for Application (VBA) were used to develop an Excel application to implement the AHP technique. The integration of GIS and AHP was developed by using Microsoft Visual Studio. Net 2003. The characteristics of candidate sites analyzed by GIS is reported and used as ranking factors in AHP analysis. The system allows users to weight the criteria for candidate sites ranking. After ranking of candidate sites, the preferred site is visualized in the GIS. The process of AHP in this study comprises the following steps (Satty, 1980; Badiru and Cheung, 2002):

- **Develop the hierarchical structure for the decision problem:** The top level of the hierarchy is the overall objective of the decision problem and the competing alternatives are at the bottom of the hierarchy. The attributes of alternatives such as selection criteria and factors, on which the final objective depends, are listed between the top and the bottom of the hierarchy. The number of levels in the hierarchy depends on the complexity of the problem.
- **Determine the relative weights of each alternative with respect to the characteristics and sub characteristics in the hierarchy:** After the hierarchy has been constructed, the users must undertake a subjective prioritization procedure to determine the weight of each element at each level of the hierarchy. Pairwise comparisons are performed at each level to determine the relative importance of each element at that level with respect to each element at the next-higher level in the hierarchy.

- Determine the relative weights of each attribute with respect to the objective.

Develop Matrix of Pairwise Comparison of attributes: The matrix of pairwise comparisons can take the following form:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix}$$

The attribute of the matrix A (m by m matrix) in the i^{th} row and j^{th} column is denoted by a_{ij}. The a_{ij} values represent the relative degree of importance of attribute i over attribute j. The possible assessment value of a_{ij} with the corresponding interpretation is shown below:

- Attribute i and j are equally important, insert 1
- Attribute i is weakly more important than attribute j, insert 3
- Attribute i is strongly more important than attribute j, insert 5
- Attribute i is demonstrably or very strongly more important than attribute j, insert 7
- Attribute i is absolutely more important than attribute j, insert 9

Intermediate numbers (2, 4, 6 and 8) are used as appropriate to indicate intermediate levels of importance. For all i and j, it is necessary that $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$.

Compute normalized relative weights of attributes: The entries of the matrix of pairwise comparisons are then normalized by dividing each entry in a column by the sum of all the entries in that column. This yields a new matrix A_w, in which the sum of the entries in each column is 1.

$$A_w = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}} \\ \vdots & \vdots & \cdots & \vdots \\ \vdots & \vdots & \cdots & \vdots \\ \frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}} \end{bmatrix}$$

Compute w_i as the average of the entries in row i of A_w to yield column vector W.

$$W = \begin{bmatrix} w_1 \\ \vdots \\ \vdots \\ w_m \end{bmatrix} = \begin{bmatrix} \dfrac{\frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} + \cdots + \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}}}{n} \\ \vdots \quad \vdots \quad \cdots \quad \vdots \\ \vdots \quad \vdots \quad \cdots \quad \vdots \\ \dfrac{\frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} + \cdots + \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}}}{n} \end{bmatrix}$$

Where, w_i represents the normalized average rating associated with each attribute. These averages represent the relative weight of the attributes that are being evaluated. The attribute which has highest value of w_i is considered to be the most important factor in the selection of a decision aid for productivity improvement.

Compute consistency ratio of pairwise comparison of attributes: Since the initial pairwise comparisons of the attributes are done based on subjective opinions of the people involved in the decision making, it is quite possible that some elements of bias and inconsistency will be present in the evaluations. Satty (1980) proposed a procedure for calculating the Consistency Ratio (CR) to determine reasonable consistency and to minimize bias. The consistency ratio is calculated as follows:

$$\text{Consistency ratio (CR)} = CI/RI$$

Where:

CI = $(\lambda_{max}-m)/(m-1)$

λ_{max} = The average consistency measure for all alternatives

$$= \frac{1}{m}\sum_{i=1}^{m} \frac{i^{th} \text{ entry in } A \times W}{i^{th} \text{ entry in } W}$$

m = No. of element

RI = The appropriate random index of m, which is shown below:

m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

If CR is sufficiently small, the decision maker's comparisons are probably consistent enough to give useful estimates of the weights for the objective function. In general, a consistency ratio of 0.10 or less is considered acceptable:

- Determine the relative weights of each alternative with respect to the attribute. After the relative weights of the attributes are obtained, the next step is to evaluate the alternatives on basis of the attributes. In this step, relative evaluation rating is obtained for each of alternative with respect to each attribute. The procedure for the pairwise comparisons of the alternatives is similar to the procedure for the attributes. Then each matrix is analyzed and normalized by using the procedure showed previously.

Compute overall desirability weight of each alternative: The attribute weights are then combined with the system weights to obtain the final AHP analysis by using the following equation:

$$\alpha_j = \Sigma_i (w_i k_i)$$

Where:

- α_j = Overall weighted evaluation for alternative j
- w_i = Relative weight for attribute i
- k_i = Evaluation rating for alternative j with respect to attribute i
- $w_i k_i$ = A measure representing the global weight of alternative j with respect to attribute i. The sum of the global weights associated with an alternative represents the overall weight α_j, of that alternative

Make a final decision based on the results: The alternative which has the highest weighted ranking should be selected as the preferred alternative.

After ES, GIS and AHP were integrated, the user interface was developed to allow users to interact with either system through graphic menu-based tools. The operations and outcomes are dependent upon users. The conceptual framework of this study is shown in Fig. 2.

RESULTS AND DISCUSSION

The results of this study were illustrated based on the application of IEGIS in Khon Kaen Province, Thailand. Fig. 3 shows the location of Khon Kaen Province.

Developing an expert system for siting of secured landfill analysis: The first page of the ES is a welcome page Fig. 4. When users entered the system, they were asked to check all the environmental sensitive areas in the province (Fig. 5) and to check all GIS data they had in hand (Fig. 6). Then the ES copied the GIS data in to geodatabase and proposed the screening criteria based on siting criteria from the Notifications No. 1 and No. 7 of Anonymous (2003), the Anonymous guidelines (2006a, b) and the existing GIS data provided by users. The screening criteria of Khon Kaen Province proposed by the ES consist of three main factors which are environmental factors, economic factors and social factors as shown in Table 1.

Integrating the GIS and ES: Based on the screening criteria proposed by the ES as shown in Table 1, ArcMap models of water factors, soil factors, forest factors, economic factors and social factors were built to screen out unsuitable areas for secured landfill sites. These models have capability to automate the GIS analysis and allow users to create their own buffer area. An example of models and the interface for inputting buffer values are shown in Fig. 7a, b, respectively.

Next the models were run to screen out unsuitable areas and identify potential areas for secured landfill sites. Figure 8a, b represent unsuitable areas and potential areas

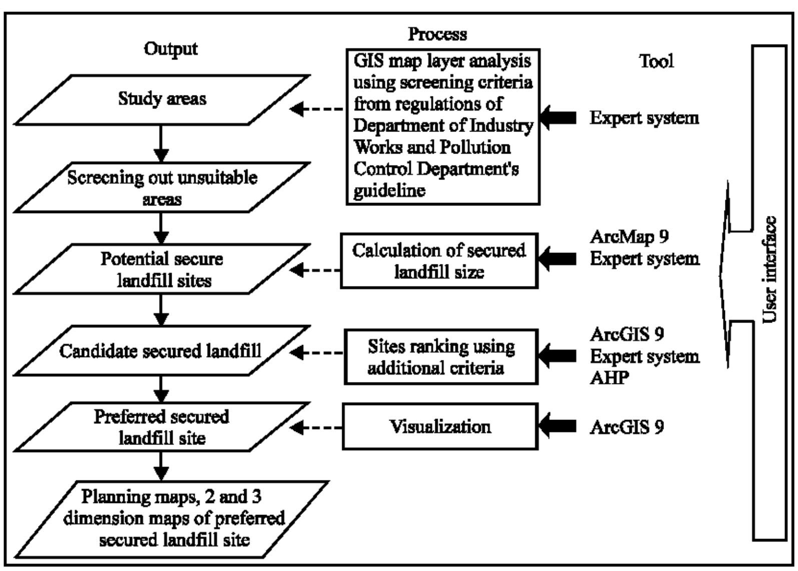


Fig. 2: Conceptual framework of this study

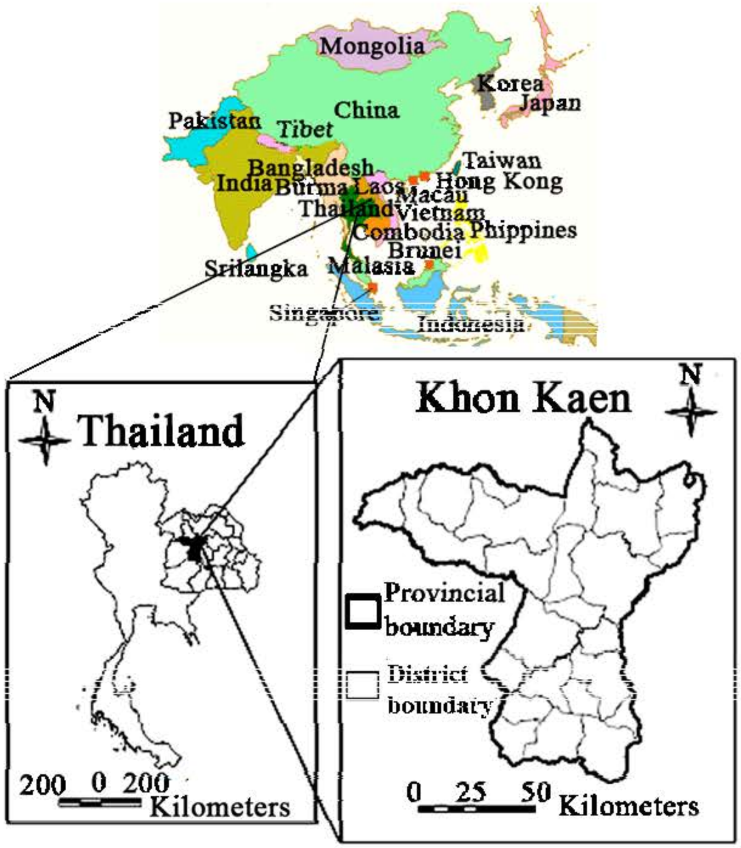


Fig. 3: Location map of Khon Kaen Province, Thailand

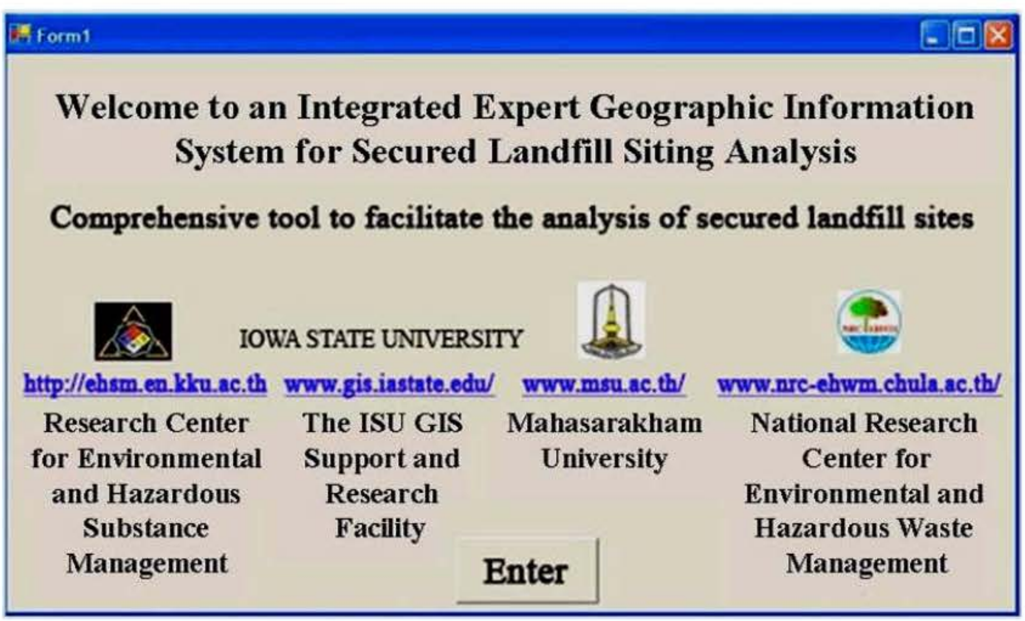


Fig. 4: First page of the expert system

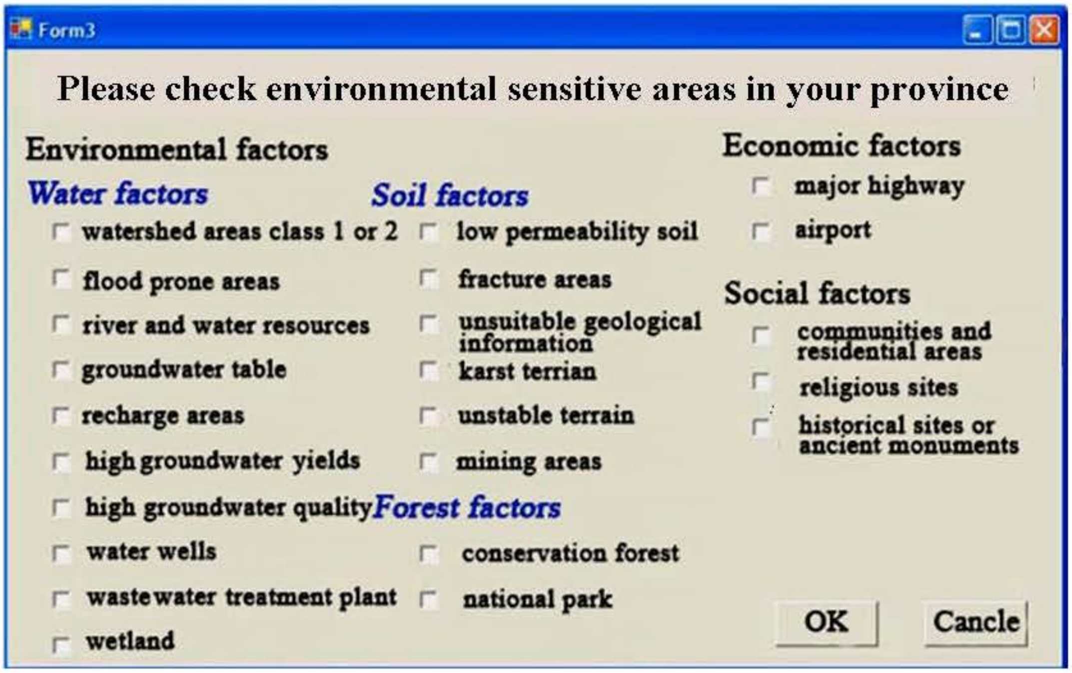


Fig. 5: Expert system asking users to input the sensitive factors in their area

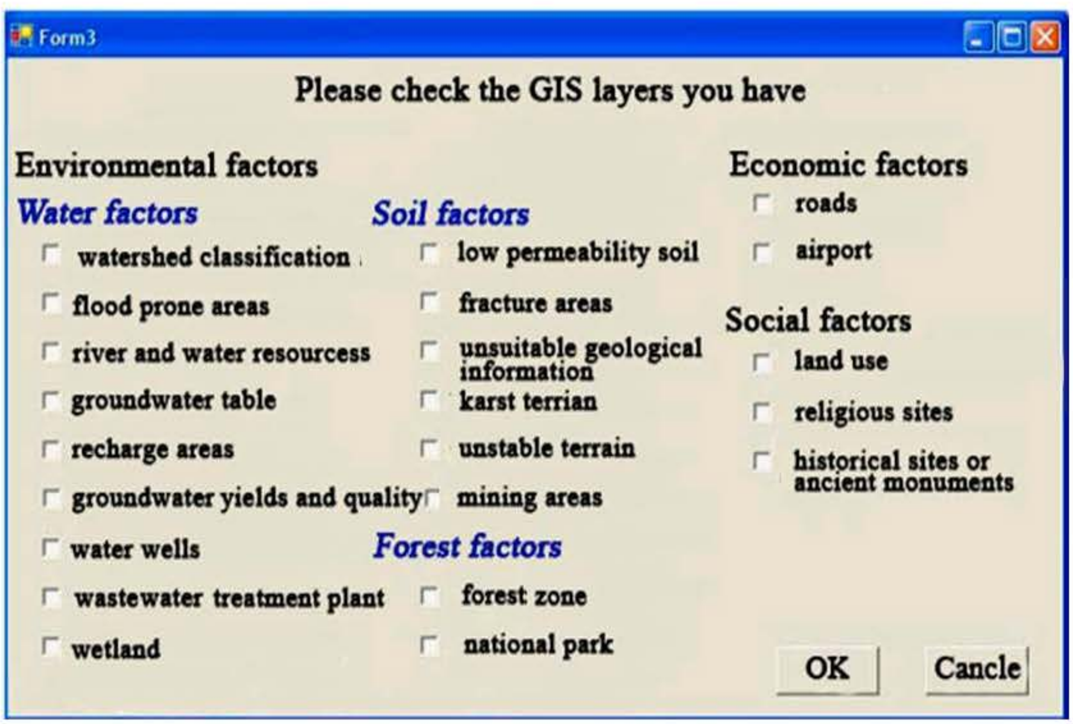
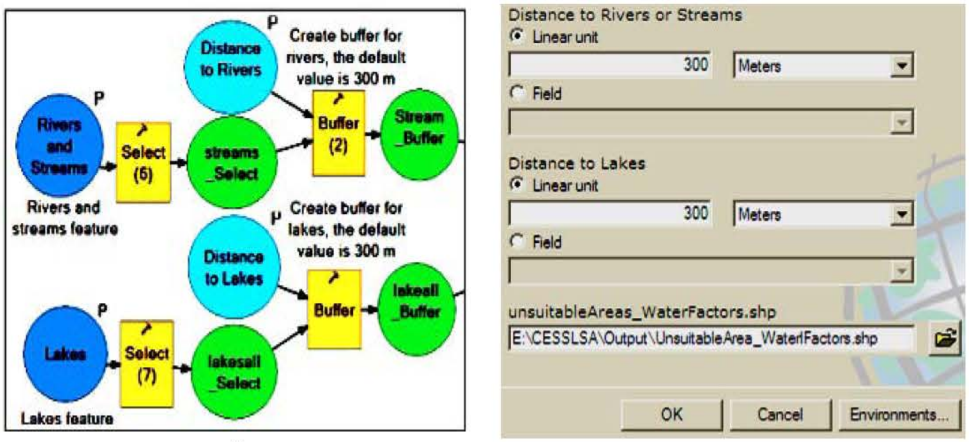
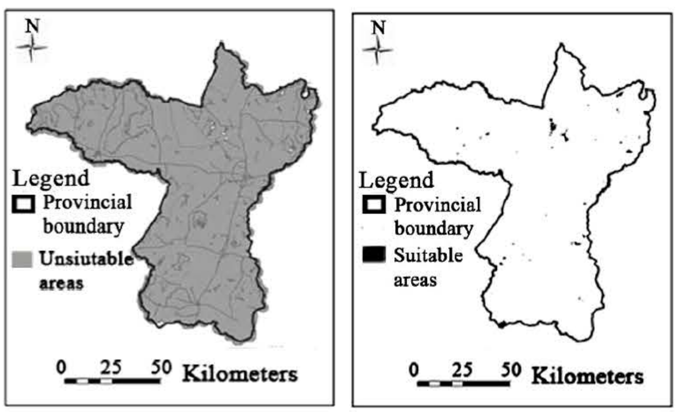


Fig. 6: Expert System asking users to input the GIS layers they have

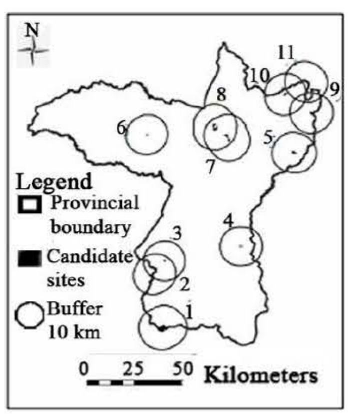


(a) (b)

Fig. 7: (a) Example of ArcMap model, (b) Example of an interface for inputting buffer values



(a) (b)



(c)

Fig. 8: (a) Unsuitable areas for secured landfill sites, (b) Potential areas for secured landfill sites and (c) Candidate sites for secured landfill and their 10 km buffer

Table 1: Screening criteria of Khon Kaen Province proposed by the Expert System

No.	Factors	Default values of buffer areas
1	**Environmental factors**	
	Water	
	Watershed areas class 1 and 2	-
	Flood prone areas	-
	River and water resources	300 m
	Groundwater table	<1.5 m
	Recharge areas	-
	High yields and high quality of groundwater	-
	Existing water wells	700 m
	Wastewater treatment plant	700 m
	Wetland	300 m
	Soil	
	Low permeability soil	
	Forest	
	Conservation forest	-
	National park	-
2	**Economic factors**	
	Major highway	>100 m <10 km
	Airport	5 km
3	**Social factors**	
	Communities and residential areas	2 km
	Religious areas	-
	Historical sites or ancient monuments	-

Table 2: Characteristics of candidate sites based on additional criteria

Candidate site	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Factor 12	Factor 13
Sites 1	19	4.6	5B	4.10	<2	>1500	2.4	0.6	18	5.5	Paddy field	48	3.7
Sites 2	29	3.4	5B	5.40	2-10	>1500	0.5	0.5	4	2.9	Paddy field	42	2.9
Sites 3	15	3.3	5B	3.50	2-10	>1500	1.3	0.8	4	5.9	Paddy field	53	2.9
Sites 4	68	3.3	4B	7.50	<2	<750	1.3	3.3	41	5.8	Field crops	58	3.0
Sites 5	32	2.3	4B	2.75	<2	<750	5.1	1.9	36	3.6	Forest	60	3.4
Sites 6	80	3.2	4A	4.90	<2	<750	1.3	1.3	36	3.9	Grass	93	2.9
Sites 7	26	3.3	4B	4.40	<2	<750	1.3	0.7	41	4.4	Field crops	68	3.0
Sites 8	19	4.1	4B	7.10	<2	<750	0.8	2.8	36	4.1	Field crops	56	3.4
Sites 9	20	2.7	4B	5.80	<2	<750	1.1	0.8	36	5.1	Field crops	43	3.2
Sites 10	19	4.0	4B	5.30	<2	<750	0.9	0.4	36	7.6	Field crops	30	3.4
Sites 11	6	4.9	4A	4.00	<2	<750	1.2	3.2	18	2.0	Field crops	13	3.1

Factor 1: No. of water well within 10 km, Factor 2: Distance to the nearest water well (km), Factor 3 : Major watershed classification, Factor 4: Average depth to water table (m), Factor 5: Groundwater yields (m^2 h^{-1}), Factor 6: Groundwater quality (TDS, mg L^{-1}), Factor 7: Distance to the nearest river (km), Factor 8: Distance to the nearest lake (km), Factor 9: Distance to the nearest major road (km), Factor 10: Major land use, Factor 11: No. of village within 10 km, Factor 12: Distance to the nearest village (km)

for secured landfill sites, respectively. After that, The ES calculated the appropriate size of secured landfill site and the result of the calculation was used as an input in a GIS analysis to identify the candidate sites for secured landfill. The results of GIS analysis show that there are eleven candidate sites for secured landfill in Khon Kaen province as shown in Fig. 8c.

Integrating the GIS and AHP: After the candidate sites were identified, the additional criteria were developed by considering factors used in screening process. In this case, there were 13 criteria which should be used as factors for ranking of candidate sites. Then ArcMap models automated GIS analysis and provided the characteristics of each candidate site based on the 13 criteria. The results of GIS analysis for characteristics of candidate sites are shown in Table 2. In The AHP application, the hierarchical structure for the decision problem was established and the overall objective of the analysis was to identify the suitable site for secured landfill in Khon Kaen Province as shown in Fig. 9. The result of determining the relative weights for the thirteen factors with respect to the objective of the analysis is shown in Table 3. The entries in Table 3 were then normalized to obtain the normalized average rating associated with each factor or the relative weights of factors as shown in the last column in Table 4. The relative weight shows that the average depth to groundwater table has the highest important rating, 0.218. It means that this factor is considered to be the most important factor in the selection of secured landfill sites. The consistency ratio of this step is 0.012 which is considered as acceptable. The relative weights of the candidate sites with respect to each factor were evaluated by using the similar procedure to the procedure for comparing the factors. The result of this step is presented in Table 5, which all consistency ratios are considered as acceptable. The relative weight showed earlier in Table 4 were combined with the relative weight of the candidate sites contained in Table 5 to obtain the overall relative

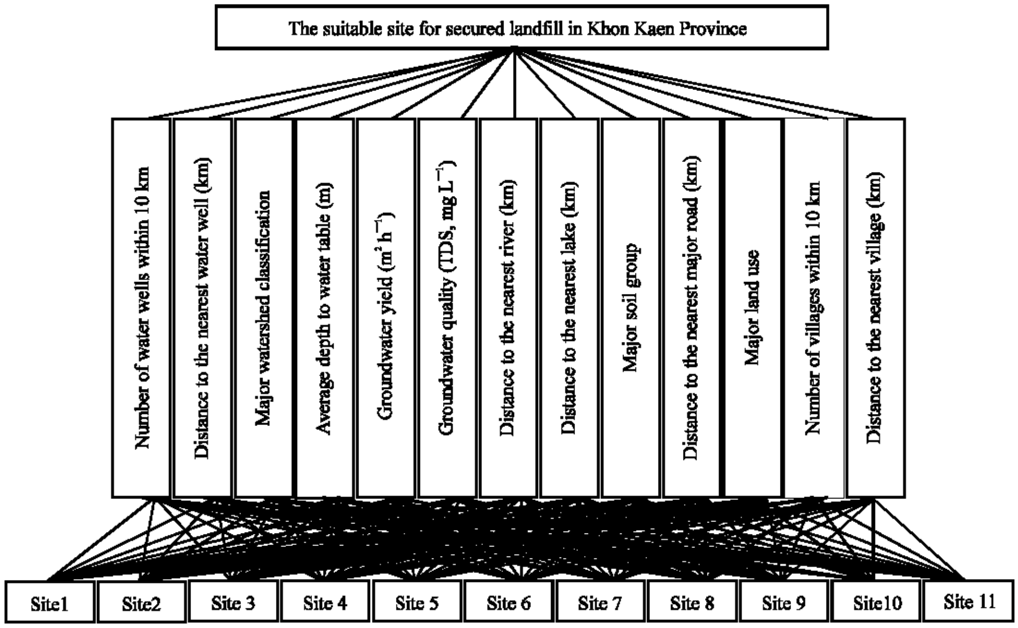


Fig. 9: Hierarchical structures for the decision problem

Table 3: Matrix of pairwise comparisons of the thirteen additional factors

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1.00	0.25	1.00	0.17	0.33	0.33	0.20	0.20	1.00	1.00	1.00	0.50	0.33
2	4.00	1.00	4.00	0.33	2.00	2.00	0.50	0.50	4.00	4.00	4.00	3.00	2.00
3	1.00	0.25	1.00	0.17	0.33	0.33	0.20	0.20	1.00	1.00	1.00	0.50	0.33
4	6.00	3.00	6.00	1.00	4.00	4.00	2.00	2.00	6.00	6.00	6.00	5.00	4.00
5	3.00	0.50	3.00	0.25	1.00	1.00	0.33	0.33	3.00	3.00	3.00	2.00	1.00
6	3.00	0.50	3.00	0.25	1.00	1.00	0.33	0.33	3.00	3.00	3.00	2.00	1.00
7	5.00	2.00	5.00	0.50	3.00	3.00	1.00	1.00	5.00	5.00	5.00	4.00	3.00
8	5.00	2.00	5.00	0.50	3.00	3.00	1.00	1.00	5.00	5.00	5.00	4.00	3.00
9	1.00	0.25	1.00	0.17	0.33	0.33	0.20	0.20	1.00	1.00	1.00	0.50	0.33
10	1.00	0.25	1.00	0.17	0.33	0.33	0.20	0.20	1.00	1.00	1.00	0.50	0.33
11	1.00	0.25	1.00	0.17	0.33	0.33	0.20	0.20	1.00	1.00	1.00	0.50	0.33
12	2.00	0.33	2.00	0.20	0.50	0.50	0.25	0.25	2.00	2.00	2.00	1.00	0.50
13	3.00	0.50	3.00	0.25	1.00	1.00	0.33	0.33	3.00	3.00	3.00	2.00	1.00
Column sum	36.00	11.08	36.00	4.12	17.17	17.17	6.75	6.75	36.00	36.00	36.00	25.50	17.17

Table 4: Normalized AHP matrix of paired comparisons

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	Row sum	Row average (relative weights of factors)
1	0.028	0.023	0.028	0.040	0.019	0.019	0.030	0.030	0.028	0.028	0.028	0.020	0.019	0.339	0.026
2	0.111	0.090	0.111	0.081	0.117	0.117	0.074	0.074	0.111	0.111	0.111	0.118	0.117	1.342	0.103
3	0.028	0.023	0.028	0.040	0.019	0.019	0.030	0.030	0.028	0.028	0.028	0.020	0.019	0.339	0.026
4	0.167	0.271	0.167	0.243	0.233	0.233	0.296	0.296	0.167	0.167	0.167	0.196	0.233	2.835	0.218
5	0.083	0.045	0.083	0.061	0.058	0.058	0.049	0.049	0.083	0.083	0.083	0.078	0.058	0.874	0.067
6	0.083	0.045	0.083	0.061	0.058	0.058	0.049	0.049	0.083	0.083	0.083	0.078	0.058	0.874	0.067
7	0.139	0.180	0.139	0.121	0.175	0.175	0.148	0.148	0.139	0.139	0.139	0.157	0.175	1.974	0.152
8	0.139	0.180	0.139	0.121	0.175	0.175	0.148	0.148	0.139	0.139	0.139	0.157	0.175	1.974	0.152
9	0.028	0.023	0.028	0.040	0.019	0.019	0.030	0.030	0.028	0.028	0.028	0.020	0.019	0.339	0.026
10	0.028	0.023	0.028	0.040	0.019	0.019	0.030	0.030	0.028	0.028	0.028	0.020	0.019	0.339	0.026
11	0.028	0.023	0.028	0.040	0.019	0.019	0.030	0.030	0.028	0.028	0.028	0.020	0.019	0.339	0.026
12	0.056	0.030	0.056	0.049	0.029	0.029	0.037	0.037	0.056	0.056	0.056	0.039	0.029	0.557	0.043
13	0.083	0.045	0.083	0.061	0.058	0.058	0.049	0.049	0.083	0.083	0.083	0.078	0.058	0.874	0.067
Column sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	13.00	1.00

CR: Consistency Ratio = 0.012

weights of the candidate sites as shown in Table 6. The overall weighted evaluation (α_j) contained in Table 6 shows that site 4 should be selected as the suitable site for secured landfill since it has the highest weight rating, 0.221. The Preferred site were then visualized in two and three dimension to present the characteristics of the site and surrounding areas within 5 kilometers as shown in Fig. 10 and 11, respectively.

The results from the application of IEGIS in Khon Kaen Province indicated that IEGIS can effectively facilitate the siting process of secured landfills. It provides decision support to users in selection of a suitable secured landfill site which means the objective of this study was achieved. The advantage of IEGIS compared to previous studies (Kontos *et al*., 2003; Eldrandaly *et al*., 2003; Way, 2005) is that it is friendly to users and even though

Table 5: Relative weights of the candidate sites with respect to each factor

Candidate site	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Factor 12	Factor 13
Site 1	0.043	0.188	0.038	0.040	0.067	0.020	0.161	0.027	0.077	0.053	0.036	0.066	0.198
Site 2	0.052	0.062	0.038	0.077	0.200	0.020	0.021	0.027	0.154	0.151	0.036	0.050	0.047
Site 3	0.108	0.055	0.038	0.032	0.200	0.020	0.061	0.038	0.154	0.047	0.036	0.079	0.054
Site 4	0.217	0.058	0.109	0.281	0.067	0.118	0.061	0.234	0.077	0.049	0.067	0.091	0.063
Site 5	0.068	0.020	0.109	0.021	0.067	0.118	0.421	0.103	0.077	0.117	0.119	0.097	0.118
Site 6	0.308	0.042	0.191	0.062	0.067	0.118	0.068	0.063	0.077	0.110	0.368	0.298	0.048
Site 7	0.048	0.049	0.109	0.051	0.067	0.118	0.044	0.037	0.077	0.090	0.067	0.128	0.063
Site 8	0.043	0.130	0.109	0.225	0.067	0.118	0.030	0.180	0.077	0.090	0.067	0.086	0.118
Site 9	0.044	0.027	0.109	0.095	0.067	0.118	0.044	0.038	0.077	0.061	0.067	0.055	0.085
Site 10	0.043	0.114	0.109	0.074	0.067	0.118	0.031	0.022	0.077	0.024	0.067	0.031	0.122
Site 11	0.024	0.255	0.038	0.040	0.067	0.118	0.058	0.231	0.077	0.208	0.067	0.020	0.085
CR	0.011	0.032	0.002	0.017	0.000	0.000	0.035	0.032	0.000	0.011	0.006	0.014	0.019

Table 6: Final AHP analysis for decision

Candidate sites	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Factor 12	Factor 13	Overall weighted evaluation (α_j)
Site 1	0.001	0.019	0.001	0.009	0.004	0.001	0.024	0.004	0.077	0.001	0.001	0.003	0.013	0.160
Site 2	0.001	0.006	0.001	0.017	0.013	0.001	0.003	0.004	0.154	0.004	0.001	0.002	0.003	0.212
Site 3	0.003	0.006	0.001	0.007	0.013	0.001	0.009	0.006	0.154	0.001	0.001	0.003	0.004	0.209
Site 4	0.006	0.006	0.003	0.061	0.004	0.008	0.009	0.036	0.077	0.001	0.002	0.004	0.004	0.221
Site 5	0.002	0.002	0.003	0.005	0.004	0.008	0.064	0.016	0.077	0.003	0.003	0.004	0.008	0.198
Site 6	0.008	0.004	0.005	0.014	0.004	0.008	0.010	0.010	0.077	0.003	0.010	0.013	0.003	0.169
Site 7	0.001	0.005	0.003	0.011	0.004	0.008	0.007	0.006	0.077	0.002	0.002	0.005	0.004	0.136
Site 8	0.001	0.013	0.003	0.049	0.004	0.008	0.005	0.027	0.077	0.002	0.002	0.004	0.008	0.203
Site 9	0.001	0.003	0.003	0.021	0.004	0.008	0.007	0.006	0.077	0.002	0.002	0.002	0.006	0.141
Site 10	0.001	0.012	0.003	0.016	0.004	0.008	0.005	0.003	0.077	0.001	0.002	0.001	0.008	0.141
Site 11	0.001	0.026	0.001	0.009	0.004	0.008	0.009	0.035	0.077	0.005	0.002	0.001	0.006	0.184

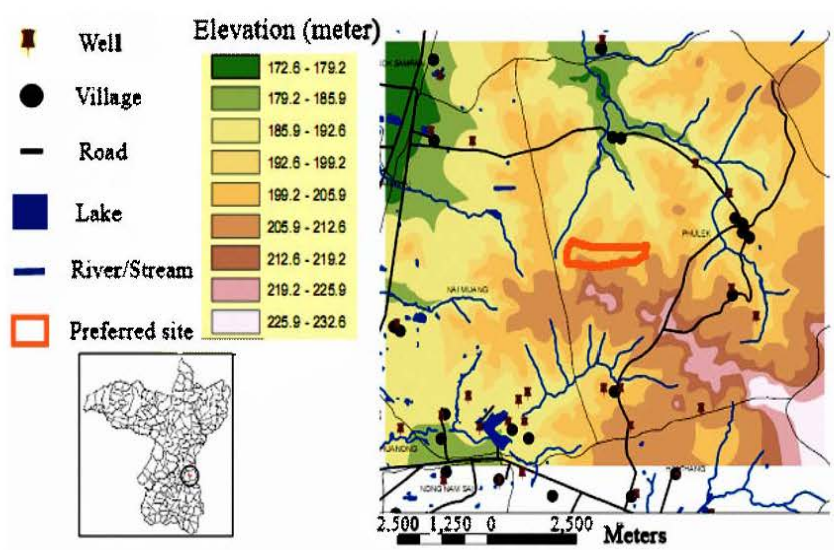


Fig. 10: 2-dimensional map of preferred site (Site No. 4)

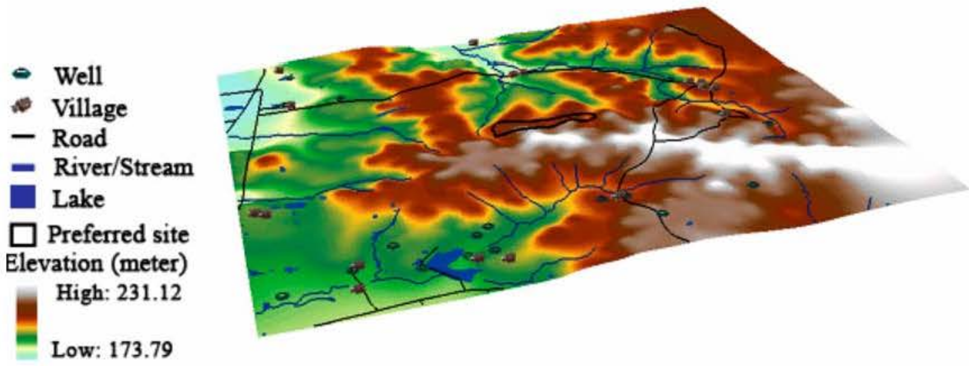


Fig. 11: 3-dimensional map of preferred site (the convection factor to place heights is 10)

they are not GIS experts, they just follow the guidance of the ES to identify the suitable secured landfill. In addition, the IEGIS could be particularly useful in situations where there are a large number of candidate sites, where there are a large number of additional criteria to be taken into consideration in the sites ranking process or where the determination of relative weights by different stakeholders is needed. Thus it could be used as a public participation tool to identify the suitable sites of secured landfill which could increase transparency in the siting procedures and improve the speed of the site selection process by incorporating public opinions at the outset of the decision-making process (Higgs, 2006). The criteria used in this study were developed according to Thai legislation and guidelines. However, the developed system is flexible thus it is not difficult to take other criteria into account.

CONCLUSION

Siting of secured landfill requires an extensive evaluation process to identify the suitable location. The integration of GIS, ES and AHP presented in this study could be a valuable tool for identifying the suitable sites for secured landfills. This system has the potential to expand the use and utility of GIS, ES and AHP and could benefit users in the secured landfill siting procedures. The development of ES and the integration of GIS, ES and AHP using Visual Studio.Net and Microsoft-Excel were successful. This study is regarded as the first step in the long term research agenda of the authors to develop the tool for facilitating secured landfill sites analysis. Since the major environment concern with secured landfill is groundwater contamination associated with infiltration of leachate (Misra and Pendey, 2005), the future research challenge is to integrate a groundwater model into the system for predicting the potential adverse impact from the preferred site to groundwater and also develop the ES to have capability to provide the measures for potential impacts from the preferred site.

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