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Combination of Geographic Information System, Fuzzy Set Theory And Analytic Hierarchy Process For Rationality Assessment Of Planned Industrial Zones: A Case Study In Vietnam

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ABSTRACT :- In Hung Ha district, planning new industrial zones along with enlarging the existing ones are the key policies of the authorities. Locations, however, of the planned industrial zones are facing protests of surrounding residential areas because of environmental impacts. The purpose of this research is to assist Hung Ha government in assessing the suitability of planned locations of industrial zones by utilizing the combinations of Geographic Information System (GIS) technology, Analytic Hierarchy Process (AHP) technique and Fuzzy set theory. Firstly, opinions were surveyed from people residing near planned locations for determining which problems were complained mostly, and subsequently consulted suggestions from the authorities to form affected factors table. Secondly, AHP was applied for calculating weights of criteria and factors, and Fuzzy set theory was employed for obtaining continuous score of relevant degree from 0 to 1. GIS technology was applied throughout the paper from standardizing input spatial data to overlapping layers. The assessment results revealed that all 18 planned industrial zones in the researched district were not rational because of close to residential areas or water sources.

Keywords :- AHP, Fuzzy set theory, GIS, Land use planning, Rationality assessment

I. INTRODUCTION

In Vietnam, the government at district level has responsibility for sustainable land use and land management. Currently, in order to implement such task, it might be said that land use planning is one of the best tool. Hung Ha government, nevertheless, is facing the problem about the disagreements over the planned locations for industrial zones from surrounding residential areas. Hence, it is urgent to conduct rationality assessment regarding spatial location for those planning objects. In general, the suitability evaluation process is really complicated due to the participation of many affecting factors in conjunction with complexities in handling geospatial data.

GIS is the best approach to geospatial data management and spatial analysis issues because this is a computer-based system (Norstrøm, 2001, Bhatt et al., 2007, Wang, 2009) allowing planners to collect, analyze and manage data in efficient way. Successful applications of GIS for land suitability assessment can be found in the papers (Muttiah et al., 1996, Aydin et al., 2013, Khahro et al. 2014, Kumar and Bansal, 2016). Particular researches concentrating on assessing land suitability levels for industrial locations use GIS technology (Chen and Delaney, 1998, Eldrandaly et al., 2003). In fact, the industrial zones, among other planning objects have been received many interests from researchers due to its impacts on environment, as well as life of citizen. Some studies have combined GIS technology with method of multiple criteria analysis (Ruiz et al., 2012, Sahnoun et al., 2012, Rikalovic et al., 2014) for improving the precision of results.

Analytic Hierarchy Process (AHP) is a widespread technique (Bunruamkaew and Murayam, 2011) for overcoming multi-criteria-based decision-making issue. This approach which allows group of planners based on their knowledge and experience to separate a problem into hierarchy, was firstly introduced by Saaty (Saaty T.L., 1980), and normally utilized to obtain weights of factors from pairwise comparison between them. Another common approach employed in solving spatial location assessment is Fuzzy set theory that normally combined with multi-criteria analyses method for dealing with measuring uncertainty based on membership functions (Kuo et al., 2013, Arabsheibani et al., 2016).

Because of magnitude of industrial areas for socio-economic development in Vietnam, along with the issues that the district government is facing, the present research will be conducted with objectives of:

(1) Evaluating the suitability level of each planned location for industrial areas in district of Hung Ha, Vietnam.

(2) Exploring the ability of integrating GIS, Fuzzy set theory, and AHP for accessing the rationality level of planned locations with respect to industrial zones.

II. MATERIALS AND METHODS

2.1. Study area and data

Locating in the northwest of Thai Binh province, Hung Ha is a district including 33 communes and 2 towns with area of 21028.68 ha covering 12.96% of total land area of Thai Binh (Fig.1). The District is bounded by Hung Yen province on the north, Ha Nam province on the west, Vu Thu district on the south, and the districts of Quynh Phu and Dong Hung on the east. In general, the study area has a fairly even and flat terrain with a slope of less than 1%, and is characterized by hot-humid tropical monsoon climate.

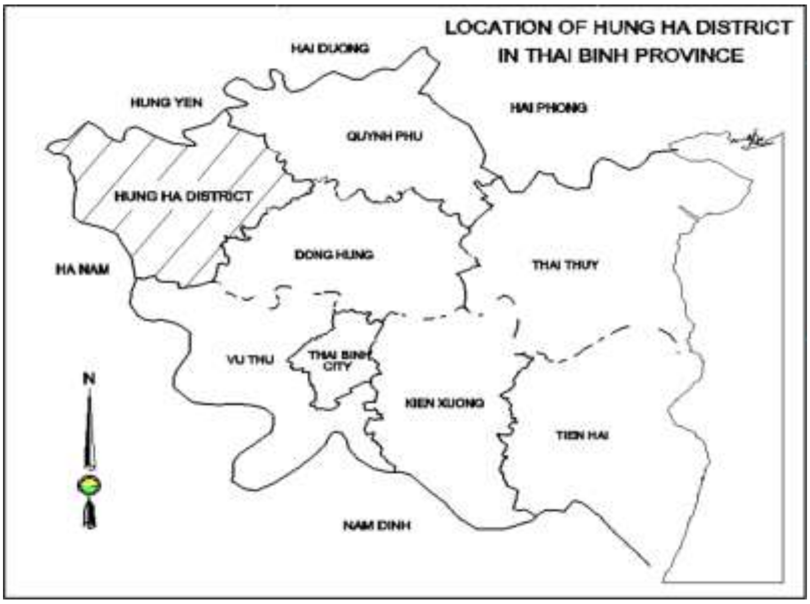

Figure 1: Location of Hung Ha district, Thai Binh province, Vietnam

In this paper, 2015 land use status map at scale of 1:10000, land use planning map to 2020 at scale of 1:10000, and 1:10000 scale topographic map were used to extract component spatial layers serving for evaluation process. Data was directly obtained from land registration office of the district and handled with ArcGIS 10.3 software. Planned industrial zones which need to be evaluated were derived from map of land use planning. In order to evaluate the locations, 10 factors were selected in which 9 factors were extracted from land use status map and 01 factor (slope) was derived from topographic map.

2.2. Selecting evaluation criteria and factors

In this study, multi-criteria assessment process was applied to evaluate the rationality of spatial locations for planned industrial zones, and the selection of factors which join the evaluation is probably the most significant preliminary step. Although many of the factors may affect the decision of whether a location is appropriate, it is impossible to involve all these factors. The following factors (Table 1) were carefully selected based on the literature reviews (Chen and Delaney, 1998, Eldrandaly et al., 2003, Ruiz et al., 2012, Sahnoun et al., 2012, Rikalovic et al., 2014), surveying attitudes of people living near the planning sites, consulting experiences from some experts in land use planning field, and suggestion from the authorities of Hung Ha district.

Table 1: Rationality evaluation factors for planned industrial zones

No.	Criteria	Factors	Abbreviation
1	Economy	Distance to Electric Supply Stations	disESS
2		Land Use Status	LUS
3		Distance to Existing Industrial Zones	disEIZ
4		Slope	slope
5	Environment	Distance to Urban Residential Areas	disURA
6		Distance to Rural Residential Areas	disRRA
7		Distance to Main Roads	disMR
8		Distance to Surface Water Sources	disSWS
9		Distance to Landfills	disLandfill
10		Distance to Historic Monument Areas	disHMA

10 proposed factors were grouped by 2 criteria: economy group in which the factors influenced the issue of construction cost, and environment group in which potential environmental impacts of the factors were considered. The abbreviation was employed for easily displaying results during the analysis process.

2.3. AHP application for determination of weights

Regarding to process of multiple criteria evaluation, one of important steps is to discover the weight of each factor. While many approaches which have been found such as analytic network process, weighted product model or regression analysis may be employed to address this, AHP (Saaty T.L., 1980, Saaty R.W., 1987) was adopted as a method to calculate factors weight in this study. For the first step, a hierarchical tree which was composed of 3 levels including objective, criteria, and factor was built (Fig.2). With regard to this research, rational assessment was the objective, and 2 criteria consisting of economy which contained 4 factors and environment which contained 6 factors.

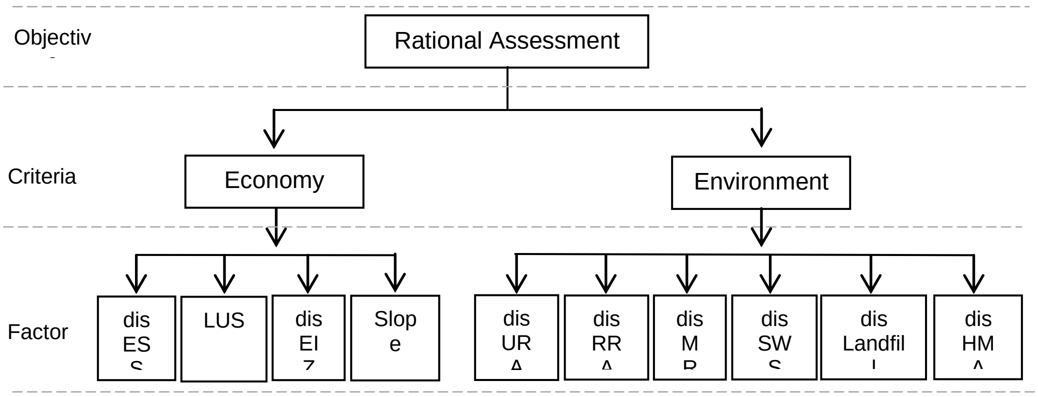

Figure 2: The hierarchical tree model for AHP technique

The second step, also the most important one, was to collect the relative comparisons between each pairwise factor in each criterion, and between pairs of criteria. 2 planners together with 3 scientists on land administration and 1 industrial zone manager were asked for comparing the level of importance between each pair factor. Based on the fundamental assessment scale ranging from 1 to 9 (Table 2), the respondents were first individually questioned, and then were met together for discussion and adjustment. Eventually, matrices representing pairwise comparisons were produced (Table 3).

The final step was to calculate the weights of factors and criteria from matrices of experts-based opinions and then the consistency of professionals' evaluation was examined by Consistency Ratio (CR), which should not exceed than 0.1 (Saaty T.L., 1980). In this paper, CR = 0.0215 for economy matrix and CR = 0.0618 for environment, which mean that all matrices were consistent. The weights of all factors were calculated by multiplying the normalized eigenvectors with the weights of criteria and the results were represented in table 4.

Table 2: The fundamental assessment scale for AHP (Source: Saaty R.W., 1987)

Scale	Explanation
1	Equal importance
3	Moderate importance
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocals	Inverse values

Table 3: Final matrices of pairwise comparison

Criteria: economy	disESS	LUS	disEIZ	Slope	Normalized eigenvector
disESS	1	1/3	1	2	0.202
LUS	3	1	2	3	0.4566
disEIZ	1	1/2	1	2	0.2212
Slope	1/2	1/3	1/2	1	0.1202
n = 4; λ_{max} = 4.0573; CI = 0.0191; RI = 0.89 ➔ CR = 0.0215 < 0.1					

Criteria: environment	disURA	disRRA	disMR	disSWS	disLandfill	disHMA	Normalized eigenvector
disURA	1	3	3	5	6	3	0.3896
disRRA	1/3	1	2	3	4	3	0.2146
disMR	1/3	1/2	1	3	5	3	0.1833
disSWS	1/5	1/3	1/3	1	2	2	0.0886
disLandfill	1/6	1/4	1/5	1/2	1	1/2	0.0457
disHMA	1/3	1/3	1/3	1/2	2	1	0.0782
n = 6; λ_{max} = 6.3863; CI = 0.0773; RI = 1.25 ➔ CR = 0.0618 < 0.1							

Table 4: Weights of criteria and factors computed by AHP

Criteria	Factors	Weight of criteria	Weight of factors	Final weights
Economy	Distance to Electric Supply Stations	0.25	0.2020	0.0505
	Land Use Status		0.4566	0.1142
	Distance to Existing Industrial Zones		0.2212	0.0553
	Slope		0.1202	0.0301
Environment	Distance to Urban Residential Areas	0.75	0.3896	0.2922
	Distance to Rural Residential Areas		0.2146	0.1609
	Distance to Main Roads		0.1833	0.1374
	Distance to Surface Water Sources		0.0886	0.0664
	Distance to Landfills		0.0457	0.0343
	Distance to Historic Monument Areas		0.0782	0.0587

2.4. Application of fuzzy set theory

In practice, there are many objects that may be explicitly classified into either a member of a set or not. In this case, the boundary of this crisp set is considered as clear or sharp (Zhang et al., 2015). However, with respect to problems that their values are approximation or uncertainty, it is difficult to decide which set they should belong to. In the 1960s, professor Zadeh introduced the new mathematical concept, named fuzzy set theory, to solve the approximate information or vagueness values (Zadeh, 1965, Wong and Lai, 2011). A fuzzy set was expressed by a function called membership function, which its value is between 0 and 1 for representing the probability of an object belongs to that set. In this paper, for instance, with regard to factor "Distance to Historic Monument Areas", the value of 0 indicated that the distance was completely unsuitable for the purpose of locating the industrial zones and the value of 1 indicated that the suitability level of this distance was 100%. Fig.3 demonstrates two kinds of membership function that were utilized in this study.

$$f(x) = \begin{cases} 0 & x \leq a \\ \dfrac{x-a}{b-a} & a < x < b \\ 1 & x \geq b \end{cases}$$

$$f(x) = \begin{cases} 1 & x \leq a \\ \dfrac{b-x}{b-a} & a < x < b \\ 0 & x \geq b \end{cases}$$

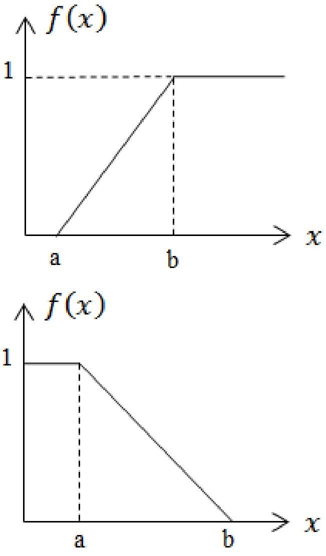

Figure 3: Two types of membership functions and their models

2.5. Calculating rationality scores for planned industrial zones

Using analysis tools in ArcGIS software, the input data layers were first analyzed by tool of "Euclidean Distance" that calculated the straight distance from each cell to the closet source. These distance values were then computed according to corresponding membership function by tool of "Raster calculator" to produce rationality layers that hold the rationality score. The land use status layer were converted from type of vector to raster and then classified and assigned score. The next step was to create a layer that total the rationality score of all input data by multiplying each rationality layer by corresponding weight (Fig.4). Eventually, the rationality score of each planned industrial zones were computed by using "Zonal Statistics as Table" tool (Table 5).

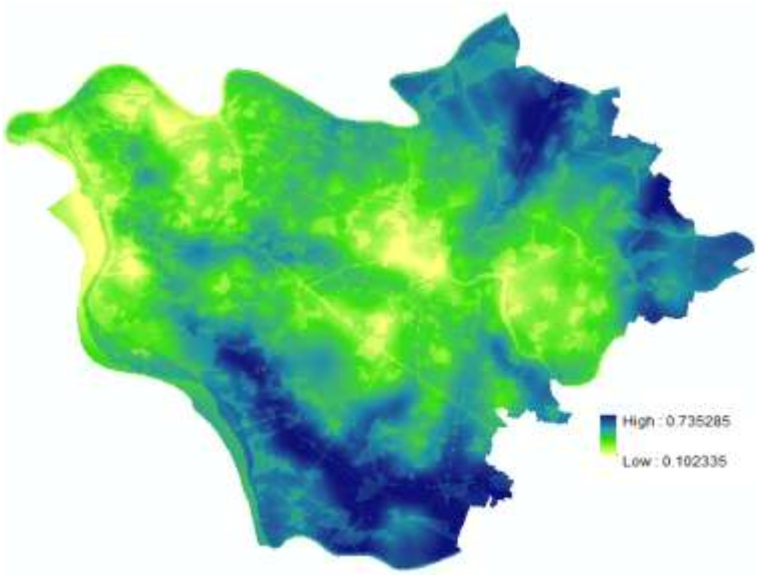

Figure 4: The total rationality score layer

Table 5: The rationality score of 18 planned industrial zones in Hung Ha district

Industrial zones	1	2	3	4	5	6	7	8	9
Rationality score	0.62	0.581	0.47	0.485	0.488	0.483	0.477	0.466	0.493
	10	11	12	13	14	15	16	17	18
	0.485	0.394	0.447	0.425	0.435	0.405	0.354	0.45	0.244

III. RESULTS

All 18 planned industrial zones in Hung Ha district were not suitable in terms of location due to close to the residential areas or surface water sources. From table 5, only two industrial zones achieved the rationality level of exceeding 50%, but less than 65% (62% and 58.1% for location 1 and 2, respectively), and all the others were less than 50%. The detailed analysis of why these locations were not rational was listed in table 6.

Table 6: The detailed analysis of 18 planned industrial zones in Hung Ha district

Industrial zone	Detailed analysis	Industrial zone	Detailed analysis
1	< 10m far from residential areas	10	< 30m far from residential areas
2	< 20 m far from a river < 30m far from residential areas < 50m far from 3 monument areas	11	< 300m far from residential areas < 10m far from surface water source < 100m far from aquaculture areas
3	< 80m far from residential areas	12	< 20m far from an urban residential area < 60m far from aquaculture areas < 10m far from a cemetery area
4	< 10m far from residential areas	13	< 30m far from 2 urban residential areas < 50m far from 2 monument areas < 100m far from aquaculture areas
5	< 20m far from residential areas	14	< 200m far from residential areas < 100m far from a monument area < 200m far from a water supply station < 100m far from aquaculture areas
6	< 250m far from residential areas	15	< 100m far from residential areas < 100m far from a school
7	< 300m far from residential areas	16	< 20m far from residential areas < 20m far from a river.
8	< 150m far from residential areas	17	< 200m far from residential areas < 250m far from a monument area
9	< 10m far from residential areas	18	< 40m far from an urban residential area < 150m far from aquaculture areas < 20m far from a river.

The detailed analysis in table 6 showed that 100% of planned locations were close to residential areas, which caused the protest from people living around because of environment problems such as pollution of noise, air, or water. 3 of sites (2, 16, and 18) accounting for 16% were nearby a river that might be useful for the water supply but easy to cause the water pollution. In addition, 22% and 27% of sites were near the historic monument areas and near the aquaculture areas, respectively.

IV. DISCUSSION

In this study, the purpose of evaluating 18 planned industrial zones for Hung Ha district using the combination of GIS, Fuzzy, and AHP methods was successfully achieved. 10 factors were chosen and calculated weights by AHP, whereas GIS was applied to process spatial input data and produce the final output results. Theory of fuzzy set was employed to determine the rationality score of input factors via membership functions. The obtained results were in agreement with reality and accepted by Hung Ha government.

The successful results in this study were illustrative of integrating AHP, GIS, and fuzzy theory for aim of assessing rationality level of planned object in land use planning. The planned objects applied in this paper were industrial zone but our recommendation was that these techniques can be used for other types such as landfill, school, or hospital. In addition, the number of criteria and factors joining the assessment also can be increased and the other multi-criteria technique may also be employed such as analytic network process, or weighted product model.

V. CONCLUSIONS

AHP, GIS and fuzzy set theory were integrated to determine the suitability level of 18 planned industrial zones in Hung Ha district, Vietnam. 2 criteria and 10 factors were selected for the evaluation and the final result showed that all planned locations was not suitable because these sites were too close to residential area (100%), historical monument areas (22%), or surface water sources (39%). This research is a demonstration of the effectiveness of utilizing fuzzy set theory as a mechanism to convert numerical data into level of suitability with the scale of 0 -1, which means 0% for lower limit and 100% for upper limit. AHP is an effective technique for computing the weights of input factors in a way that the consistency may be examined by consistency ratio, whereas GIS is a powerful tool for overcoming the spatial data process and producing output results in a friendly format. The integration of these 3 methods provides a powerful means for dealing with the problem of assessing the rationality of planned objects in land use planning.

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