Optimal Position Proposal for Construction of Municipal Solid Waste Landfill Using an Approach of Fuzzy Set Theory and AHP in a GIS Environment: A Case Study in Hoai Duc District, Hanoi City, Vietnam

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Abstract
Vietnam is a developing country with a rapid population growth rate and the inevitable consequence that the amount of Municipal Solid Waste (MSW) released into the environment is growing. Currently, MSW landfill is still a popular choice in Vietnam because of advantages such as cheap, easy construction, handling many types of garbage. However, landfills are often opposed by people living around because of negative environmental impacts including air pollution, water pollution, and soil pollution. In this research, the combination of Fuzzy set theory and Analytical Hierarchy Process (AHP) in a Geographic Information System (GIS) environment was applied to propose optimal locations for constructing MSW landfill in Hoai Duc district, Hanoi city, Vietnam. 2 criteria and 8 factors were selected via literature review and Vietnamese regulations on construction of landfills. Data used in this study include spatial data layers extracted from the land use status map in 2018 and map of land use planning to 2020 of Hoai Duc district. These maps were collected from the Department of Natural Resources and Environment of the district and then converted, standardized and layers extracted in the GIS environment. AHP method was used to calculate weights of factors and Fuzzy set theory was applied to obtain the continuous reasonable score from 0 to 1. The whole process was conducted in GIS software called ArcGIS. The results showed that there were 2 potential locations with a reasonable score of more than 70% that can be built for MSW landfill purpose including the position in Van Con commune with an area of 90 ha and a position in An Thuong commune with an area of 16 ha. The approach in this research can be a useful reference for planners in selecting the optimal location for the purpose of MSW landfill construction.

1. Introduction

Waste and waste disposal has become a hot topic in many countries around the world, including Vietnam. In 2011, Hanoi city of Vietnam produced approximately 2,372,500 tons of Municipal Solid Waste (MSW) accounting for 11% of the total national emissions (Thanh et al., 2015). However, with the current rapid economic development, the amount of MSW emitted to the environment will increase rapidly and thus, if there is no appropriate treatment, this huge amount of waste will pollute the environment, destroy the urban landscape, affect human health and waste land resources. Currently, there are many methods used for MSW disposal purpose in which landfill is still a popular choice used in Vietnam and many countries around the world. However, the selection of MSW landfill is a complex process for planners because to make a decision of which location is optimal, it is necessary to take into account many socio-economic factors as well as environmental ones. Therefore, combination of Geographic Information System (GIS), Fuzzy set theory and Multi-Criteria Analysis (MCA) methods will be very appropriate tools to solve this problem.

Since the 70s of the previous century, American scientists have approached the technique of MCA and overlaying maps to select the best location for solid waste landfill construction. In the late 1980s, the research trend of optimal site selection spread to European countries and some developed countries in Asia. In recent years, there have been many researches on application of GIS, MCA in the selection of solid waste landfill sites. Elahi and Samadyar (2014) used GIS technology and AHP method to find out the most suitable locations for construction of solid waste landfill. The authors stated that in order to solve the problem of site selection, it is necessary to use MCA method and also emphasize that GIS is a powerful support tool for spatial data analysis phase. The applicability of GIS and MCA in the selection of solid waste landfill site has also been indicated by Isalou et al., (2013). This author used the Analytic Network Process (ANP) method in combination with Fuzzy set theory to calculate the weights of factors and explore the best position.

In another studies, Yildirim et al., (2018) designed a process for the municipal solid waste landfill site selection considering economical, sociological and environmental criteria. In order to implement this task, the authors applied the GIS and a multi-criteria decision making technique, namely Spatial-integrated Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). TOPSIS was applied in this research to integrate environmental, economical and sociological criteria for determining landfill locations in Bursa Province, Turkey. ArcGIS 10.1 software was utilized for Least Cost Path Analysis with cost surface was produced. Results of this study were six of the most suitable sites for locating landfills and the Kayapa district was determined as the most suitable area. Majumdar et al., (2017) dealt with landfill site selection problem by using AHP method in which candidate sites were checked by two kinds of index namely Landfill Site Sensitivity Index and Economic Viability Index. Kharat et al., (2016) defined that landfill location selections is a complex process and their research concentrated on determining, assessing, and prioritizing criteria and finally tried to find out the relationship between criteria. The methods were applied in this study including: fuzzy Delphi method was used to gather the critical factors; fuzzy-AHP method was utilized to compute the weight of factors; and Decision-making Trial and Evaluation Laboratory technique was used to overcome the importance and causal relationships among them.

Generally, the combination of GIS and MCA to solve the problem of optimal location selection is quite common because GIS is the most appropriate approach to issues related to geospatial data management and analysis (Bhatt et al., 2007), and MCA, in particular here is the AHP method, is one of the most commonly used methods to address multi-criteria decision-making issues (Bunruamkaew and Murayam, 2011). Saatsaz et al., (2018) conducted a research on evaluating the location suitability of an existing landfill in Zanjan, Iran using the combination of AHP method and GIS techniques along with fieldwork surveys. In this research, the authors established four criteria, 12 factors and used AHP to calculate the weights of them. GIS techniques were employed to create a landfill suitability map based on the final suitability scores. With purpose of examining a methodology, which is based on AHP method in a GIS environment, Randazzo et al., (2018) want to determine the potential locations that may be used for building municipal solid waste landfills. In this research, the author's first attempt was to divide the study areas into excluded areas and potential ones based on Italian current laws. The next step was to apply the AHP method to calculate the weights of involving criteria and the suitable locations was finally assessed by method of Simple Additive Weighting (SAW). The suitability was presented in a scale from 0 to 10 and ranked by applying a spatial clustering process.

In addition to combining GIS and AHP, another popular approach is to combine GIS, AHP with Fuzzy set theory in which Fuzzy Logic Membership Functions are applied to overcome the measuring uncertainty (Arabsheibani et al., 2016 and Kuo et al., 2013). Al-Ruzouq et al., (2018) combined fuzzy membership and AHP method in a GIS environment to find out the best suitable location for landfill site in Sharjah city of United Arab Emirates. Torabi-Kaveh et al., (2016) developed a process applying GIS along with fuzzy analytical hierarchy process (FAHP) to deal with problem of landfill location selection in Iranshahr, Iran.

In this study, Hoai Duc district of Hanoi city in Vietnam is selected as a case study for determining the optimal MSW landfill site. Factors that influence the decision-making process are considered through literature review and Vietnamese legal regulations. Influence of factors is determined by AHP method and the member functions are applied to obtain the continuous reasonable score from 0 to 1. The analysis process is implemented by GIS software named ArcGIS.

With the rapid socio-economic development of Vietnam, the planning for the landfill site is important and urgent. However, there are many issues related to position selection due to the environmental impacts and therefore, this study is conducted with the objective of combining methods including AHP, fuzzy theory and GIS to explore potential sites for landfill construction. The research is limited within Hoai Duc district and the influencing factors are selected in accordance with the circumstances and regulations in Vietnam.

2. Materials and Methodology

In this study, first of all, the factors affecting decision making will be carefully selected through prior researches and especially the regulations in Vietnam on the location of landfill. These factors will be grouped and evaluated for importance level by the AHP method. Next, because each criterion will have different reasonable thresholds, the member functions of fuzzy theory will be applied to convert the reasonable score from discrete form to continuous form, which has a value range from 0 to 1. GIS is employed throughout the process of standardizing, analyzing, overlaying data to displaying and storing the obtained results. The final result will be the most optimal positions for the construction of landfills in the study area.

2.1 The Study Area and Data

Having an administrative area of 84.93 km² with 1 town and 19 communes, Hoai Duc is a district of Hanoi city and has a very convenient location for economic development due to its proximity to economic centers. Hoai Duc is bounded by districts of Dan Phuong and Phuc Tho on the North, districts of Ha Dong and Chuong My on the South, districts of Quoc Oai and Phuc Tho on the West and districts of Tu Liem and Ha Dong on the East. Generally, Hoai Duc is located in the Red River and Day River Delta regions with tilting terrain from North to South and from West to East. In addition, located in tropical monsoon area, 1 year divided into 4 seasons, the district has the annual average temperature from 23.1 - 23.5 degrees and the annual average rainfall from 1600 - 1800 mm.

Hoai Duc is facing many difficulties related to MSW treatment due to the rapid development of the economy. In fact, there is not yet any centralized waste disposal site in the district and all waste still depends on the external waste treatment locations. Therefore, how to determine an optimal position for the construction of MSW landfills is an important issue to be addressed in Hoai Duc.

Each selected criterion will have the corresponding spatial layer and these layers will be extracted from the land use status map in 2018 and map of land use planning to 2020 of Hoai Duc district with the scale of these two maps is 1:10000. These maps are collected from the Department of Natural Resources and Environment of the district.

2.2 Analytic Hierarchy Process (AHP)

There are many factors that influence the decision to choose a suitable location for landfill construction and each factor also has different levels of impact. Additionally, while there are many different approaches to determine the influence of each factor such as using ANP, TOPSIS, WPM (Weighted Product Model), AHP was selected as a method to determine the weights of criteria and factors because of simple in use and its popularity. Proposed by Saaty in the 1980s (Saaty, 1980 and 1987), AHP is the most commonly used MCA method and has a high level of objectivity as well as being consistent with human thinking. The implementation process of AHP consists of 4 main steps (Saaty and Vargas, 2001): (1) Decompose an unstructured situation into small components; (2) Arrange components or factors in a hierarchical order; (3) Assign numerical values to subjective comparisons of the importance of the factors. The comparison is implemented between pairs of factors and is combined into a square matrix. The importance of the factors is evaluated based on the opinions of experts on a scale as shown in Figure 1; (4) Calculate and summarize the results to determine the importance of the factors.

When carrying out the evaluation of factors, the importance level of the factors to be evaluated depends on the subjective opinions of the decision makers. Therefore, in order to ensure the consistency of the output results, the Consistency Ratio - CR is used according to the following formula (Saaty and Vargas, 2001):

$$CR = \frac{CI}{RI} \quad CI = \frac{\lambda \max - n}{n-1}$$

$$\lambda \max = \frac{1}{n} \times \left(\frac{\sum_{n=1}^{4} w_{1n}}{w_{11}} + \frac{\sum_{n=1}^{4} w_{2n}}{w_{22}} + \frac{\sum_{n=1}^{4} w_{3n}}{w_{33}} + \frac{\sum_{n=1}^{4} w_{4n}}{w_{44}} \right)$$

Equation 1

In which: *CI* is Consistency Index; *RI* is Random Index; λ_{max} is Principal Eigen value and W_{ij} is standardized factor value of row *i* and column *j*.

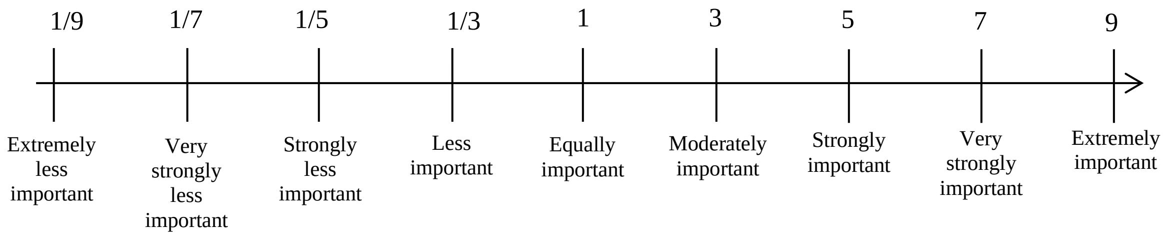


Figure 1: The AHP comparison scale

2.3 Fuzzy Set Theory

In daily life, there are many objects that can easily identify whether or not it belongs to a set and the boundary of this set is considered as clear (Zhang et al., 2015). However, for objects whose values are unclear or approximate, it is difficult to determine exactly which set these objects belong to. In 1965, the fuzzy set theory was introduced by Zadeh to address uncertainties due to inaccuracy or lack of clarity (Zadeh, 1965). Applications of fuzzy set theory can be found in many different fields such as artificial intelligence, computer science, medicine or decision-making theory.

Consider X as a set of x. A fuzzy set is a set expressed in the form of a membership function $\mu_M(x)$ that demonstrates the ability X belongs to set M. The value representing the membership level of an element is in the range of 0 to 1. If $\mu_M(x)=0$, means that the element x is completely out of set M and vice versa if $\mu_M(x)=1$, means that the element x is purely of set M (Zadeh, 1965). Figure 2 shows one types of membership function.

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

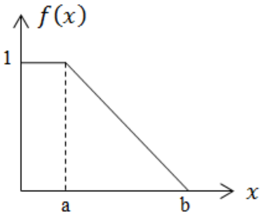


Figure 2: Example of membership functions

For establishing the membership functions in this research, we first need to determine the range of values for each influencing factor. Next, based on the divided values, the graph will be plotted to visualize and from there, the membership functions will be established accordingly. For example, with the factor of distance to common roads, the steps will be conducted as follows:

- Range of values from 0 - 200m: suitable level increases gradually when the distance is closer to 200m (graph goes up);
- Values range from 200 - 500m: This is the most appropriate distance (horizontal graph);
- Values range from 500 - 1000m: suitable level gradually decreases when distance is closer to 1000m;
- Values range greater than 1000m: not suitable.

From this distance division, the graph showing the variation of the value will be plotted and finally from this one, proceeds to build the membership function accordingly (Figure 3).

$$f(x) = \begin{cases} \dfrac{x}{200} & 0 < x < 200 \\ 1 & 200 \le x \le 500 \\ \dfrac{1000-x}{1000-500} & 500 < x < 1000 \\ 0 & x \ge 1000 \end{cases}$$

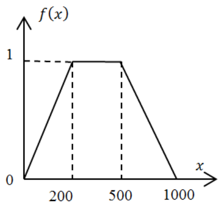


Figure 3: Membership function and graph of Distance to normal road factor

2.4 Criteria and Factors Selection

The criteria and factors selection that affects the determination of the location of MSW landfill is an important step that has a great impact on the accuracy of the output results. There have been many authors studying this issue and have proposed many different influencing factors. For instance, in research on choosing the MSW landfills applying ANP method and GIS with a case study in Iran, Motlagh and Sayadi (2015) proposed a series of 12 factors including slope, water resources, soil parameters, land use, fault, distance to protected areas, distance to the road, distance to urban areas, distance to village, distance to airport, distance to historical place and distance to industries. Rahmat et al., (2017) also suggested 11 different factors concentrating so much on environment aspect such as distance to groundwater, distance to urban areas, distance to rural areas, distance to surface water and sensitive ecosystems, to construct a framework for selection of landfill location. Eskandari et al., (2012) in attempt to establish the evaluation process for siting landfills, even took 16 factors covering economic, social and environmental aspects.

For the selection of factors, the authors first outlined a list of typical factors from the literature review. However, because each country or region has different characteristics, this list will be shortened and omitted factors that are not suitable for the study area and also be added factors that comply with the regulations of Vietnam in landfill position selection. Next step, a group of five experts including one person working in the urban management department of Hoai Duc district, 2 experts work in the field of land management and 2 experts research in the field of environmental management has been selected to comment on the list. After careful consideration of socio-economic characteristics as well as actual needs from managers of the study area, the 8 most important factors and classified into 2 groups including economy and environment to serve for the research purpose have been selected (Table 1). Distance to common roads and land use status are 2 factors classified to the economic group because these factors affect the construction cost when building landfills and the remaining 8 factors belong to the group of environment because of environmental impacts. The abbreviation is used for the brief presentation of research results.

3. Research Results

3.1 Weight Calculation of Criteria and Factors

Before calculating the weight of criteria and factors, the problem of optimal MSW landfill site selection was decomposed and arranged into three levels including objective, criteria and factors. The hierarchy tree model was created as shown in Figure 4. In order to identify the weights of criteria and factors, 6 experts in different fields were asked to fill in a questionnaire containing the comparison matrices of importance levels between criteria and factors. The output results of the weights calculation process by AHP method are shown in Table 2.

3.2 Fuzzy Set Theory Application

The factors after being weighted by the AHP method will be scored by application of the Fuzzy set theory. The membership function of each factor will be constructed and the reasonable score will be from 0 to 1. For example, the member functions and graphs of 8 factors are given in Table 3 below.

3.3 The Optimal Location Proposal for MSW Landfill

In order to suggest the most suitable location for the construction of MSW landfills, it is necessary to first create distance raster layers where the value of each pixel presents the distance from that pixel to the influence factors. These raster layers will then be used as input data in conjunction with the predefined membership functions to produce fuzzy raster layers in which each pixel presents a value between 0 and 1 (Figure 5). Particularly, the land use status layer will be converted from vector format to raster and then classified and assigned scores. All operations are performed by ArcGIS software. The final step is to create a reasonable raster layer that is synthesized from all fuzzy raster layers (Figure 5).

Table 1: Criteria and factors for MSW landfill site selection

Criteria	Factors	Regulations	Abbreviation
Economy	1. Distance to common roads	To facilitate the transportation and collection of waste, the distance to common roads is as close as possible.	DisCR
	2. Land use status	Priority should be given to the use of land use types such as unused land, low economic agricultural land, and landfills being used.	LUS
Environment	3. Distance to urban residential areas	Maximize the distance from landfills to the urban areas.	DisUA
	4. Distance to rural residential areas	Maximize the distance from landfills to the rural areas.	DisRA
	5. Distance to surface water sources	Do not construct landfills near water sources, riverside.	DisSWS
	6. Distance to industrial zones	Should not be too close to industrial zones.	DisIZ
	7. Distance to relics and cultural areas	The farther away from cultural sites, the better.	DisRCA
	8. Distance to main roads	Should not be too close to the main roads	DisMR

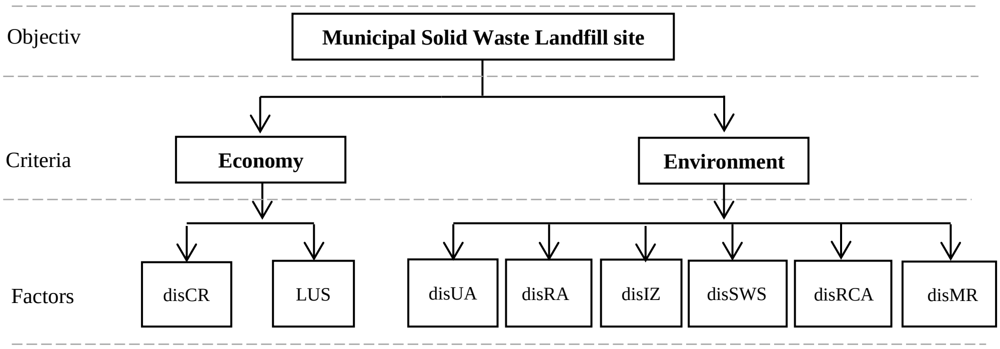
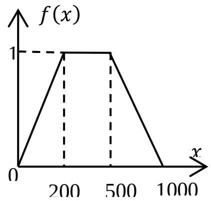
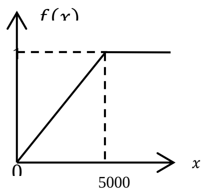
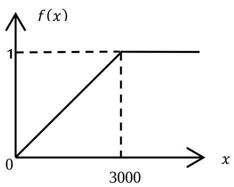
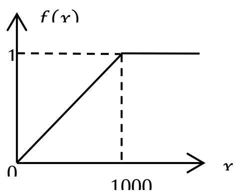
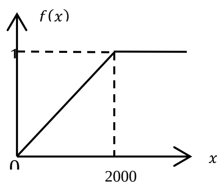


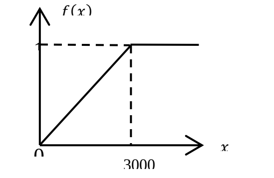
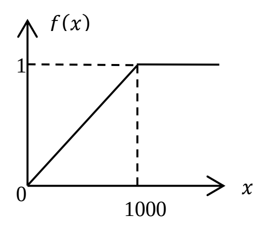
Figure 4: The AHP hierarchy tree model for MSW landfill site selection

Table 2: Results of weight calculation of criteria and factors

Criteria	Factors	Weight of criteria	Weight of factors	Final weights
Economy	1. Distance to common roads	0.25	0.12	0.03
	2. Land use status		0.16	0.039
Environment	3. Distance to urban residential areas	0.75	0.46	0.348
	4. Distance to rural residential areas		0.23	0.169
	5. Distance to surface water sources		0.17	0.128
	6. Distance to industrial zones		0.07	0.049
	7. Distance to relics and cultural areas		0.19	0.139
	8. Distance to main roads (highways, national highways, provincial roads, railways)		0.13	0.098

Table 3: Membership functions and graphs of 8 factors

No.	Factors	Range of value	Membership functions	Graphs
1	Distance to common roads	0 – 3000 m	$f(x) = \begin{cases} \frac{x}{200} & 0 < x < 200 \\ 1 & 200 \le x \le 500 \\ \frac{1000 - x}{1000 - 500} & 500 < x < 1000 \\ 0 & x \ge 1000 \end{cases}$	
2	LUS	- Unused land - Agricultural land -Non-agricultural land - Protected land	1 0.8 0.4 0	
3	Distance to urban residential areas	0 – 5000 m	$f(x) = \begin{cases} \frac{x}{5000} & 0 < x < 5000 \\ 1 & x \ge 5000 \end{cases}$	
4	Distance to rural residential areas	0 – 3000 m	$f(x) = \begin{cases} \frac{x}{3000} & 0 < x < 3000 \\ 1 & x \ge 3000 \end{cases}$	
5	Distance to surface water sources	0 – 1000 m	$f(x) = \begin{cases} \frac{x}{1000} & 0 < x < 1000 \\ 1 & x \ge 1000 \end{cases}$	
6	Distance to industrial zones	0 – 2000 m	$f(x) = \begin{cases} \frac{x}{2000} & 0 < x < 2000 \\ 1 & x \ge 2000 \end{cases}$	

No.	Factors	Range of value	Membership functions	Graphs
7	Distance to relics and cultural areas	0 – 3000 m	$f(x) = \begin{cases} \frac{x}{3000} & 0 < x < 3000 \\ 1 & x \geq 3000 \end{cases}$	
8	Distance to main roads	0 – 1000 m	$f(x) = \begin{cases} \frac{x}{1000} & 0 < x < 1000 \\ 1 & x \geq 1000 \end{cases}$	

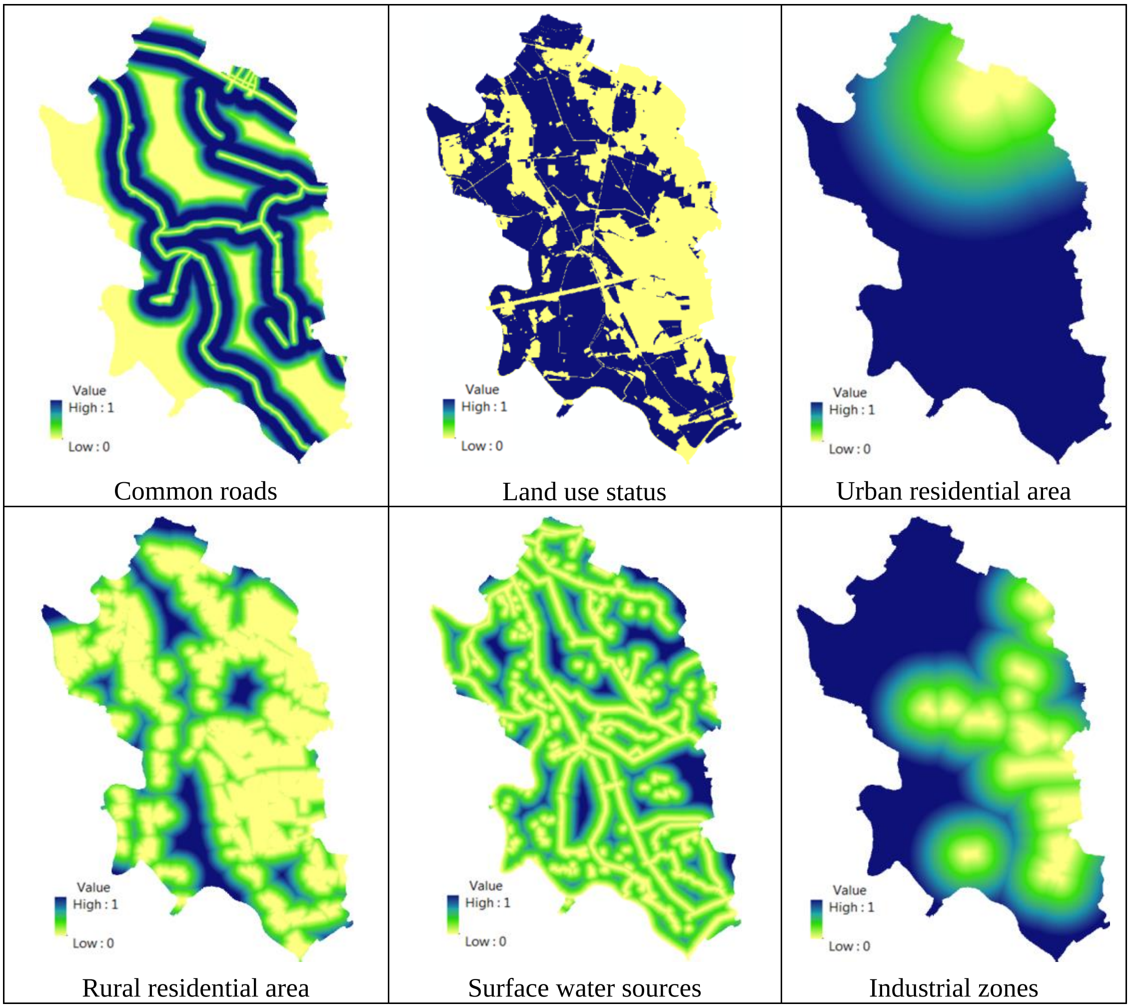


Figure 5: Fuzzy raster layers for MSW landfill site selection (continue next page)

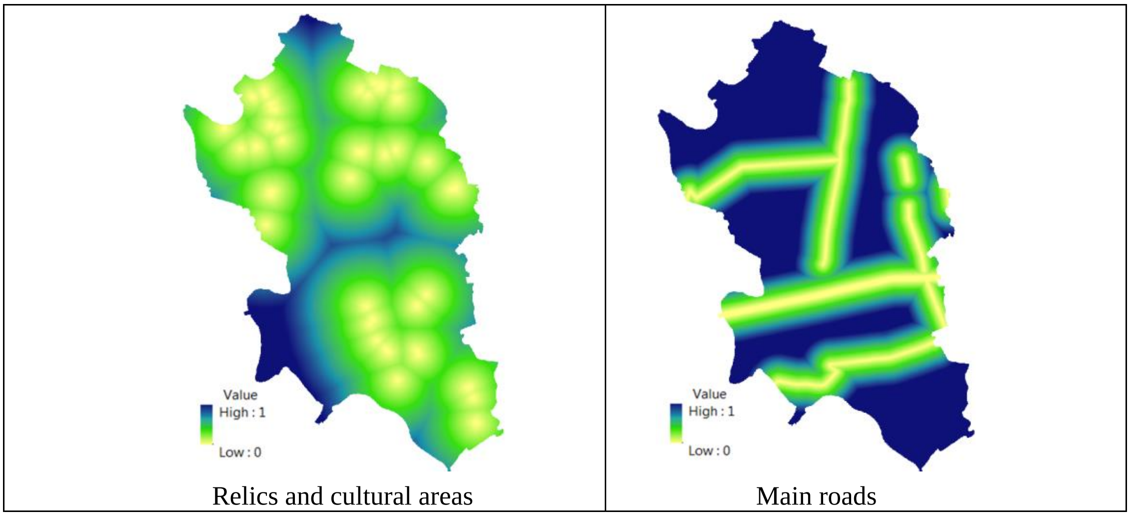


Figure 5: Fuzzy raster layers for MSW landfill site selection (continue next page)

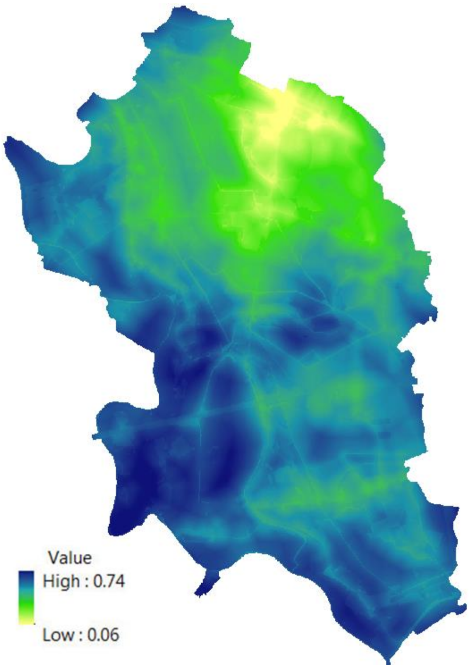


Figure 6: The reasonable raster layer for MSW landfill site selection

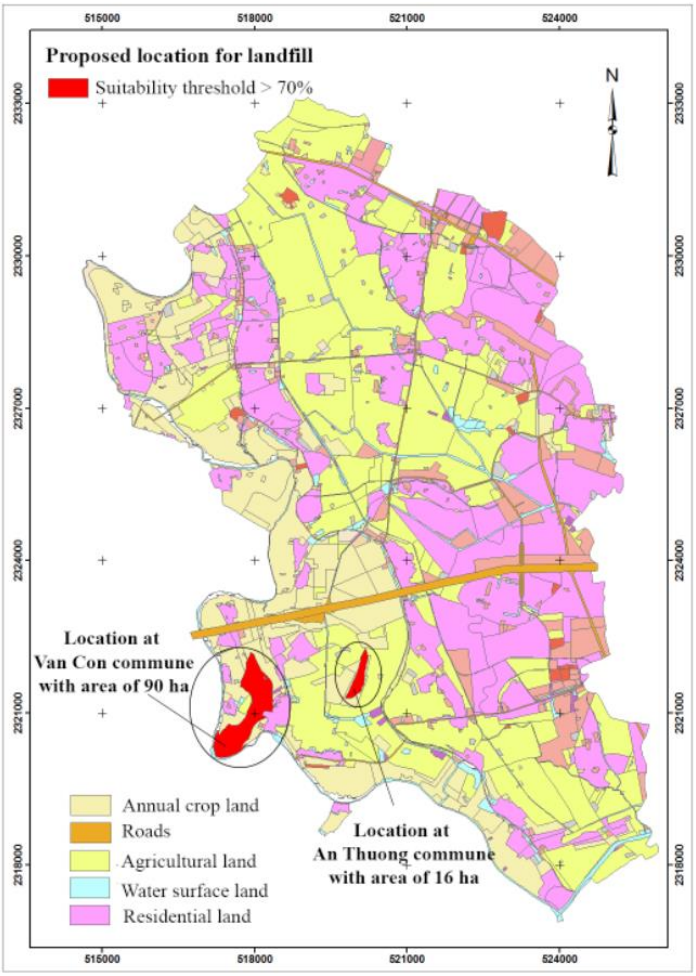


Figure 7: The proposed locations with suitability threshold >70%

Each input layer represents an influence factor which has an influence level calculated by the AHP method. Therefore, when adding values of input layers, it is necessary to multiply their corresponding weight. From Figure 6, it can be seen that the maximum reasonable value reaches 0.74 (corresponding to the maximum suitability of 74%). For the purpose of proposing suitable locations for the construction of MSW landfills, the author has chosen a suitable threshold greater than 0.7 (Suitable level of 70% or more) and obtained 2 locations with the area of 90 ha (Located in Van Con commune) and 16 ha (Located in An Thuong commune) as shown in Figure 7.

4. Discussion

From the Figure 7, it can be seen that there are 2 optimal positions proposed with a reasonable level greater than 70%, including a position located in Van Con commune with the area of 90ha and a location in An Thuong commune with the area of 16ha. According to Vietnam construction standard TCXDVN 261:2001 on design standard for solid waste landfills, Hoai Duc district with a population of about 214 thousand people and annual solid waste volume is about 52.9 thousand tons, the area of a MSW landfill need to be from 10 to 30 ha. Thus, both of these positions satisfy the condition of the landfill area. However, because the proposed location in Van Con commune is located at the district boundary, this location is likely to be affected by the neighboring districts. Therefore, the proposed location in An Thuong Commune will be prioritized for the purpose of building a MSW landfill in Hoai Duc District.

The research results obtained 2 most potential positions (with appropriate level> 70%) for building MSW landfill in Hoai Duc district, Hanoi city. Thus, the number of potential locations is very limited while the economic development of the district is increasing rapidly along with the volume of MSW is growing. Therefore, in addition to the plan of constructing MSW landfills, it is recommended that Hoai Duc also needs to find other waste disposal plans, such as building a waste recycling facilities to solve the problem in a long-term and sustainable way. Although this research is carefully designed and implemented, some of the limits are inevitable. For example, in addition to the influencing factors mentioned in the study, there are other factors affecting the process of location selection such as wind direction, geology, soil, and groundwater. These factors have not yet been included in this study because data sources cannot be collected. Further studies may consider these additional factors to improve the reliability and accuracy of the output results.

5. Conclusions

The methods of AHP, Fuzzy set theory along with GIS technology were selected for the creation of the process of optimal MSW landfill site selection. We have selected the 8 most important factors that affect the decision-making process and divided them into 2 groups including the economy and the environment. While these factors were weighted by the AHP method, the fuzzy theory was used through member functions to bring the reasonable thresholds of each factor from the discrete to continuous form with the values ranging from 0 to 1. The authors have set a threshold for a location that is considered to be reasonable at 70% and the results have shown that there are 2 positions that meet this condition located in Van Con and An Thuong communes.

For Hoai Duc district, the standard area for construction of a landfill is about 10-30 ha and the area of the 2 proposed sites has met this requirement with the results of 90ha and 16ha respectively. However, the location in An Thuong commune is given higher priority because the location in Van Con commune is located at the boundary between districts, so it will be affected by other districts. From the results obtained in this study, it can be said that with these approach planners can refer to support the decision-making process in the construction of solid waste landfills. However, in the future, landfills should be replaced by waste recycling facilities to address MSW issues in a sustainable manner.

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