Full Length Research Paper

Integration of GIS and fuzzy logic for land fill site selection

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Abstract. This research presents an integration of GIS with fuzzy logic for landfill site selection in the Iskandar region (latitude: 1° 26' 23.45'' N & Longitude: 103° 37' 21'' E) in Malaysia alongside with the customized GIS application for doing this study. Landfill selection in an area is a critical issue in the decision making process because of its great impact on the environmental health, ecology and economy of the region. Several factors have considered in the siting process, including topography and geology, administrative boundaries, cadastral, hydrology and road network, fuzzy multi criteria decision analysis and GIS are integrated to solve the problem of landfill site selection and based on our criteria to develop a ranking of the potential landfill areas. At the first step, GIS digital map overlay techniques were used (customized GIS application), in order to find the suitable sites. The second step was a fuzzy logic approach that the system ranked sites on a scale of 0–100%, with 100% being the most appropriate one. At the third step the potential sites that were selected from the last step will be ranked by Analytical Hierarchy Process (AHP) in order to prioritize the potential sites.

Keyword: Urban Management, Fuzzy logic, Landfill, GIS, Environment

1. INTRODUCTION

Waste dumping is the main method of the solid waste disposal. Insufficient collection and inappropriate disposal of solid wastes give rise to land, water and air pollution, and pose risks to human health and the environment. So selecting a suitable site for landfill is of importance. Site selection analysis decides the best location for various land uses. The success of a site selection analysis can be directly attributed to comprehensive project preparation, along with an objective, methodical, and detailed process. The set of selection criteria in combination with GIS software and data from the region is considered for analysis are identified more through personal experiences and knowledge or literature than through any methodical approach.

1.1. Weighted Linear Combination (WLC)

Weighted Linear Combination is one type of Index Modeling in GIS that calculates the value of index for per unit area and based on the index values produces a ranked map (Kang-Tsung chang., 2008). The primary consideration in developing an index model, either vector- or raster based, is the method for computing the index value. WLC is a common method for computing the index value (Kang-Tsung chang., 2010).

1.2. Fuzzy Modeling

In human thinking and language we often use uncertain or vague concepts. Our language and thinking is not binary, i.e., yes or no, zero or one, black and white. These uncertain or vague concepts are said to be fuzzy. We encounter fuzziness almost everywhere in our everyday lives (Wolfgang Kainz., 2006).

Many phenomena show a degree of vagueness or uncertainty that cannot be properly expressed with crisp sets of class boundaries. Spatial features usually do not have clearly defined concepts like “close”, or “suitable”, “steep” and boundaries, can better be expressed in degrees of membership in a fuzzy set than with a binary yes/no classification. (Wolfgang Kainz., 2006). Many researchers such as: (Ojha et al., 2007), (Klir, 1988), (Lotfi Zadeh, 1965), (Harg, 1992) and (Hellmann, 2001) have studied about fuzzy logic in various areas.

1.3. GIS based Landfill Site Selection Analysis

The site selection process requires a flexible GIS tool that is capable of combining attributes of various thematic layers easily as well as conducting additional layer-based analyses such as buffer zone analysis, slope analysis and so on.

Site selection analysis can be improved by using GIS. GIS is a suitable tool for site selection since it has the capability to manage large amount of spatial data that comes from various sources (Kao et al., 1996). Therefore, some researchers such as: (Ahmed Mussa and Suryabhagavan 2019), (Township, 2016), (Harg, 1992), (ANNUAL REPORT, 2016), (Yildirim et al., 2018), (William, 2015) and (Environmental Guidelines, 2016) studied Solid waste dumping site selection using GIS. Their goals were to select suitable site for landfill.

1.4. Integration of Fuzzy Logic & GIS

MCDM or multi criteria decision making analysis: a set of alternatives that are evaluated on the basis of conflicting and incommensurate criteria.

Criteria is considered a generic term that includes both the concepts of attributes and objective. Accordingly, two broad classes of MCDM can be distinguished:

- 1- MADM (multiattribute decision making)
- 2- MODM (multiobjective decision making)

Both MADM and MODM are further categorized into single_decision_maker problems and group decision maker problems. These two categorized are, in turn, subdivided into deterministic, probabilistic, and fuzzy decisions.

Deterministic problems assume that the required data and information are known with certainty and that there is a known deterministic relationship between every decision and the corresponding decision consequence. Probabilistic analysis deals with a decision situation under uncertainty about the state of the problem's environment and about the relationships between the decision and its consequences (Malczewski, 2004).

2. METHODS

In order to find a new site for a landfill in Iskandar region in Johor, Malaysia should come up with a ranked suitability map as it shows a relative range of values indicating how suitable each location is on the map. This research solves this problem with the 3 following methods then compares the results:

- 1- Weighted Linear Combination (WLC)
- 2- Fuzzy logic approach
- 3- Analytic hierarchy process (AHP)

In this fuzzy land suitability the physical and social conditions of the study area have to consider. One of the most significant activities in fuzzy logic is the selection of a suitable membership function of a fuzzy set.

There are two types of membership functions (Wolfgang Kainz., 2006).

- 1- Linear membership functions (Figure 1)
- 2- Sinusoidal membership functions (Figure 2).

Figure 1: Linear membership function

Figure 2: Sinusoidal membership function

2.1. Data Collection Technique

These steps were objectives that should be solved (see Figure 3).

Figure 3: Diagram of objective, process model

2.2. Distance from Residential Areas from Land Parcel Layer

As the landfill should be sited away from residential areas so a map is needed to display the distances from residential areas. Hence, the distances reclassified to 4 classes as follow (table 1).

Table 1: classified distances from land parcels

Distance (m)	Condition	Scale value
500 - 0	Restricted	1
1000 - 500	Excellent	2
2000 - 1000	Good	3
4000 - 2000	Fair	4

2.3. Distance from Road Network from Toll highway, highway, Main Road & Secondary Road Layers

It is very important that the landfill site be in an appropriate or optimum distance from road network, if our landfill is close to major roads or highways it'll get an eyesore view to those who passes through. If it is too far, then the fuel and labor cost will increase. So, landfill is better to locate close to secondary roads. Table 2 illustrates distances from Highways, main and secondary roads that these distances were used for the classification.

Table 2: classified distances from main road, highway & secondary road

Main Road		Secodary Road		Highway		Tolled Highway	
Distance	Scale value	Distance	Scale value	Distance	Scale value	Distance	Scale value
200- 0	1	500- 0	4	0 - 300	1	0 - 300	1
1500 - 200	4	1000 - 500	3	300- 3000	4	300- 2000	4
3000 - 1500	3	3000 - 1000	2	3000-6000	3	2000-7000	3
3000-12000	2	10000 - 3000	1	6000 -10851	2	7000 -13000	2

2.4. Combining the Suitability Maps

The suitability model is to combine the reclassified outputs. The underneath percentage influences will be specified to the compatibility maps. The values in parentheses are the percentage divided by 100 to normalize the values (table 3). This normalized to each suitability map value will be assigned:

Table 3: The normalized value that assigned to each suitability map

Distance to rivers	Rivers	15%	(0.15)
Land use type	relanduseras	8%	(0.08)
slope	EXreslope	20%	(0.20)
soil	regeologras2	20%	(0.20)
Distance to secondary road	REsecroaras	15%	(0.15)
Distance to main road	remainroad1	12%	(0.12)
Distance from land parcels	relandparcel	10%	(0.10)

2.5. Deriving Soil Type from Geology Layer

The geology's attribute was classified on base of the permeability of soil, our best interest is a soil with less permeability like clay, peat, silt so these types of soil would have more suitability (Figure 4).

Figure 4: soil suitability map

2.6. Creating Distance from River Fuzzy Map

After measuring distance from River, use the resulted layer for conditional statement. The Con function's name is short for statement... The Con function is a local function that is evaluated on a cell-by-cell basis.

2.7. Selecting Suitable Type of Land Use and Geology

The raster layers contain geology and land use, they have to reclassify the layers from the old values to the new fuzzy values that are given in Table 4:

Table 4: Old and new values that are used in the reclassification

Geology		Landuse	
Old Values	New Values	Old Values	New Values
1	2	1	2
2	5	2	5
3	8	3	8
4	10	4	10

They have to reclassify to an integer value. This means that the reclassification has to be made with the new fuzzy values multiplied by 10. The results illustrated on Figures 5 and 6.

Figure 5: fuzzy map of Geology

Figure 6: fuzzy map of land use

2.8. Convex Combination

A convex combination is a linear combination of points (which can be vectors, scalars) where all coefficients are non-negative and sum up to 1. All possible convex combinations will be within the convex hull of the given points.

As a particular example, every convex combination of two points lies on the line segment between the points. The maximum value of any convex combination of Fuzzy membership function is 1. The following Equation and the land parameter weights w have to be used in the calculation of the convex combination of the raster layers that contains the fuzzy values:

$$\mu_A(x) = \sum_{j=1}^k w_j \mu_{A_j}(x) \quad x \in X$$

The following formula is the convex combination, the parameters are multiplied by their weight, it can be run in raster calculator, but it is better to multiply every layer with its correspond weight in raster calculator and make a new layer for each one. Then sum the resulted layers in raster calculator. Figure 7 indicates the reclassification of the convex combination.

[geologyfuzzy] * 0.2+ [landparclfuzzy] * 0.1+ [landusefuzzy1] * .08+ [mainroadfuzzy] * 0.12+ [rivefuzzy] * 0.15+ [secondrfuzzy] * 0.15+ [slopfuzzy] * 0.20.

3. RESULTS AND DISCUSSION

3.1. AHP Approach

The multi criteria evaluation (MCE) technique integrated with analytical hierarchy process (AHP) that combined Boolean logic for constrains and Fuzzy logic for factors is used to overlay the results in one final digital map. Six criteria namely, land use, land parcel, geology, river, main road, and secondary road, slope were examined to establish spatial decision support system.

3.2. Making Comparison Matrix

DR THOMAS L. SAATY, demonstrated mathematically that the EIGENVECTOR is the best approach for solving the pairwise comparison matrix.

HOW TO SOLVE FOR THE EIGENVECTOR?

- 1- A short computational way to obtain this ranking is to raise the pairwise matrix to powers that are successively squared each time.
- 2- The row sums are then calculated and normalized.
- 3- The computer is instructed to stop when the difference between these sums in two consecutive calculations is smaller than a prescribed value.

Having a comparison matrix, to compute priority vector, which is the normalized Eigenvector of the matrix. The method that is used is only an approximation of Eigen value and Eigen vector of a reciprocal matrix. In fact, for small matrix this approximation is worked well and there is no guarantee that the rank will not reverse because of the approximation error. Nevertheless it is easy to compute because all we need to do is just to normalize each column of the matrix. At the end will show the error of this approximation.

3.3. Squaring the matrix

The mathematical operations and measuring the EIGEN vector has been done in Excel software (Table 5). The follow matrix is first comparison matrix that should be squared (Table 6).

Table 5: Mathematical operations and measuring the EIGEN vector

	ST	DFR	DFM	LP	DLU	DSR	SLOPE
ST	1	2	3	5	7	3	1
DFR	0.5	1	3	3	5	1	0.5
DFM	0.33	0.33	1	5	7	0.33	0.33
LP	0.2	0.33	0.2	1	1	0.2	0.2
DLU	0.14	0.2	0.14	1	1	0.2	0.14
DSR	0.33	1	3	5	5	1	0.33
SLOPE	1	2	3	5	7	3	1

Soil type	ST
Distance From River	DFR
Distance Main Road	DFM
Land Parcel	LP
Distance Land Use	DLU
Distance Secondary Road	DSR
SLOPE	SLOPE

Table 6: Squaring the matrix

	6.96	13.4	25.98	58	72	14.39	6.96
Square The Matrix	4.12	6.98	13.3	36	46	7.59	4.12
	3.2439	5.36	6.94	22.94	26.92	5.37	3.2439
	1.037	1.926	3.33	6.99	8.85	2.196	1.037
	0.8322	1.5362	2.52	5.7	6.94	1.6862	0.8322
	4.18	6.96	12.68	36.3	45.62	6.97	4.18
	6.96	13.04	25.98	58	72	14.39	6.96

3.4. Compute the Eigen Vector

At first sum the rows then the next step is to normalize by dividing the row by the row totally.

This process must be iterated until the Eigen Vector solution doesn't change from the previous iteration e.g. four decimal places. Until one more iteration would show no difference to four decimal places.

The result of Eigen Vector (the weights that should be multiplied by each criterion) (Table 7).

Each factor is a map layer multiply by its own corresponding weights 1- Accessibility to secondary road * 0.15

2- Distance from main road *0.09

3- Distance from river *0.16

4- Geology(soil type) * 0.26

5- Land use type * 0.02

6- Distance from land parcel *0.03

7- Slope. *0.25

The layers are multiplied by their corresponding weights on raster calculator and the resulted map illustrated on figure 8.

Table 7: The result of Eigen Vector

Soil type	ST	0.263426
Distance From River	DFR	0.157671
Distance Main Road	DFM	0.09881
Land Parcel	LP	0.033862
Distance Land Use	DLU	0.026762
Distance Secondary Road	DSR	0.156043
SLOPE	SLOPE	0.263426

Figure 7: the reclassification of convex combination

Figure 8: Result of Analytical Hierarchy Process

3.5. Analysis of the Results of Weighted Linear Combination (WLC)

Once the result from spatial analysis comes up with a suitability map for specific regions and selecting those areas over 64 ha should verify that if it is correct. Overall 52 regions were selected that after elimination of those regions with an area less than 64 ha only 4 regions were selected. Now, after overlaying the final result (the 4 selected areas) with land use layer none these four regions (7, 27, 28, and 15) fall on restricted areas.

Then final map was overlaid with the river layer, as it can be seen on Figure 9, the polygons number 27 & 28 are in catchment area and narrow branches of rivers passes over there. And river number 7 is partially in catchment area so it can be said that the polygon number 15 is the best one. But in any case field observation is of importance.

Figure 9: the resulted map of overlaying the river with the candidate sites

3.6. Analysis of the Results of Fuzzy Logic

$129558 \times 25 \times 25 = 80973750 \text{ m}^2$ is the area with 80% suitability, it depends on the decision makers to decide which area to select, the necessary part is the field observation, e.g. those areas that are more than 90% suitability are selected then by field observation the best part is selected. Figure 10 shows the regions that have over 80% suitability.

The results show that around 8% of the region has more than 80% suitability. And amongst them those areas with more than 640000 m^2 were selected that illustrated in figure 10.

Figure 10: Regions with over 80% suitability and Area > 640000m²

After overlaying the resulted map with land use layer polygons like polygons number 1443, 1551,1044,...are located in regions that there is road network or is a developing region and their attribute table has not been updated. So these polygons restricted and removed from another part of the analysis.

3.7. Analysis of the Analytical Hierarchy Process (AHP)

After reclassifying the resulted AHP map to 4 classes and selecting those polygons with over 80% suitability, then the reclassified map was overlaid with the final fuzzy map (figure 11), it can be seen that polygon results of AHP are less than fuzzy approach that this issue can demonstrate the flexibility of AHP in site selection that improves the results of fuzzy logic by bringing the comments of decision makers into decision making process. Another important issue that can be interpreted from the AHP's resulted map is that the candidate places are less than the 2 last approaches (WLC and Fuzzy logic) are located in forbidden areas like river catchments or developing land parcels. It shows that the AHP approach can efficiently bring the decision makers points into analysis and give us a better view and more sophisticated selections.

Figure 11: overlaying the result of AHP with Fuzzy approach

The final suitability results were divided into 4 discrete categories from low to high suitability, for example

$129558 \times 25 \times 25 = 80973750 \text{ m}^2$ is the area with 80% suitability, it depends to decision makers to decide which area to select, the necessary part is to field observation e.g. those areas that are more than 90% suitability are selected then by field observation the best part is selected. The final result of AHP approach is relatively the same as fuzzy approach, but with a little more restriction. The customized GIS approach (overlay method), only shows places with 100% suitability.

4. CONCLUSIONS

Fuzzy Logic prepares a different way to approach a problem of site selection. The method concentrates on what the system should do rather than trying to model how it works. If this is even possible, one can focus on solving the problem rather than mathematically trying to model the system. Generally, for very complex processes, the employment of fuzzy logic should be helpful, while there is no simple model of mathematical, if the processing of expert knowledge is to be performed for highly nonlinear processes. According to literature, if the conventional method outputs a satisfying result, an easily and quickly solvable and adequate mathematical model already exists, or the problem is not solvable, the employment of fuzzy logic is not recommendable. A significant factor of the landfill sitting process is an appropriate technique for evaluating the fundamental compatibility of all available land for sanitary landfill as a helping in selection of a limited number of sites for more detailed evaluation.

The technique should establish criteria to illustrate the relative land suitability for sanitary land filling. In addition, the technique should be practical, taking into account the resources available and should explain clearly and directly the analysis and results in an easily understandable format.

The proposed process includes four steps: establishment of suitability criteria, site screening, establishment of the AHP evaluation criteria, and site Evaluation. An integrated system was developed to aid the analyst in finding the optimum site for the facility sought. This system integrates two main tools (AHP and Arc GIS) in a way that achieve the right and accurate solution to help the decision maker in determining appropriate values for the physical suitability criteria. The system was successfully tested in determining the optimum land suitability for housing.

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