COMBINING GIS, FUZZY LOGIC, AND AHP MODELS FOR SOLID WASTE DISPOSAL SITE SELECTION IN NASIRIYAH, IRAQ

ABDULHASAN, M. J.[1] – HANAFIAH, M. M.[1*] – SATCHET, M. S.[2] – ABDULAALI, H. S.[3] – TORIMAN, M. E.[4] – AL-RAAD, A. A.[1,5]

[1]*Center for Earth Sciences and Environment, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia*

[2]*Civil Engineering Department, University of Thi-Qar, Nasiriyah, Iraq*

[3]*Department of Architecture, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia*

[4]*School of Social, Development and Environmental Studies, Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia*

[5]*Department of Biology, College of Science, Al-Muthanna University, Al-Muthanna Governorate, Iraq*

**Corresponding author*
e-mail: mhmarlia@ukm.edu.my; phone: +60-3-8921-5865; fax: +60-3-8925-3357

(Received 3rd Feb 2019; accepted 8th Apr 2019)

Abstract. Finding locations suitable for disposal of solid waste is one of the fundamental challenges facing municipal cities and environmental stability. The present study aims to identify the most suitable solid waste disposal site using Geographic Information System (GIS), remote sensing, and the multi criteria decision-making (MCDM) technique. In addition, the study compares the proposed method for suitability with the traditional analytic hierarchy process (AHP) approach. A new validation approach was applied to evaluate the accuracy of the AHP and Fuzzy logic methods based on the selected solid waste locations. Remote sensing data (ASTER GDEM) and field/reference maps were used to derive 12 conditioning factors required to produce a suitable location for solid waste disposal. The result shows that the accuracy of AHP, based on the consistency index (CI), is acceptable (greater than 0.1). However, Fuzzy logic was shown to be more accurate than AHP. The total surface areas of suitable locations based on AHP and Fuzzy models are 4.4 km² and 13.35 km², respectively. This study showed that AHP, Fuzzy logic and GIS can be integrated for waste management decision issues related to site selection to reduce negative effects on the environment and inhabitants.
Keywords: *waste management, landfill site selection, remote sensing, multi-criteria decision analysis*

Introduction

Selection of landfill locations for solid waste (SW) is determined by waste management operations based on multiple factors, including the geographic formation of a region. The decision for this selection is vested in governmental authorities (Hanine et al., 2016). Location selection for solid waste landfills is crucial for every region due to the cost implications, difficulty of reversal, and long-term commitment required (Gorsevski et al., 2012; Liu et al., 2014). Finding suitable location for landfills is also very challenging due to various factors, such as increasing waste quantities, population growth, environmental and public health risk factors, and decreasing land availability for waste disposal (Srivastava and Nema, 2012). Therefore, geographic information should not be the only criteria for site selection, however, flexibility to accommodate future changes should also be considered in regional policies. In determining solid waste disposal landfill sites, environmentally friendly and financially sound

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

selection is a challenge. Selecting a suitable landfill location involves a considerable array of points, criteria, and verification of a given set of limitations to ultimately provide an optimal solution.

The analytic hierarchy process (AHP) method is one of the most commonly used methods for multi-criteria decision-making (MCDM) (Beskese et al., 2015; Moeinaddini et al., 2010). It is capable of solving complex decision-making problems across various fields (Saaty et al., 2000; Uyan, 2013; Tavares et al., 2011). It is also used to determine the consistency of weightings for criteria by constructing a matrix for pairwise comparisons. This combination provides an appropriate language to manage imprecision criteria and integrate qualitative analysis with quantitative factors.

Even though many researches have proposed the use of Fuzzy multi-criteria decision-making methods, very few have applied the combined use of these methods for the selection of suitable landfill location. Torabi-Kaveh et al. (2016) proposed a combination of Geographic Information System (GIS) with a Fuzzy analytical hierarchy process (FAHP) to determine suitable locations for landfill site in Iranshahr, Iran. Chabuk et al. (2017) combined GIS analysis and MCDM for selecting landfill locations in Al-Hashimiyah Qadhaa, Babylon, Iraq. Foroughian and Eslami (2015) presented a study using GIS and AHP indicators for identification of solid waste disposal landfill sites in the city of Susa. Various techniques have been utilized for selecting landfill locations (Gbanie et al., 2013; Khorram et al., 2015; El Baba et al., 2015; Rathore et al., 2016). These authors determined that a combined evaluation using MCDM methods in landfill location selection is imperative. This is due to the fact that relative advantages of several methods depend on the characteristics of the problem domain.

The present study aims to determine a suitable disposal site using Fuzzy logic approach and justify the approach by comparing with traditional AHP approach, which is used for determination of suitable waste disposal sites in Nasiriyah, Iraq. Currently, there is only one available landfill site in Nasiriyah and it does not meet the relevant scientific and environmental standards. The main objective of this paper is to propose the best method for identification of solid waste disposal sites that is suitable for Nasiriyah, Iraq, and fulfills environmental and scientific criteria.

Materials and methods

The map layers were prepared using GIS and cover the most important 12 criteria in the study area. The landfill site selection model is illustrated in *Figure 1*. The raster maps of selected criteria were prepared and the final map of landfill siting was produced in the GIS software. Each raster map for the selected criteria was divided into categories, with each category is given appropriate weight. The final map of landfill siting was determined using GIS single output map algebra. The methodology and framework adopted in this study is presented in *Figure 1*.

Study area

This research was conducted in Nasiriyah, Iraq. The Governorate of Thiqar is located to the south of Iraq at the intersection of longitude 31° 01’ E to 31° 08’ E and latitude 46° 08’ N to 46° 18’ N. The city of Nasiriyah is the administrative center of the governorate and is 380 km to the south of Baghdad and 214 km to the north of Basra City. The total area is 12,900 km^2, equivalent to 5,160,000 acres. The desert land area covers 6.7% of the governorate and has a population of about 1.99 million. This population is expected to grow significantly over the next decade as a result of significant economic and security improvements. It is also home

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

to the largest marshlands of Iraq, with an area of 1,048,600 acres, which is 3.1% of the total area of Iraq. *Figure 2* shows the map of the area.

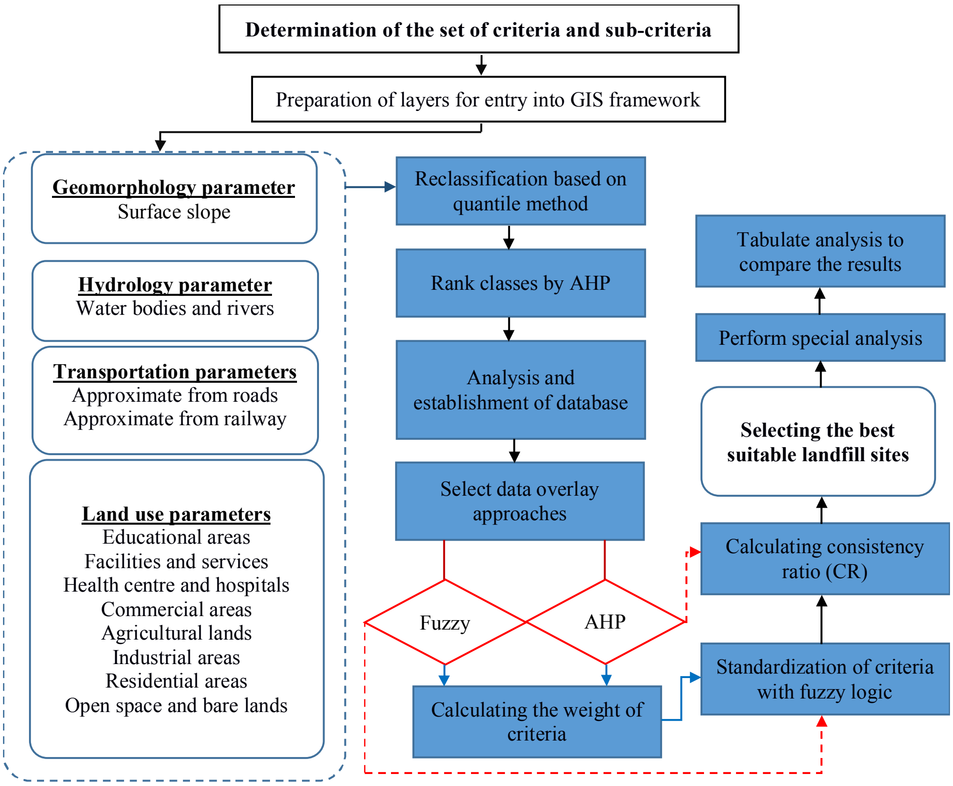


***Figure 1.** Conceptual framework of the present study*

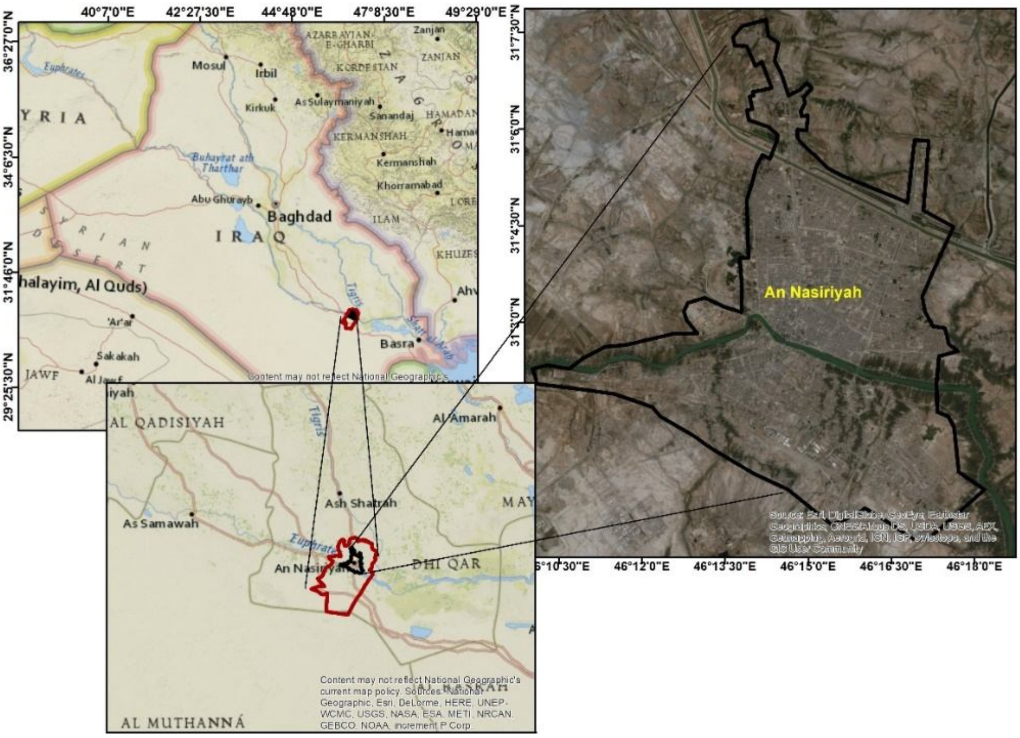


***Figure 2.** Map of the study area*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

Suitability criteria

In this study, 12 criteria were derived from 4 main criteria to determine suitable areas for solid waste disposal sites; these criteria were slope, distance from bodies of water, distance from roads, distance from railways, distance from open space, distance from agricultural lands, distance from health centers and hospitals, distance from residential areas, distance from commercial areas, distance from industrial areas, distance from facilities, and distance from educational areas, as shown in *Table A1* in the *Appendix* and *Figure 3*.

Analytic hierarchy process

Due to its simplicity and robustness in finding weights and combining heterogeneous data, AHP has been applied for MCDM, conflict management, total quality management, suitability analysis, resource allocation, design, and engineering (Jiang and Eastman, 2000; Vaidya and Kumar, 2006; Gorsevski et al., 2006; Şener et al., 2010; Vasiljević et al., 2012). In addition, it has been applied in many practical applications across fields, including site selection (Abdullahi et al., 2014). The various factors considered are not of equal importance in the determination of a potential solid waste site, therefore, the importance of each parameter was identified. In terms of the suitability of a solid waste site, hydrological formation has more importance in weight than distance from railways. Therefore, a weighted linear combination (WLC) was used in this study, in line with Drobne and Lisec (2009) and Kritikos and Davies (2011). It can be considered a hybrid of qualitative and quantitative techniques (Ayalew et al., 2004).

Determination of weights

The MCDM module was used for the weight-selecting criteria (Drobne and Lisec, 2009). A pairwise comparison referred to as the analytic hierarchy process developed by Saaty (1980) was used in this study. This method includes the comparison of each factor against every other factor in pairs (Chang et al., 1996). The weights of criteria in Saaty's technique were computed by applying the main eigenvector of the square reciprocal matrix of the pairwise comparisons between the two factors (Drobne and Lisec, 2009). The pairwise comparison evaluates the two criteria against each other to determine the most important criteria for a given objective.

Estimating consistency of pairwise comparisons

The accuracy of pairwise comparisons was evaluated by calculating the consistency ratio (CR), which is the ratio of the consistency index (CI) and the randomness index (RI). CR was used to estimate the relative weightings of all criteria on a consistency ratio in which values under 10% are considered acceptable. Otherwise, the consistency ratio allows for reevaluation of comparisons. *Table A2* shows the RI developed by Saaty et al. (1977), based on the order of the matrix according to the number of criteria. *Equations 1* and *2* show the consistency ratio and consistency index, respectively.

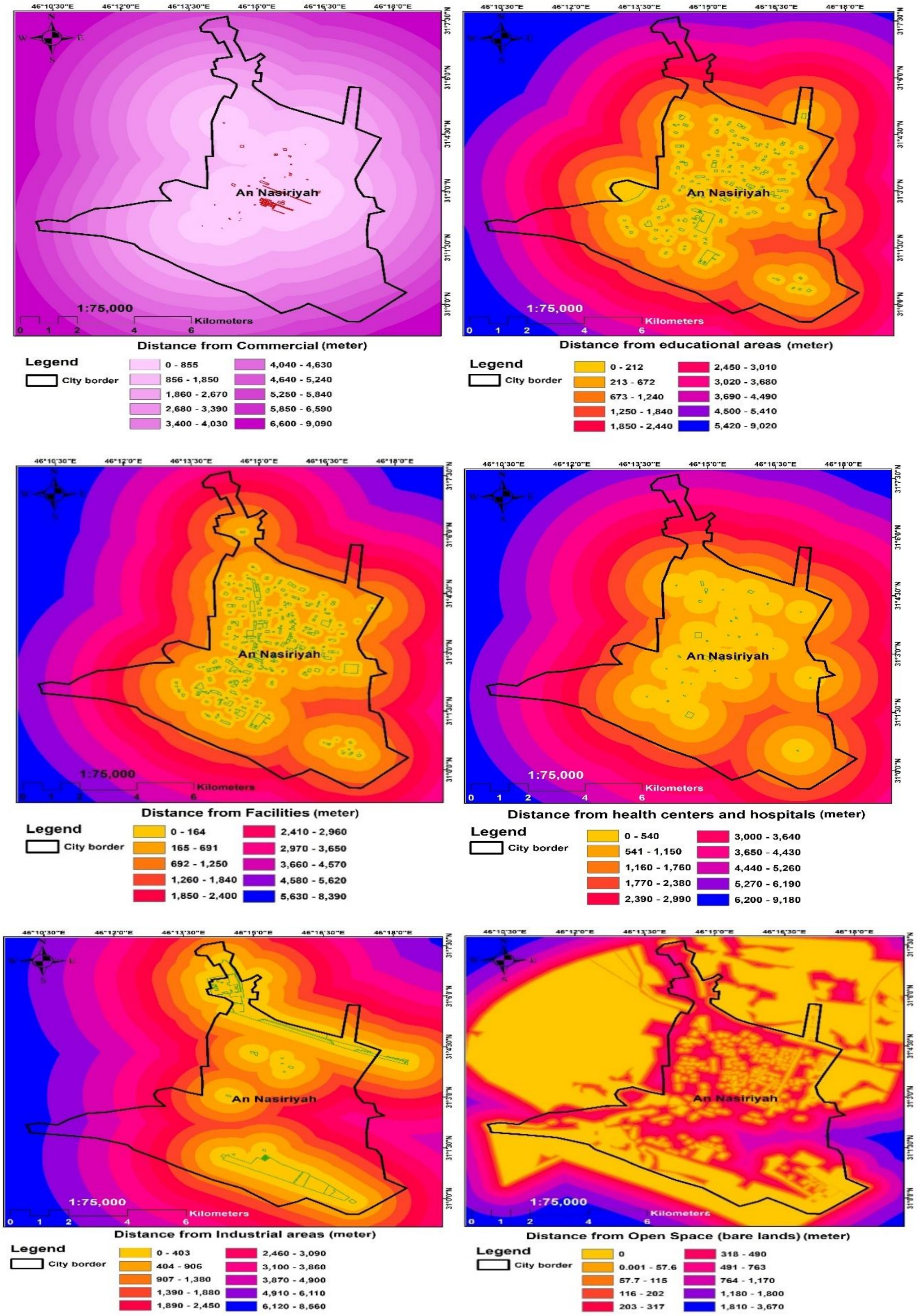
$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad \text{(Eq.1)}$$

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

CI is calculated using *Equation 2:*

$$CI = \frac{\lambda max - n}{n - 1} \quad \text{(Eq.2)}$$

where: λmax = (Weight1*S1 + Weight2*S2 + Weight3*S3+…………) and n = number of criteria.



http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

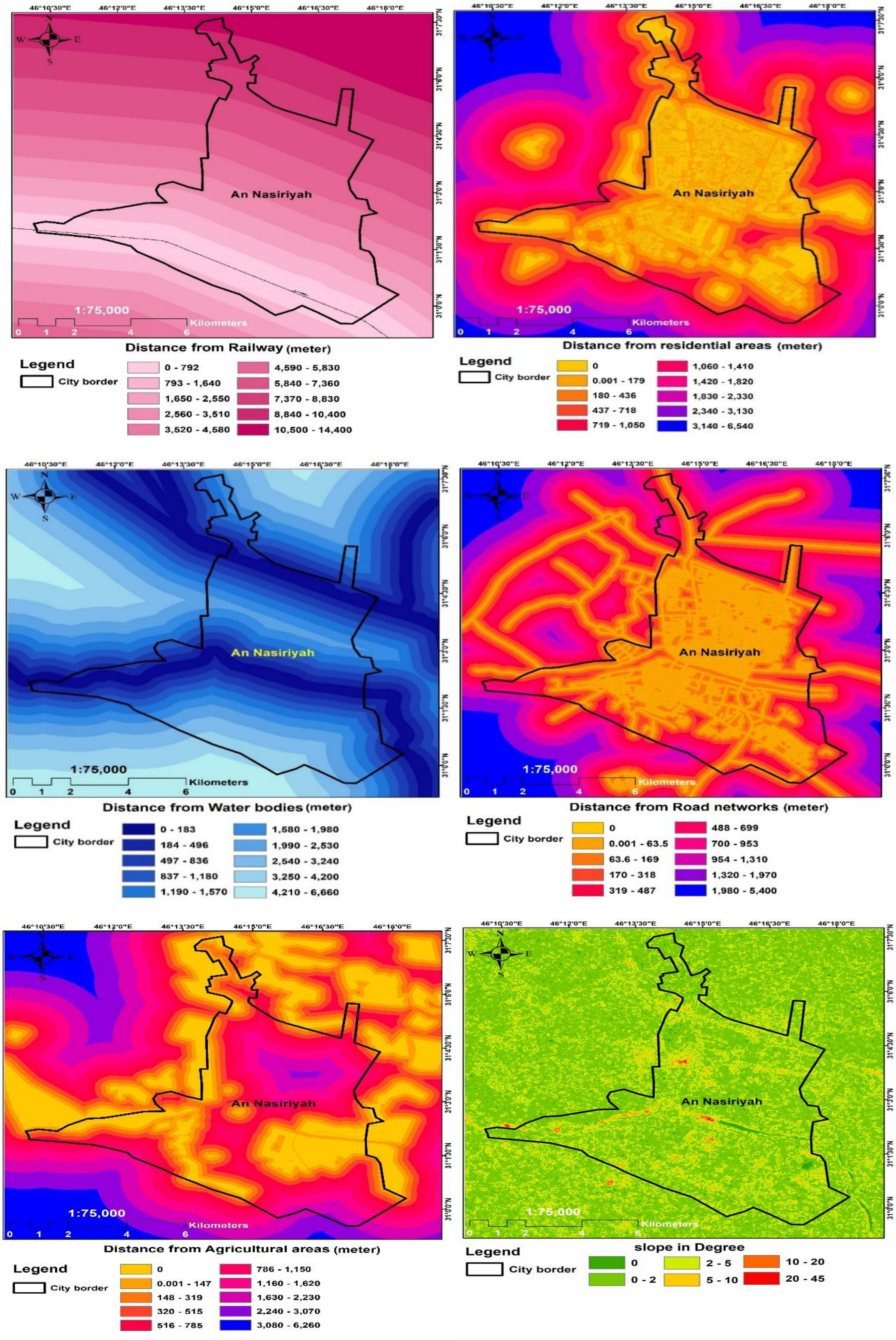


Figure 3. *Suitability indexes in the current study; slope, distance from water bodies, distance from roads, distance from railways, distance from open space, distance from health centres and hospitals, distance from commercial areas, distance from agricultural lands and distance from industrial areas*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

Application of the fuzzy logic model

In a Fuzzy approach, suitability of land is mapped by pixels of causal factor layers. Pixel values are numeric and range from 0 to 1, from not suitable to very suitable. Pixel values must be within the range of 0 to 1, although there is no practical constraint on the choice of the values. Values can be chosen to reflect the degree of membership of a set based on subjective judgment (Amato et al., 2018) or can be derived by various functions representing reality (Eastman et al., 2003). In this study, linear functions were used to represent the reality function. Fuzzy logic is preferred for land suitability evaluation due to its ability to estimate land use suitability on a continuous scale, which helps to cope with vagueness and uncertainty (Elaalem et al., 2012). Site suitability application using Fuzzy logic comprises three steps, as shown below:

Step 1: Normalization or standardization of land characteristics using fuzzy set models

Fuzzy logic helps the user to determine the likelihood that a site is suitable or unsuitable. This step assigns values from 0 to 1, with 0 being not likely or unsuitable and 1 being most likely or suitable (Elaalem et al., 2012). Thus, the higher Fuzzy value implies the ideal of the site. When assigning Fuzzy values, four types of membership need to be understood to choose the best fits of the analysis criteria. There are four types of membership function in Fuzzy systems: linear, small, large and Gaussian. In this study, the linear membership function was used to normalize the parameters, due to its dependence on input parameters. If the input parameters seem chaotic, similar to a time series, the Gaussian type of membership function would be suggested, otherwise, the linear type is recommended (Qiu et al., 2014). High Fuzzy membership is assigned to large or small values, and Fuzzy membership decreases at a constant rate. A triangular membership function is specified by three parameters {a, b, c} as shown in *Equation 3* (Önüt and Soner, 2008):

$$\text{Triangulation}(x; a, b, c) = \begin{cases} 0, & x \leq a \\ \dfrac{(x-a)}{(b-a)}, & a \leq x \leq b \\ \dfrac{(c-x)}{(c-b)}, & b \leq x \leq c \\ 0, & c \leq x \end{cases} \qquad \text{(Eq.3)}$$

Step 2: Generation of the criteria map layers

Fuzzy logic offers an alternative scaling approach, using linguistic variables to represent quantitative and qualitative criteria (Sreedevi et al., 2016). For quantitative criteria, such as return on resources, representation by a linguistic variable requires the definition of term sets, such as “very low,” “low,” “medium,” “high,” and “very high”. In this study, linear membership function was used to normalize the parameters because it depends on input parameters. The linear membership function is suggested if the input parameter is not chaotic (Elaalem et al., 2012). This step assigns values from 0 to 1, with 0 being not likely or unsuitable and 1 being most likely or suitable. The range between 0 and 1 for membership function corresponds to the intensity of importance of each criterion, which is obtained from the literature and experts’ opinions.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

Step 3: Generation of the overall land suitability map layers

Once the appropriate Fuzzy membership value for data criteria is assigned, several reclassified surfaces showing values from 0 to 1 are generated (Klir and Yuan, 1995), and subsequently, the Fuzzy logic model is applied. This step is similar to weighted site selection, which is a site selection method that allows users to rank raster cells and assign a relative importance value to each layer so that different reclassified surfaces can be compared to each other. In order to complete this step, one of several Fuzzy overlay types must be chosen. In this study, the "AND" Fuzzy overlay type was used due to its ability to determine the best values in finding locations that meet all criteria (Qiu et al., 2014).

Results and discussion

Classification of criteria

Each criterion was classified into 10 classes based on the quantile model, except for slope, which was classified into six classes using GIS software. The results showed that variation in each class affects the rank of the class. In some criteria, values were close to the target and thus achieved a higher rank. For some other criteria, values far from the target were considered an advantage and given high weight. For instance, low-distance classes of the open space criteria are more suitable for waste landfill, while far-distance classes in education are more suitable for solid waste landfill allocation. Some criteria prioritize the middle classes; for example, landfill sites should be located neither too close nor too far from residential areas.

Figure 4 illustrates the weight variation in slope, distance from bodies of water, distance from roads, distance from railways, distance from open space, distance from agricultural lands, distance from health centers and hospitals, distance from residential areas, distance from commercial areas, distance from industrial areas, distance from facilities, and distance from educational areas. An indirect linear relationship between the average of each class and its ranking was found for slope indicates that flat areas are weighted higher than steep fields for landfill site selection.

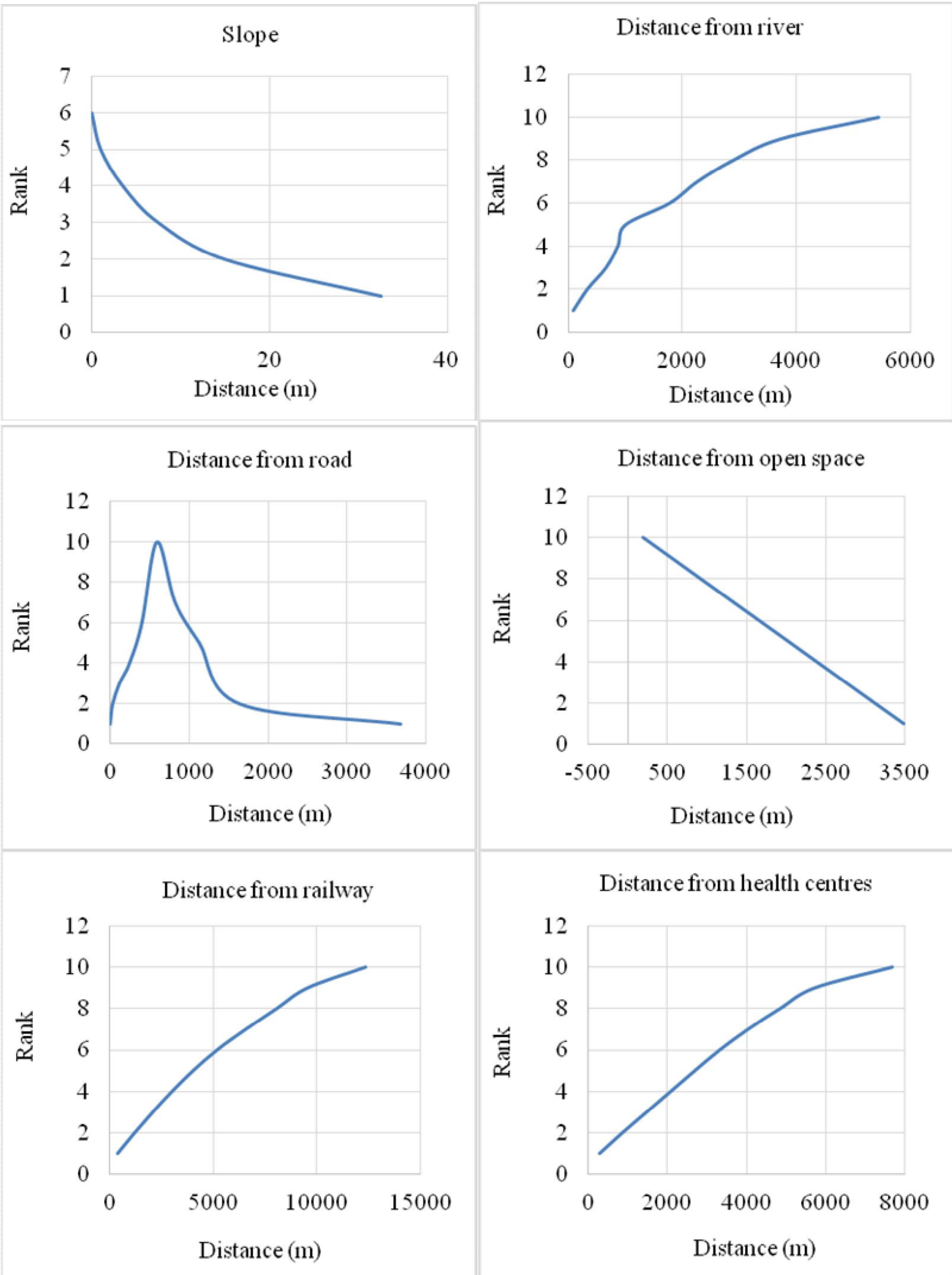
A direct linear relationship was obtained for other criteria. The farther the distance from rivers, the higher the rank for landfill suitability, as shown in *Figure 4*. Greater distance from hospitals or health centers, roads, railways, agricultural lands, public facilities, educational areas, and commercial centers equates to a higher rank and suitability for landfill. For residential areas, the logarithmic relationship shows that distances too close or too far (greater than 3 km) from residential areas receive a lower rank and are thus unsuitable for solid waste disposal. This is because if the distance is too close, the landfill can infect the inhabitants with diseases or odors, while placing dump sites too far away from the source of the waste is uneconomical and time-consuming. *Figure 4* also shows that the class too close or far from industrial areas, mostly out of the city, showed a lower rank for solid waste landfill.

Table A3 shows the classification and rank for 12 criteria based on the quantile method using GIS software. Six classes of slope show that a 0 degree angle of steepness achieved the highest rank using the AHP model, implying that these are the most suitable classes for landfill use. Inversely, the lowest classes are those with a 45 degree angle of steepness; these are ranked as 1. Ten classes of distance from the river indicated that the class at an average of 91 meters away from the river had the lowest

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

rank using the AHP model, thus is least suitable for landfill. Inversely, the most suitable class is ranked with 9, which is 3,721 m away from water bodies.

Table A3 also shows that the class at an average of 593 m away from roads achieved the highest rank of suitability for landfills, using the AHP model, while the lowest suitable classes, ranked number 1, recorded the closest and farthest distance classes from the road (0 and 3,684 m). The highest suitable class that attained rank number 10 indicating the greatest distance from the railways (12,393 m) and from railway. For agricultural, commercial and residential areas, the highest suitable class gained ranking number 10 at distance of 7,688 m away from health centers, 2,730 m away from residential areas and 7,839 m away from commercial areas, respectively.



http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

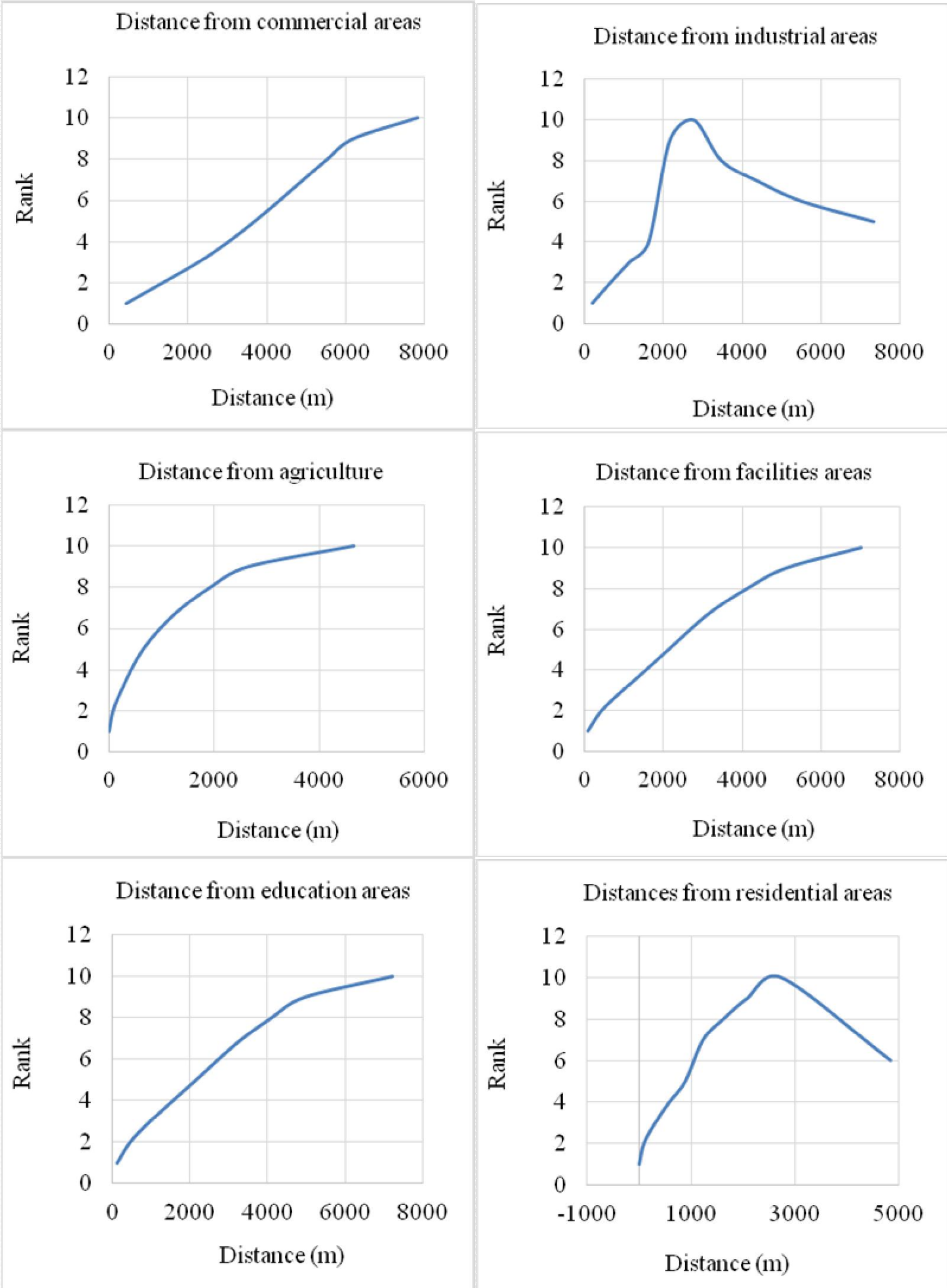


Figure 4. *Weight variation in: slope, distance from river, distance from roads, distance from railways, distance from open space, distance from agricultural lands, distance from health centres and hospitals, distance from residential areas, distance from commercial areas, distance from industrial areas, distance from facilities areas and distance from education areas*

Table A3 also shows that the highest suitable class for industrial areas and facilities ranked number 10, representing an average distance from industrial areas of 2,770 m and from the facilities of 7,007 m, respectively. The highest suitable class for education areas obtained ranking number 10, which is the farthest distance from educational

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

facilities (7,216 m). The soil stratification is not significantly contributed to the site selection as the study area has mostly covered by one soil type. In addition, due to the impervious surface of the study area, pollution might not be possible to deeply penetrate through the soil surface to groundwater. In contrary, there is a high chance to affect the surface water bodies.

Selection of suitable sites for solid waste using the AHP model

Questionnaires were prepared based on expert's response regarding to the most significant factors in the selection of suitable sites for a solid waste landfill in the study area. After the preparation of the conditioning factors using GIS, the weights of each factor were calculated using the geometric mean method to determine the final weight of each factor. Then, the factors were reclassified based on their weights and prepared using a raster calculator to generate a suitability map, which describes the suitable locations for solid waste landfill. The result of the pairwise comparison matrix obtained from questionnaires for the 12 criteria is shown in *Table 1.*

Table 1. *Pairwise comparison matrix extracted from questionnaires for 12 criteria*

Pairwise comparison matrix	Solid waste landfill selection											
	Res	**Open**	**Road**	**Ind**	**Agri**	**Edu**	**Health**	**Faci**	**Com**	**Slope**	**Rail**	**WB**
Residential	1	2	4	3	5	8	7	7	9	9	8	6
Open space	1/2	1	3	3	4	6	6	5	8	8	8	4
Road	1/4	1/3	1	1/2	2	5	4	3	6	7	6	2
Industrial	1/3	1/3	2	1	1	4	3	3	5	5	6	2
Agricultural	1/5	1/4	1/2	1	1	3	2	2	5	5	5	1
Educational	1/8	1/6	1/5	1/4	1/3	1	1/3	1/3	2	3	4	1/4
Health	1/7	1/6	1/4	1/3	1/2	3	1	1	4	6	5	1
Facilities	1/7	1/5	1/3	1/3	1/2	3	1	1	3	5	4	1/5
Commercial	1/9	1/8	1/6	1/5	1/5	1/2	1/4	1/3	1	2	2	1/6
Slope	1/9	1/8	1/7	1/5	1/5	1/3	1/6	1/5	1/2	1	1/2	1/7
Railway	1/8	1/8	1/6	1/6	1/5	1/4	1/5	1/4	1/2	2	1	1/9
River	1/6	1/4	1/2	1/2	1	4	1	5	6	7	9	1

*Res = Residential, Open = Open Space, Ind = Industrial, Agri = Agricultural, Edu = Educational, Faci = Facilities, Com = Commercial, Rail = Railway, WB = Water Bodies

The pairwise comparison matrix shown in *Table 1* was assembled from the input of 13 different experts in the field of environmental and waste management. The results were summarized based on the average of the distributed questionnaires. *Table 2* shows the weight of each criteria in percentage and their ranks from the most to the least important criteria. It was deduced that proximity to residential areas was the most important criteria in solid waste selection. The second most important parameter was observed to be proximity to open space followed by distance from roads and industrial facilities. Inversely, the slope and distance from railways were determined to be the least important criteria in terms of landfill selection.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

Table 2. *Weightage for criteria in percentage*

Criteria	AHP-Weightage (%)
Residential	26.36
Open Space	19.63
Road	10.35
Industrial	10.13
Agricultural	7.19
Educational	2.97
Health	5.29
Facilities	4.58
commercial	1.97
Slope	1.40
Railway	1.63
River	8.50

The accuracy of AHP is within acceptable limits, as the CI (0.128) is greater than 0.1. In addition, Lambda value of 13.41 and the Randomness Index (RI) with 1.54 were observed to show high accuracy based on the CI. The CI/RI ratio is 0.083 implying that the experts assigned the weight of each criterion logically, and the prioritization of the criteria was consistent. *Figure 5* is a suitability map produced using the AHP model that shows the suitable areas in green and non-suitable areas in gray. It was observed that suitable areas were almost distributed across the entire study area. However, most suitable areas were found outside the city, mostly toward to the west and south of the study area. The overall area of very highly suitable lands for solid waste was found to be about 1.66 km^2. Therefore, field visits are required to identify the final location of the solid waste landfill. The suitability map produced in GIS using AHP model shows that suitable sites are not clustered in one single area, but distributed over different locations within the study area. This indicates that some of the conditioning factors have a huge influence on the selection process for suitable sites and were distributed across the study area.

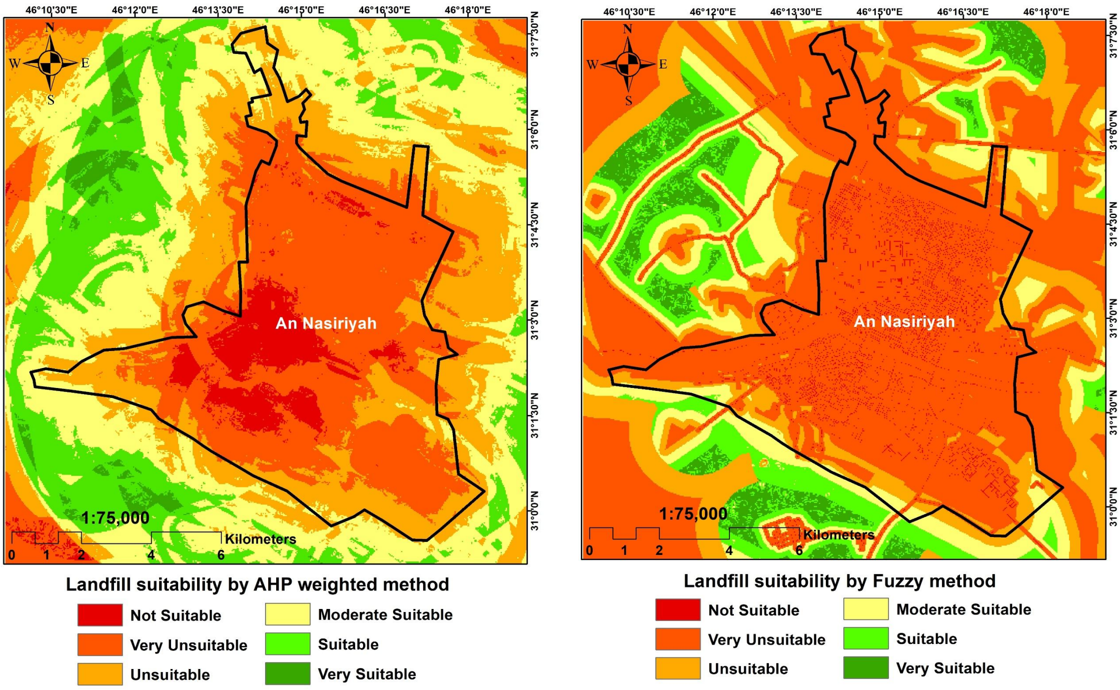
Suitable areas were determined using the AHP model and were mostly found far from urban areas, and no suitable area was observed around the city borders. These sites require further investigation to determine the possibility of constructing a solid waste disposal field.

Selection of suitable sites for solid waste using the fuzzy model

The suitability map produced using the Fuzzy model is presented in *Figure 5*. The map shows suitable and unsuitable locations in the study area, identified based on 12 factors for solid waste disposal. The map shows that most suitable areas are located in the middle and in the north part of the study area. On the other hand, the southern part of the study area was observed to have no identified suitable site for solid waste, thus, should be ignored in the field visit. The overall surface area of suitable land is estimated to be 13.35 km^2. The suitability map produced using the Fuzzy model shows the spatial distribution of the suitable areas and their patterns in the study area. It can be observed that most of the suitable areas are clustered into groups and are not randomly scattered in different directions. This indicates that the suitable areas identified are homogenous

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

and share similar characteristics with each other. This is very important for decision makers, as it makes final selection easier and more accurate. Decision makers can use this method to easily identify suitable areas for constructing solid waste landfill sites in a particular area.



a b

Figure 5. *Map produced using a) AHP model and b) fuzzy model*

It is imperative to compare the results of the AHP and Fuzzy models to identify their similarities and possible differences. The comparison between the maps produced by these models showed that the AHP maps identified the suitable areas as scattered regions, while the Fuzzy model generated a map with clustered suitable areas. It was observed that the AHP map located suitable areas in almost all parts of the study area, while the Fuzzy map identified suitable areas at the middle and northern parts of the study area. In terms of the surface area of suitable lands identified, the AHP model indicated 4.14 km^2 area as highly suitable, while the Fuzzy model identified 13.35 km^2 as highly suitable for solid waste landfill. *Figure 6* illustrates the percentage of landfill suitability based on the AHP and Fuzzy Models with 2% and 5% for very suitable areas.

Table 3 shows the results of the AHP model in terms of very suitable landfill areas, 4.14 km^2, and very unsuitable areas, 60.6 km^2. The Fuzzy model obtained 13.35 km^2 for very suitable areas and 131.56 km^2 for very unsuitable areas (*Table* 3). In addition, the Fuzzy model showed more areas considered very suitable compared to the AHP model, which could be due to the mathematical nature of the Fuzzy algorithm. The common areas identified by both methods showed the most suitable lands for waste disposal landfills, far away from residential areas and close to bare lands. Traditional AHP approach is more simplistic and robust while Fuzzy logic approach help in coping with vagueness and uncertainty of determining site suitability. The results further display that

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

the AHP maps identified the suitable areas as scattered regions, while the Fuzzy model generated a map with clustered suitable areas.

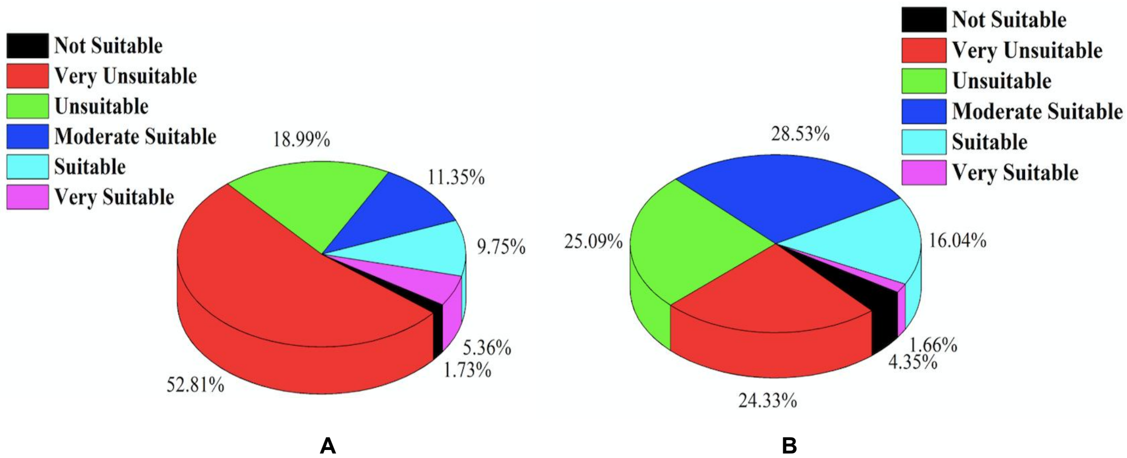


Figure 6. *Percentage of landfill suitability A) fuzzy model and B) AHP model*

Table 3. *The results of AHP and fuzzy models*

Suitability class	Cell count		Area (m^2)		Area (km^2)		Percentage (%)	
	AHP	**Fuzzy**	**AHP**	**Fuzzy**	**AHP**	**Fuzzy**	**AHP**	**Fuzzy**
Not suitable	12036	4790	10832400	4311000	10.83	4.31	4.35	1.73
Very unsuitable	67332	146178	60598800	131560200	60.60	131.56	24.33	52.81
Unsuitable	69456	52570	62510400	47313000	62.51	47.31	25.09	18.99
Moderate suitable	78969	31411	71072100	28269900	71.07	28.27	28.53	11.35
Suitable	44389	26997	39950100	24297300	39.95	24.30	16.04	9.75
Very suitable	4600	14836	4140000	13352400	4.14	13.35	1.66	5.36
Total area	**276782**	**276782**	**249103800**	**249103800**	**249.10**	**249.10**	**100**	**100**

However, a field visit is required to confirm the final location for the landfill site in order to take into account other factors that were excluded in the model, such as the population and other environmental changes. There may be some changes to the sites that may not be favorable for the intended purposes. Therefore, a field investigation was conducted to further assess the reliability of the proposed methodology. A handheld GPS device (GeoExplorer 6000) was used to determine the location of the sites. *Figure 7* shows the location of the most suitable sites obtained during field investigation. The information acquired from field measurements allow for the assessment of the precision and reliability of the produced suitable areas for waste disposal landfill.

Several studies have been conducted for the site selection and disposal of the solid wastes by applying multi-criteria decision analysis (MCDA) using GIS as shown in *Table 4*. However, in this work shown Fuzzy logic was more accurate than AHP. The most significant physical parameters were derived and then ranked according to their contribution to landfill. This model is a first attempt in our study area. We optimized knowledge driven method by data driven approach in order to minimize the spatial errors.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

Figure 7. *The most suitable sites identified during field investigation (A: 31° 3'32.81"N, 46°13'41.20"E; B: 31° 0'27.49"N, 46°11'5.09"E)*

Table 4. *The comparison of technique of landfill site selection*

Study area	Technique	Criteria	References
Mexico	MCDM and GIS	Social, economic and environmental criteria, proximity cost consideration	Delgado et al. (2008)
Northern Italy	MCDM, simple additive weighting	Social, economic and environmental criteria	Geneletti (2010)
Karaj, Iran	GIS, cluster analysis, AHP	Social, economic and environmental criteria	Moeinaddini et al. (2010)
Iran	AHP for weights, GIS, simple additive weighting	Social, economic and environmental criteria	Eskandari et al. (2012)
Macedonia	MCDM: AHP and ordered weighted average	Economic and environmental criteria	Gorsevski et al. (2012)
Turkey	AHP for weights	Social, economic and environmental criteria	Yildirim (2012)
Iraq	MCDM and GIS	Social, economic and environmental criteria	Mohammad Ali Al-Anbari (2014)
Morocco	MCDM, GIS and remote sensing	Social, economic and environmental criteria	Abdelhakim El Maguiri (2016)
			Zeinhom El Alfy (2018)
Mansoura city, Egypt	MCDM, GIS, AHP	Social, economic and environmental criteria	Zeinhom El Alfy (2018)
Nasiriyah city, Iraq	MCDM, GIS and Fuzzy logic, AHP	Social, economic and environmental criteria	Present study

Conclusion

In this study, 12 criteria were used in an overlaying analysis of potential areas with GIS to identify a suitable landfill site in Nasiriyah, Iraq. A combination of GIS, AHP and Fuzzy logic models were used in this study; layers such as slope, distance from bodies of water, distance from roads, distance from railways, distance from open space, distance from agricultural lands, distance from health centers and hospitals, distance

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

from residential areas, distance from commercial areas, distance from industrial areas, distance from facilities, and distance from educational areas were considered. The criteria weightings were derived from the AHP method by constructing a matrix of pairwise comparisons between criteria.

This study found the areas identified by both methods as most suitable, which were observed to be outside of the city boundary, mostly to the west and south of the study area and met the requirements of environmental, economic and residential factors. The common areas identified in both methods showed the most suitable lands for waste disposal landfill with an appropriate distance from residential areas and open space. Therefore, the result showed that a combination of GIS, AHP and Fuzzy models using multi-scientific and environmental criteria could be used to develop an effective and efficient methodology for selecting suitable landfill sites in Nasiriyah, Iraq. It can be concluded that the methodology applied in the present study is capable in locating the suitable landfill site in Nasiriyah city, thus future study should be carried out as well at other provinces in Iraq. It is recommended that future study should consider other important parameters such as soil type, soil layer stratification, levels and movements of the groundwater, etc. These parameters need to be studied in detail and field work analysis needs to be conducted for providing accurate and comprehensive study.

Acknowledgements. Marlia M. Hanafiah was supported by the Universiti Kebangsaan Malaysia (DIP-2017-006) and the Ministry of Education Malaysia (FRGS/1/2018/WAB05/UKM/02/2).

REFERENCES

[1] Abdullahi, S., Mahmud, A. R. B., Pradhan, B. (2014): Spatial modelling of site suitability assessment for hospitals using geographical information system-based multicriteria approach at Qazvin city, Iran. – Geocarto International 29(2): 164-184.
[2] Al-Anbari, M. A., Al-Ansari, N., Jasim, H. K. (2014): GIS and multicriteria decision analysis for landfill site selection in AL-HashimyahQadaa. – Natural Science 6(5): 282-304.
[3] Amato, F., Tonini, M., Murgante, B., Kanevski, M. (2018): Fuzzy definition of rural urban interface: an application based on land use change scenarios in Portugal. – Environmental Modelling & Software 104: 171-187.
[4] Ayalew, L., Yamagishi, H., Ugawa, N. (2004): Landslide susceptibility mapping using GIS-based weighted linear combination, the case in Tsugawa area of Agano River, Niigata Prefecture, Japan. – Landslides 1: 73-81.
[5] Beskese, A., Demir, H. H., Ozcan, H. K., Okten, H. E. (2015): Landfill site selection using Fuzzy AHP and Fuzzy TOPSIS: a case study for Istanbul. – Environmental Earth Sciences 73(7): 3513-3521.
[6] Chabuk, A., Al-Ansari, N., Hussain, H. M., Knutsson, S., Pusch, R., Laue, J. (2017): Combining GIS applications and method of multi-criteria decision-making (AHP) for landfill siting in Al-Hashimiyah Qadhaa, Babylon, Iraq. – Sustainability 9(11): 1932.
[7] Delgado, O. B., Mendoza, M., Granados, E. L., Geneletti, D. (2008): Analysis of land suitability for the siting of inter-municipal landfills in the Cuitzeo Lake Basin, Mexico. – Waste Management 28(7): 1137-1146.
[8] Drobne, S., Lisec, A. (2009): Multi-attribute decision analysis in GIS: weighted linear combination and ordered weighted averaging. – Informatica 33: 459-474.
[9] Eastman, J. R. (2003): IDRISI Kilimanjaro: guide to GIS and image processing. – Idrisi Production, Clark University.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

[10] El Alfy, Z., Elhadary, R., Elashry, A. (2010): Integrating GIS and MCDM to deal with landfill site selection. – International Journal of Engineering & Technology 10(6): 32-42.
[11] El Baba, M., Kayastha, P., De Smedt, F. (2015): Landfill site selection using multi-criteria evaluation in the GIS interface: a case study from the Gaza Strip, Palestine. – Arabian Journal of Geosciences 8(9): 7499-7513.
[12] El Maguiri, A., Kissi, B., Idrissi, L., Souabi, S. (2016): Landfill site selection using GIS, remote sensing and multicriteria decision analysis: case of the city of Mohammedia, Morocco. – Bulletin of Engineering Geology and the Environment 75(3): 1301-1309.
[13] Eskandari, M., Homaee, M., Mahmodi, S. (2012): An integrated multi criteria approach for landfill siting in a conflicting environmental, economical and socio-cultural area. – Waste Management 32(8): 1528-1538.
[14] Foroughian, A., Eslami, H. (2015): Application of AHP and GIS for landfill site selection (A case study: city of Susa). – Journal of Scientific Research and Development 2(5): 129-134.
[15] Gbanie, S. P., Tengbe, P. B., Momoh, J. S., Medo, J., Kabba, V. T. S. (2013): Modelling landfill location using geographic information systems (GIS) and multi-criteria decision analysis (MCDA): case study Bo, Southern Sierra Leone. – Applied Geography 36: 3-12.
[16] Geneletti, D. (2010): Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites. – Waste Management 30(2): 328-337.
[17] Gorsevski, P. V., Jankowski, P., Gessler, P. E. (2006): An heuristic approach for mapping landslide hazard by integrating fuzzy logic with analytic hierarchy process. – Control and Cybernetics 35: 121-146.
[18] Gorsevski, P. V., Donevska, K. R., Mitrovski, C. D., Frizado, J. P. (2012): Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: a case study using ordered weighted average. – Waste Management 32(2): 287-296.
[19] Hanine, M., Boutkhoum, O., Tikniouine, A., Agouti, T. (2016): Comparison of fuzzy AHP and Fuzzy TODIM methods for landfill location selection. – SpringerPlus 5: 501.
[20] Jiang, H., Eastman, J. R. (2000): Application of fuzzy measures in multi-criteria evaluation in GIS. – International Journal of Geographical Information Science 14(2): 173-184.
[21] Khorram, A., Yousefi, M., Alavi, S. A., Farsi, J. (2015): Convenient landfill site selection by using fuzzy logic and geographic information systems: A case study in Bardaskan, East of Iran. – Health Scope 4(1): e19383.
[22] Kritikos, T. R., Davies, T. R. (2011): GIS-based multi-criteria decision analysis for landslide susceptibility mapping at northern Evia, Greece [GIS-basierte multikriterielle Entscheidungsanalysen zur Kartierung von Massenverlagerungspotenzialen im nördlichen Evia, Griechenland]. – Zeitschrift der Deutschen Gesellschaft für Geowissenschaften 162(4): 421-434.
[23] Liu, H. C., You, J. X., Fan, X. J., Chen, Y. Z. (2014): Site selection in waste management by the VIKOR method using linguistic assessment. – Applied Soft Computing 21: 453-461.
[24] Sreedevi, R. P., Vimala, V., Rameswari, P., Sateesh, S. (2016): an application of fuzzy logic and DEA in agriculture sector. – International Journal of Engineering Science 6(5): 4876-4878.
[25] Moeinaddini, M., Khorasani, N., Danehkar, A., Darvishsefat, A. A. (2010): Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj). – Waste Management 30(5): 912-920.
[26] Qiu, F., Chastain, B., Zhou, Y., Zhang, C., Sridharan, H. (2014): Modeling land suitability/capability using fuzzy evaluation. – GeoJournal 79(2): 167-182.
[27] Önüt, S., Soner, S. (2008): Transshipment site selection using the AHP and TOPSIS approaches under fuzzy environment. – Waste Management 28(9): 1552-1559.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

[28] Rathore, S., Ahmad, S. R., Shirazi, S. A. (2016): Use of the suitability model to identify landfill sites in Lahore-Pakistan. – Journal of Basic and Applied Sciences 12: 103-108.
[29] Saaty, T. L. (1977): A scaling method for priorities in hierarchical structures. – Journal of Mathematical Psychology 15(3): 234-281.
[30] Saaty, T. L. (1980): The Analytic Hierarchy Process: Planning, Priority Setting, Resources Allocation. – McGraw Hill, New York.
[31] Saaty, T. L. (2000): Fundamentals of Decision Making and Priority Theory. – McGraw Hill, New York.
[32] Şener, Ş., Şener, E., Nas, B., Karagüzel, R. (2010): Combining AHP with GIS for landfill site selection: a case study in the Lake Beyşehir catchment area (Konya, Turkey). – Waste Management 30(11): 2037-2046.
[33] Srivastava, A. K. Nema, A. K. (2012): Fuzzy parametric programming model for multi-objective integrated solid waste management under uncertainty. – Expert Systems with Applications 39(5): 4657-4678.
[34] Tavares, G., Zsigraiová, Z., Semiao, V. (2011): Multi-criteria GIS-based siting of an incineration plant for municipal solid waste. – Waste Management 31(9-10): 1960-1972.
[35] Torabi-Kaveh, M., Babazadeh, R., Mohammadi, S. D., Zaresefat, M. (2016): Landfill site selection using combination of GIS and Fuzzy AHP, a case study: Iranshahr, Iran. – Waste Management & Research 34(5): 438-448.
[36] Uyan, M. (2014): MSW landfill site selection by combining AHP with GIS for Konya, Turkey. – Environmental Earth Sciences 71(4): 1629-1639.
[37] Vaidya, O. S., Kumar, S. (2006): Analytic hierarchy process: an overview of applications. – European Journal of Operational Research 169(1): 1-29.
[38] Vasiljević, T. Z., Srdjević, Z., Bajčetić, R., Miloradov, M. V. (2012): GIS and the analytic hierarchy process for regional landfill site selection in transitional countries: a case study from Serbia. – Environmental Management 49(2): 445-458.
[39] Yildirim, V. (2012): Application of raster-based GIS techniques in the siting of landfills in Trabzon Province, Turkey: a case study. – Waste Management & Research 30(9): 949-960.

APPENDIX

Table A1. *Sub-criteria factors extracted from main criteria*

Main criteria	Sub-criteria
G) Geomorphology parameter	G1) Slope
H) Hydrology	H1) Distance from water bodies
T) Transporting parameters	T1) Distance from railway
	T2) Distance from road
L) Land use parameters	L1) Distance from educational areas
	L2) Distance from facilities and services
	L3) Distance from health centres and hospitals
	L4) Distance from commercial areas
	L5) Distance from agricultural areas
	L6) Distance from industrial areas
	L7) Distance from residential areas
	L8) Distance from open space

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

Table A2. *Fundamental scale of AHP multi criteria decision making*

Fundamental scale (row v column)	
Extremely less important	1/9
	1/8
Very strongly less important	1/7
	1/6
Strongly less important	1/5
	1/4
Moderately less important	1/3
	1/2
Equal importance	1
	2
Moderately more important	3
	4
Strongly more important	5
	6
Very strongly more important	7
	8
Extremely more important	9

Table A3. *Sub-classes and rank of slope, distance from river, distance from roads, distance from railways, distance from open space, distance from agricultural lands, distance from health centres and hospitals, distance from residential areas, distance from commercial areas, distance from industrial areas, distance from facilities areas and distance from education areas*

Slope			
From (degree)	**To (degree)**	**Average (degree)**	**Rank**
0	0	0	6
0	2	1	5
2	5	3.5	4
5	10	7.5	3
10	20	15	2
20	45	32.5	1
River (meter)			
From (meter)	**To (meter)**	**Average (meter)**	**Rank**
0	183	91	1
183	496	339	2
496	836	666	3
836	1175	871	4
175	1567	1005	5
1567	1985	1776	6
1985	2533	2259	7
2533	3238	2885	8
3238	4204	3721	9
4204	6659	5431	10

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

Distance from the road			
From (meter)	**To (meter)**	**Average (meter)**	**Rank**
0	0	0	1
0	64	32	2
64	169	116	3
169	318	243	4
318	487	402	6
487	699	593	10
699	953	826	7
953	1313	1133	5
1313	1969	1641	2
1969	5398	3684	1
Distance from the railway			
From (meter)	**To (meter)**	**Average (meter)**	**Rank**
0	792	396	1
792	1641	1217	2
1641	2546	2094	3
2546	3508	3027	4
3508	4584	4046	5
4584	5829	5206	6
5829	7356	6592	7
7356	8828	8092	8
8828	10356	9592	9
10356	14430	12393	10
Distance from open space (bare land)			
From (meter)	**To (meter)**	**Average (meter)**	**Rank**
0	367	184	10
367	735	551	9
735	1102	918	8
1102	1469	1286	7
1469	1837	1653	6
1837	2204	2020	5
2204	2571	2387	4
2571	2938	2755	3
2938	3306	3122	2
3306	3673	3489	1
Distance from health			
From (meter)	**To (meter)**	**Average (meter)**	**Rank**
0	540	270	1
540	1152	846	2
1152	1764	1458	3
1764	2377	2071	4
2377	2989	2683	5
2989	3637	3313	6
3637	4429	4033	7
4429	5257	4843	8

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

5257	6194	5725	9
6194	9182	7688	10
Distance from commercial			
From (meter)	**To (meter)**	**Average (meter)**	**Rank**
0	855	428	1
855	1853	1354	2
1853	2672	2263	3
2672	3385	3029	4
3385	4026	3706	5
4026	4632	4329	6
4632	5238	4935	7
5238	5844	5541	8
5844	6592	6218	9
6592	9086	7839	10
Distance from agriculture			
From (meter)	**To (meter)**	**Average (meter)**	**Rank**
0	0	0	1
0	147	74	2
147	319	233	3
319	515	417	4
515	785	650	5
785	1154	969	6
1154	1620	1387	7
1620	2233	1927	8
2233	3068	2651	9
3068	6259	4663	10
Residential			
From (meter)	**To (meter)**	**Average (meter)**	**Rank**
0	0	0	1
0	179	90	2
179	436	308	3
436	718	577	4
718	1051	884	5
1051	1410	1230	7
1410	1820	1615	8
1820	2332	2076	9
2332	3127	2730	10
3127	6536	4831	6
Industrial			
From (meter)	**To (meter)**	**Average (meter)**	**Rank**
0	403	201	1
403	906	655	2
906	1376	1141	3
1376	1880	1628	4
1880	2451	2165	9
2451	3089	2770	10

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722

3089	3861	3475	8
3861	4902	4381	7
4902	6110	5506	6
6110	8561	7336	5
Facilities			
From (meter)	**To (meter)**	**Average (meter)**	**Rank**
0	164	82	1
164	691	428	2
691	1250	970	3
1250	1842	1546	4
1842	2401	2122	5
2401	2960	2681	6
2960	3651	3306	7
3651	4572	4112	8
4572	5625	5099	9
5625	8388	7007	10
Distance from educational			
From (meter)	**To (meter)**	**Average (meter)**	**Rank**
0	212	106	1
212	672	442	2
672	1238	955	3
1238	1839	1539	4
1839	2441	2140	5
2441	3006	2724	6
3006	3679	3342	7
3679	4492	4085	8
4492	5412	4952	9
5412	9019	7216	10

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1703_67016722