# Evaluation of optimum areas for municipal landfill sites using AHP and ANP in GIS: A case study

**Rouzbeh Shad[١], Pooya Vosough Grayli[٢]**

**١- Assistant Professor of Civil Engineering department, Engineering faculty, Ferdowsi University of Mashhad, Mashhad, Iran, rouzbeh_shad@yahoo.com**

**٢- Graduated from Ferdowsi University of Mashhad in Civil Engineering, pgrayli@yahoo.com**

pgrayli@yahoo.com

**Abstract**

This paper is aimed at applying integration of Geospatial Information System (GIS) and multi-criteria decision making (MCDM) methods as a tool in a manner in which ignoring environmental, economic, scientific and engineering judgment is avoided. Firstly, utterly unsuitable areas are excluded to promote the efficiency and accuracy prior to applying MCDM methods. Subsequently, the remaining areas are not completely unsuitable, yet not the most appropriate locations for a landfill. Afterwards, potential sites are obtained from more suitable locations. Considering too many criteria in the first stage could decrease the efficiency of the Analytic hierarchy process (AHP) method; therefore, to deploy a more pragmatic approach, a limited number of criteria are considered for initial selection of candidate sites. In the second stage, potential sites are evaluated and ranked through a more thorough investigation utilizing the analytic network process (ANP) method. Additionally, Buffers for unsuitable zones of less emphasized importance are eliminated too, and more criteria are taken into account.

**Keywords: Multi-criteria decision making methods, Site selection, Municipal Waste, Landfill, GIS**

## ١. INTRODUCTION

The exponential increase in the production of municipal waste due to population boom and subsequent growth of cities in developing countries necessitates pursuing development of economically viable and environmentally sustainable approaches for eradication of solid waste. Recent advances in methods of treating solid waste and recycling has enabled municipalities to alleviate this problem, yet not sufficed to resolve it. Therefore, landfills are the most commonly-practiced technique to respond to the problem of solid waste nowadays. However, imprudent measures such as employing an unsuitable waste management system could cause perpetuating damages and put lives of generations at stake. For example, landslides, in not-stabilized dumps due to liquefaction caused by seismic motions, that inflicted casualties are not unheard of. Additionally, negligence could result in contamination of soil and groundwater as well as loss of indispensable recourses and jeopardizing the wildlife. Consequently, it is absolutely essential to develop environment-friendly landfills and rigorously designate and evaluate the most suitable sites. Varied factors ,which may conflict, are to be investigated and weighted against each other. To satisfy contradictory parameters is challenging. For instance, not only should the location of sanitary landfills be as far as possible from residential areas, but also it has to be economically feasible at the same time. Therefore, it is crucial to found landfills in an optimum range of urban areas, which makes landfill site selection a cumbersome and interminable process demanding expertise in wide-ranging fields. In this paper, an integration of GIS, which has revolutionized time-consuming site selection procedures such as positioning sanitary landfills, and MCDM is utilized as a flexible framework to obtain and evaluate the potential sites.

(Charnpratheep, Zhou, and Garner ١٩٩٧) [١] explored the prospect of coupling fuzzy set theory and the analytic hierarchy process (AHP) into a raster-based geographical information system for the preliminary screening of landfill sites in Thailand. The proposed model had advantage over the fuzzy min-operator intersection with respect to the ability to integrate criteria's preferences into the screening process that yielded agreeable results. (Al-Jarrah and Abu-Qdais ٢٠٠٦) [٢] addressed the problem of sitting a new landfill effectively using an intelligent system based on fuzzy inference. (Chang, Parvathinathan, and B. Breeden ٢٠٠٧) [٣] employed a two stage analysis synergistically to form a spatial decision support system (SDSS) for the waste management in a fast-growing urban region, south Texas. Sensitivity analysis was performed using Monte Carlo simulation where the decision weights associated with all criteria were varied to investigate

their relative impacts on the rank ordering of the potential sites. (Sumathi, Natesan, and Sarkar ٢٠٠٦) [٤] addressed the sitting of a new landfill using a multi-criteria decision analysis (MCDA) and overlay method using GIS. The proposed system could accommodate new information on the landfill site selection by updating its knowledge base. (Onut and Soner ٢٠٠٨) [٥] deployed a fuzzy TOPSIS based methodology to solve the solid waste transshipment site selection problem in Istanbul, Turkey. The criteria weights were calculated using the AHP. (Guiqin et al. ٢٠٠٩) [٦] built a hierarchy model for solving the solid waste landfill site selection problem in Beijing, China. The candidate sites were divided by 'best', 'good' and 'unsuitable' landfill areas. Best landfill areas represented optimal sites. (Pires, Chang, and Martinho ٢٠١١) [٧] integrated the AHP and the technique for order of performance by similarity to ideal solution (TOPSIS) for alternative screening and ranking in order to help the decision makers in a Portuguese waste management system. The AHP was used to determine the essential weighting factors, screening and ranking was carried out by TOPSIS under uncertainty expressed using an interval-valued fuzzy (IVF) method. (V. Gorsevski et al. ٢٠١٢) [٨] used the AHP to elicit attribute weights while the ordered weighted averaging (OWA) operator function was used to generate a wide range of decision alternatives. The usefulness of the approach was illustrated by different OWA scenarios. (Khadivi and Fatemi Ghomi ٢٠١٢) [٩] presented a location selection procedure to construct an undesirable facility applying analytic network process (ANP) and data envelopment analysis (DEA) approaches in two stages. A total of four undesirable facility locations were evaluated.
Unlike many conducted researches, in this paper, suitability of each potential site due to the impact of direction of prevailing wind on roads in addition to sensitive sites in proximity is not overlooked. Furthermore, constructional costs connecting sites to existing roads and transportation through them from a sample city are introduced into the decision making model. Two approaches are deployed considering varied criteria, which included binary and fuzzy criteria. Additionally, a multistage process is applied to enhance the accuracy in which candidate sites from an AHP overlay are ranked employing the ANP method. Regarding the mentioned decision making methods, the ANP method has more resemblance to the manner a person usually makes decisions, because the importance of criteria depends on the alternatives. However, the impact of each alternative on the weight of criteria is not included in judgment in the AHP method.
This paper is organized as follows: Firstly, an elimination layer is created merging buffer zones from varying criteria. Afterwards, an AHP overlay is derived taking into consideration several large scale fuzzy criteria. Subsequently, the elimination layer is superimposed on the AHP overlay to eradicate the unsuitable areas. Secondly, several candidate sites due to an adjusted overlay are ranked using ANP method to obtain the optimum site for Mashhad, which is the ultimate goal of this research.

## ٢. METHODS AND MATERIALS

The case study of this city is Mashhad city, which is located in Khorasan Razavi state. To enhance the accuracy of site selection maps of a whole Khorasan region are obtained. Consequently, if there is an urban center or fault outside the initial study area (Razavi Khorasan) but in the close proximity of it, the impact on the vicinity inside the study area is not neglected.
The AHP is a multi-criteria decision making methodology based on absolute pair-wise comparisons relying on expert judgment to derive priority weights. Establishing a flexible framework, it incorporates trade-offs in decision making model allowing reasonable amount of inconsistency to achieve overall ranks. In this method the final results are quite easy to interpret.
Pair-wise comparison matrix is composed as follows in Equation ١:

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ \dots & \dots & \dots & \dots \\ w_i/w_1 & w_i/w_2 & \dots & w_i/w_n \\ \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{bmatrix} \quad (١)$$

With regard to equation١, wi is the weight derived from pair-wise comparisons. Final weights of each criteria can be determined solving the following eigenvalue problem where $\lambda$ is the maximum eigenvalue of the matrix in Equation ٢.

$$Aw = \lambda w \quad (٢)$$

Firstly, judgment based on expert advice is obtained through pair-wise comparisons. Afterwards, the corresponding matrix is established, and sanity of the comparisons is checked. In case of insanity of the model, it is prudent to adjust the matrix asking participating experts to alter their opinion. Finally, equation ۲ is solved to derive the final weights.
Refer to decision making with the analytic hierarchy process by (Saaty ۱۹۹۰) [۱۰] for more information.
The ANP incorporates the interconnections between clusters of elements, while, the AHP uses a linear structure which is not able to capture the dependence and feedback between criteria and alternatives. The impact of alternatives on importance of criteria is considered. The supermatrix whose elements are matrices of column priorities is determined employing equation ۳.

$$W = \begin{array}{ll} & \begin{array}{cccc} e_{11}e_{12}\dots e_{1N} & e_{21}e_{22}\dots e_{2N} & \quad & e_{N1}e_{N2}e_{NN} \end{array} \\ \begin{array}{ll} Cluster_1 & \begin{array}{c} e_{11} \\ \dots \\ e_{1N} \end{array} \\ Cluster_2 & \begin{array}{c} e_{21} \\ \dots \\ e_{2N} \end{array} \\ Cluster_N & \begin{array}{c} e_{N1} \\ \dots \\ e_{NN} \end{array} \end{array} & \begin{bmatrix} w_{11} & w_{12} & \dots & w_{1N} \\ w_{21} & w_{22} & \dots & w_{2N} \\ \dots & \dots & \dots & \dots \\ w_{N1} & w_{N2} & \dots & w_{NN} \end{bmatrix} \end{array} \qquad (۳)$$

Concerning equation ۳, wi is the weight derived from pair-wise comparisons.
In order to calculate the weighted supermatrix, the pair-wise comparison matrix is normalized. Afterwards, the normalized matrix is taken to the power of an arbitrary number to obtain the limit matrix and the final priorities. Refer to fundamentals of the analytic network process by (Saaty ۱۹۹۹) [۱۱] for more information.

In this paper, an integration of GIS and MCDM is utilized as a flexible framework to obtain and evaluate the potential sites.

## ۳. RESULTS AND DISCUSSION

### ۳,۱ FIRST STAGE IMPLEMENTATION

In this paper two approaches are introduced with regard to criteria: binary and fuzzy. Regarding binary criteria, each point is either suitable or unsuitable due to spatial location. In other words, these criteria include only a safety buffer in order to exclude the utterly unsuitable areas associated with them. However, in the fuzzy approach points can be unsuitable or have different degrees of suitability. Accordingly, first of all, an elimination layer should be created superimposing unsuitable areas in accordance with both binary and fuzzy criteria.
Safety buffers include restricted areas of fuzzy criteria and unsuitable locations due to binary criteria. Applied buffers surpass all expectations in the regulations used in the literature (Tables ۱ and ۲)

**Table ۱ Buffers (Refer to (Sener ۲۰۰٤) [۱۲] for further information.)**

| Environment – Geology | Buffer (meters) |
|---|---|
| Protected areas | ۲۰۰۰ |
| Faults | ٥۰۰ |
| Swamps | ۱۰۰ |
| Sand dunes | ۱۰۰ |
| Orchards | ۱۰۰ |
| Forests | ۱۰۰ |
| Residential centers | Buffer (meters) |
| Urban centers | ٥۰۰۰ |
| Villages | ۱۰۰۰ |
| Tourist attractions | ۱۰۰۰۰ |

| | |
|---|---|
| International boundaries | ١٠٠٠٠ |
| Transportation - industries | Buffer (meters) |
| Arterial Roads | ٥٠٠ |
| Local Roads | ١٠٠ |
| Railroads | ١٠٠ |
| Airports | ١٣٠٠٠ |
| Industrial centers | ٥٠٠ |
| Industrial-agricultural centers | ٥٠٠ |
| Mines | ٥٠٠ |
| Hydrology | Buffer (meters) |
| Rivers | ٥٠٠ |
| Lakes | ١٠٠٠ |
| Qanats[١] | ٥٠٠ |
| Flood plains | ١٠٠ |

**Table ٢ Fuzzy Criteria (Refer to (Sener ٢٠٠٤) for further information.)**

| Distance to Arterial Roads (meters) | Rate |
|---|---|
| ٠< *D*<٥٠٠ | Restricted |
| ٥٠٠< *D*<١٠٠٠ | ٧ |
| ١٠٠٠< *D*<١٥٠٠ | ٥ |
| ١٥٠٠< *D*<٢٠٠٠ | ٣ |
| *D*>٢٠٠٠ | ١ |
| Distance to Local Roads (meters) | Rate |
| ٠< *D*<١٠٠ | Restricted |
| ١٠٠< *D*<٥٠٠ | ٥ |
| ٥٠٠< *D*<١٠٠٠ | ٣ |
| ٢٠٠٠<*D* | ١ |
| Slope (°) | Rate |
| ٠< *S*<٥ | ٥ |
| ٥<*S*<١٠ | ٣ |
| ١٠< *S*<١٥ | ١ |
| ١٥<*S* | Restricted |
| Distance to urban centers (meters) | Rate |
| ٠<*D*<٥٠٠٠ | Restricted |
| ٥٠٠٠<*D*<١٠٠٠٠ | ٩ |
| ١٠٠٠٠<*D*<١٥٠٠٠ | ٧ |
| ١٥٠٠٠<*D*<٢٠٠٠٠ | ٥ |
| ٢٠٠٠٠<*D*<٢٥٠٠٠ | ٣ |
| ٢٥٠٠٠<*D*<٣٠٠٠٠ | ٢ |
| ٣٠٠٠٠<*D* | ١ |
| Distance to Agricultural Land Use(m) | Rate |
| *D*<٥٠٠ | ١ |
| *D*>٥٠٠ | ٥ |

The AHP method is a multi-criteria decision making method through pair-wise comparisons relying on the expert judgment to derive priority scales. AHP method (Saaty ١٩٩٠) [١٠] is utilized to generate a GIS-based overlay and locate the potential sites. Six criteria were taken into account for initial pair-wise comparison through the AHP. Weights derived from criteria pair-wise comparison is according to Table ٣.

Considering two aspects of the road criteria necessitates a fuzzy approach. A road is a vital infrastructure and means of transportation of municipal waste. Therefore, sites with easier access to roads are more economically feasible. On the other hand, the nuisance and odor associated with municipal waste is an issue. Therefore, distance to roads is not an absolute criterion.

Regarding slope, in case of leakage, leachate permeates in a more uncontrollable manner in steep slopes. Additionally, steep slope makes the construction more challenging. At the same time, necessary safety measures are to be taken to avoid environmental damages.

[١] A Qanat is a gravitational water supply system comprised of a series of vertical shafts connected through a tunnel, which brings water from the water table to the surface(Salih ٢٠٠٦) [١٣].

Close vicinity of urban areas should be avoided due to health hazards and public opinion. Therefore, close proximity of cites are restricted. At the same time, remote areas are not economically viable.
Allocating barren lands for landfill is more preferable than agricultural lands. Barren lands can be expropriated for this matter, which results in considerable save in financial resources. In addition, damaging local economies is avoided to a significant degree.

**Table ۳ Derived weights.**

| | Distance to urban centers | Distance to agricultural land use | Slope | Distance to arterial roads | Distance to local roads |
|---|---|---|---|---|---|
| Weights | ۰,۳٥٦ | ۰,۲۲۳ | ۰,۲۲۳ | ۰,۱۱۹ | ۰,۰۷۹ |

The buffer for binary criteria is superimposed on the AHP overlay to eliminate the unsuitable areas from the overlay. Suitable areas are achieved according taking into account more suitable areas according to final elimination buffer. In addition, suitable areas for urban centers of whole Khorasan Razavi is illustrated in Figure ۱.

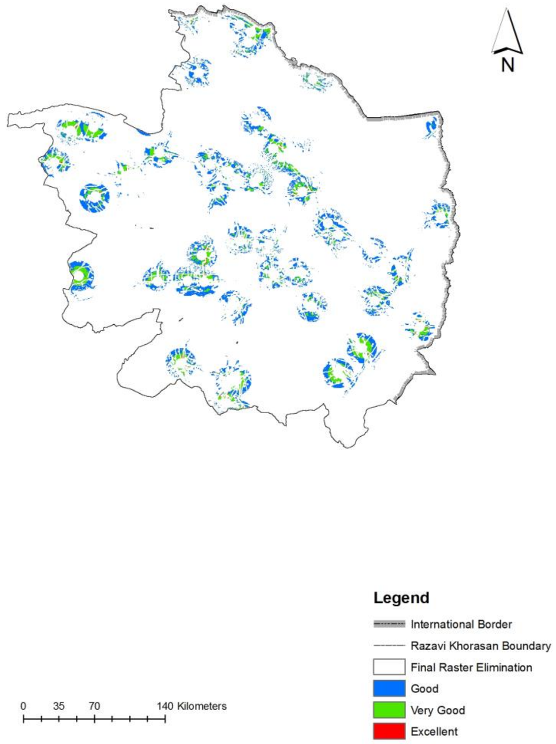


**Figure ۱ Suitable areas for urban centers of Khorasan Razavi.**

### ۳,۲. SECOND STAGE IMPLEMENTATION

If the site selection is to be limited to Mashhad, being close to other urban centers is not an economic advantage. Therefore, existence of two urban centers in vicinity of metropolitan of Mashhad (Shandiz and Torghabeh) decreases the efficiency of first stage for this matter. Consequently, the factor ‘Distance to urban centers’ should be replaced with ‘Distance to Mashhad’ to locate the potential sites. Additionally, the eliminated areas from the first stage including other urban areas buffer are superimposed so that unsuitable areas including the close vicinity of Torghabeh and Shandiz are fully excluded. Figure ۲ illustrates reformed outputs for Mashhad city.


**Figure ٢ Reformed outputs.**

More factors are incorporated in the preliminary modified superimposed layer to choose the candidate sites. For instance, geology maps, quality and depth of water table data and locations of water wells were collected and buffer-related appropriate measures are taken into account before selecting the candidate sites.
The designed ANP model includes two clusters: Costs and Benefits.
Considering that the two criteria of the benefits cluster are both of the same distance unit, the impact of alternatives on the importance of criteria in the cost clusters due to their relative quantity is considered in the ANP model. This interconnection makes the model more complicated than a simple hierarchy model (Figure ٣). In Figure ٤, candidate sites for Mashhad city are shown. Dots in the left hand side illustration show water wells.

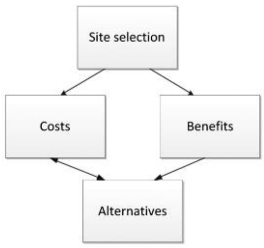


**Figure ٣ ANP model interconnections.**

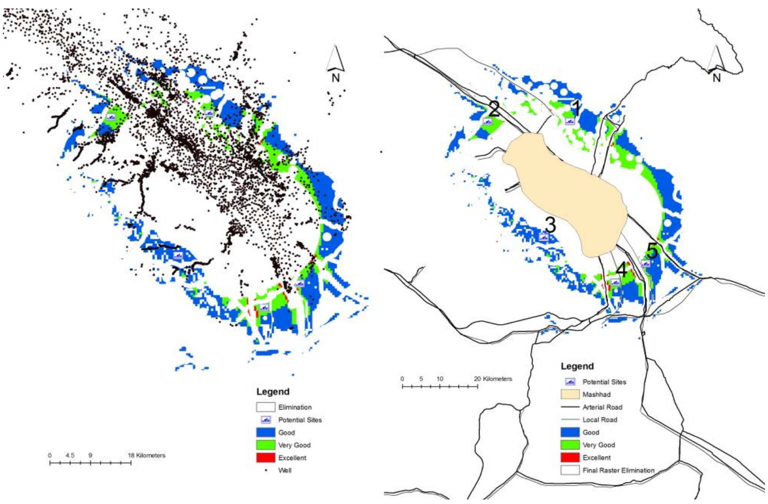


**Figure ٤ Candidate sites.**

### ۳,۲.۱. Benefits and Costs

Straight distance to Mashhad, which is the distance the crow flies, is considered as one of the criteria in the ANP model. Minimizing the landfill-related nuisance according to this criterion does not concur with the financial aspect of site selection.
In the preliminary analysis distance to faults was taken into account as a binary criterion .The study area is somewhat prone to earthquakes. Therefore, earthquakes could result in catastrophic consequences with unforeseen circumstances and disastrous magnitude. Therefore, distance to faults is incorporated in the ANP model.
Although a buffer zone is considered for infrastructure and sensitive sites, intensive wind can spread the landfill-related odor further. Therefore, possible impact of wind to the proximity due to its direction is introduced in the model to address this problem.
Roads are essential infrastructure for transportation of municipal waste and daily commute of staff to the site. Generally, one of the costliest phases of any project is construction of the necessary infrastructure.
Considering that the landfills are designed to be operational for many years, it is important to minimize operational costs such as distance through existing roads network, which is proportional to transportation costs and amount of consumed fuel and corresponding environmental damages throughout the years.

### ۳,۲.۲. The ANP model output

Based on figure ٥, site ۳ is the least suitable alternative due to remoteness and impact of prevailing wind toward Mashhad. Additionally, it is the closest candidate site to a fault. Regarding sites ۱, ۲ and ۳ there is a trade-off between criteria, especially suitability concerning direction of the prevailing wind and connectivity to the roads network and other distance-related criteria. Finally, being the farthest potential site to a fault and according to balanced suitability of other criteria, candidate site ٥ stands the best potential landfill site among the alternatives.

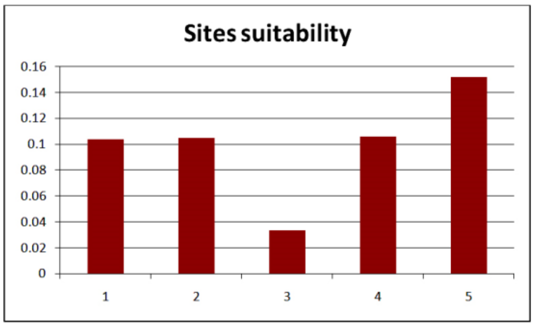


**Figure ٥ Sites' suitability derived from the limit matrix.**

## ٤. Conclusion

Notwithstanding considerable advances in the methods of treating solid waste and recycling, sanitary landfills are urgently required for disposal of residual matters; a landfill site must fulfill numerous criteria. Touching innumerable environmental, economic, sanitary and political issues, landfill site selection is a formidable challenge including elaborate, sensitive and laborious processes. In recent years, rampant growth of municipal waste production has caused complications in large cities. Mashhad, which is not an exception from the mentioned growth trend, was selected as the case study of this research. In this paper, the problem is addressed utilizing a multi-stage GIS-based approach. Taking into account different sets of criteria, authors aim to locate the suitable site in a more optimized manner.
It is rather tricky to handle criteria that may not concur. Therefore, it is important to establish a model that is flexible enough to incorporate contradicting criteria. Two sets of criteria were introduced: fuzzy and binary. Criteria of less sensitivity in impact are treated as binary criteria. In other words, only a buffer zone was devised to eradicate the unsuitable areas due to binary criteria. Additionally, different criteria such as prevailing wind direction, which few papers have taken into account, are considered.
In the first stage, a number of general criteria are included in the decision making model and corresponding utterly unsuitable areas are eliminated from the created AHP overlay.
In the second stage, more delicate criteria of less impact are introduced to the model incorporating the ANP method to rank the available candidate sites derived from the first stage. Finally, the candidate sites were

compared and ranked. All candidate sites are relatively suitable, however, the goal was to establish a multi-stage approach to determine the most suitable site based on diverse criteria. In the end, potential site ٥ was determined as the most suitable site. The model can be improved by considering more climatology and Eco/Sociology criteria.

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دانشگاه فردوسی مشهد

# نهمین کنگره ملی مهندسی عمران
# 9th National Congress on Civil Engineering

بسمه تعالی

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گواهی می شود مقاله ای با مشخصات ذیل در نهمین کنگره ی ملی مهندسی عمران ارائه و در مجموعه مقالات این کنگره درج گردیده است.

عنوان مقاله:

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دکتر احمد شوشتری

دبیر کنگره