Journal of Environmental Health and Sustainable Development

Landfill Site Selection Using Geographic Information System and Fuzzy-AHP Model: A Case Study of Ilam Township, Iran

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ARTICLE INFO

ORIGINAL ARTICLE

Article History:
Received: 04 April 2020
Accepted: 10 July 2020

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Keywords:
Landfill,
Fuzzy-AHP,
Geographic Information System,
Ilam City.

ABSTRACT

Introduction: Landfill siting is a difficult, complex, and protracted process, which requires evaluating different criteria. A suitable site should be located to dispose the municipal solid wastes hygienically (sanitary landfill), which is one of the fundamental subjects related to the environmental stability of the human settlements. The aim was to select a suitable waste disposal area using fuzzy-Analytic Hierarchy Process (AHP) models.

Materials and Methods: To conduct this study, the information about elevation, slope, soil, drainage, vegetation, land use, population, and roads were produced and corrected in layers called shape files using the Geographic Information System (GIS) software. Finally, weights were applied in expert choice software by combining and overlapping information layers in GIS.

Results: Based on the fuzzy-AHP model, 6 sites were identified as suitable areas for municipal waste disposal. Among the selected sites, one site was highly suitable, two were suitable, and three sites were moderately suitable. These areas with an area of 83.8 km^2 are located along the west part of the city adjacent to the Iraqi border. The unsuitable sites for municipal waste disposal were located in the eastern and northeastern areas.

Conclusion: However, applying fuzzy-AHP model provides the necessary conditions for assessing effective relationships among discrete criteria. In the end, combining these models and their findings represented advantages of this kind of modeling and improved scoring in all of these pixels.

Citation: Ahmadi M, Nikseresht M, Najafi E, et al. ***Landfill Site Selection Using Geographic Information System and Fuzzy-AHP Model: A Case Study of Ilam Township, Iran.*** J Environ Health Sustain Dev. 2020; 5(3): 1043-52.

Introduction

In recent years, the suitable landfill site selection has attracted the attention of numerous researches and academic studies [1-3]. Despite the efforts to prevent, reduce, and, recycle the wastes, appropriate management of the Municipal Solid Waste (MSW) is a major environmental crisis [4, 5]. If landfill selection does not meet the standards, landfills will have harmful impacts on the environment. Therefore, suitable siting of landfills is one of the important factors in waste management and planning [6, 7]. This issue is of great importance, especially with the rapid growth of the urban communities and the effects caused by solid waste dumps in the areas surrounding settlements [8]. The suitable area for landfill selection has always been a difficult and complicated process [9, 10]. Wide range of methods exists for landfill siting, which can find a suitable area for such installations. Most related studies in this field used the Geographic Information

[DOR: 20.1001.1.24766267.2020.5.3.4.3]
[DOI: 10.18502/jehsd.v5i3.4276]

System (GIS) technique as a proper tool to manage large volumes of spatial data from a variety of sources [11, 12]. However, concerns exist about the destructive effects of inappropriate landfill dumping from
the past to the present [13, 14]. Modern landfill techniques require cost and time [15, 16]. MSW is a waste type that contaminates the environment and creates inappropriate environmental conditions. The MSW management is a major challenge in urban areas throughout the world, especially in the cities of developing countries [17, 18]. The inappropriate and unsafe burial of these wastes makes recycling difficult [19]. Given that site selection for MSW is a critical factor for managing wastes, selecting a suitable landfill site is of great importance. Disposal of urban waste has now become one of the challenges in the world [20-22]. In the city of Ilam, large amount of waste is produced daily, which is buried in unsafe ways [23]. Selection of the suitable areas for MSW in the study area is the first step in waste management, [24, 25] which involves studying spatial environment, collecting relevant information, as well as careful analyzing data. Furthermore, selecting a suitable model for landfill location is very important. Various models and methods were applied to select suitable landfill sites in various contexts such as models, Boolean login, as well as fuzzy and hierarchical models [26, 27].The most important factors for selecting a landfill site include exact selection of factors, preparation of layers, accurate field examination, and calculation of the model accuracy [28, 29]. Many researchers used a variety of methods in the field of MSW Collection by GIS [30]. In this regard, we can refer to Fuzzy models with expert classification [31-33]. These researchers evaluated many environmental factors such as climate, topography, slope, soil, drainage, vegetation, land use, population, and road to identify the suitable areas. Many researchers applied other models in waste disposal management [34, 35]. In fact, their goal was to combine several models and compare them to select appropriate areas for waste disposal. The results of many studies show the efficiency of GIS and remote sensing in waste management of urban areas, which are buried improperly. No research has been conducted in this field to identify suitable areas for waste disposal. So, this study was carried out to fill this gap in the research literature and achieve precise and applied results in Municipal Solid Waste in areas with high vulnerability and low number of conservation programs. Regarding the daily production of 220 tons of waste in the city of Ilam as well as the lack of suitable places for landfilling and municipal waste dumping, this study was conducted to assess and compare the fuzzy-AHP models used for landfill in Ilam (Figure 1).

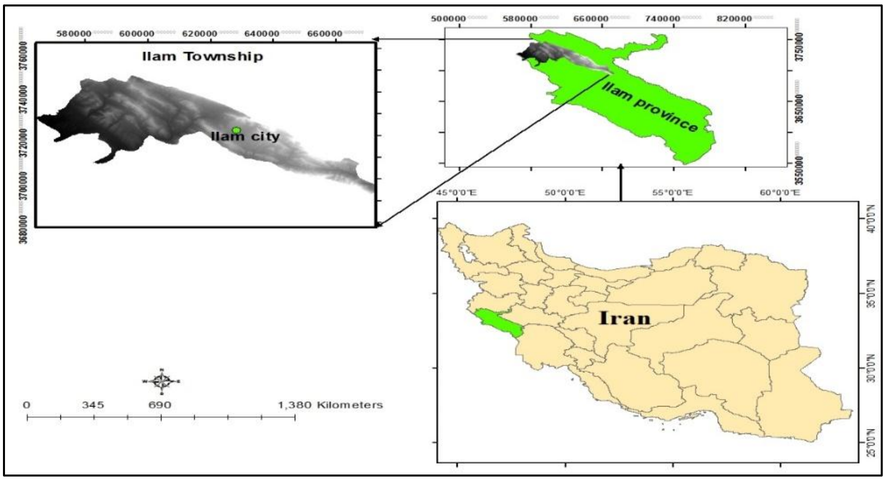

Figure 1: Location of the study area.

[DOR: 20.1001.1.24766267.2020.5.3.4.3]
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Materials and Methods

In the present study, the aim was to select a suitable area for municipal waste disposal using fuzzy-AHP model. Preliminary information and data were collected using both desk research and field studies. To identify suitable areas for landfill, the map of topography, slope, rain, faults, land use, and hydrology were used. In this research, the initial goal was to select a suitable site for landfill in Ilam City. At the second stage, 7 sub-criteria were considered: 1: Geological, 2: Pedology, 3: Hydrological, 4: Hydrogeological, 5: Meteorology, 6: Communication path, 7: Population centers. At the third level, 28 sub-criteria were included (Figure 2). This hierarchical method (fuzzy-AHP) helps decision-makers to address and solve a complex problem in a hierarchical structure (Table 1).

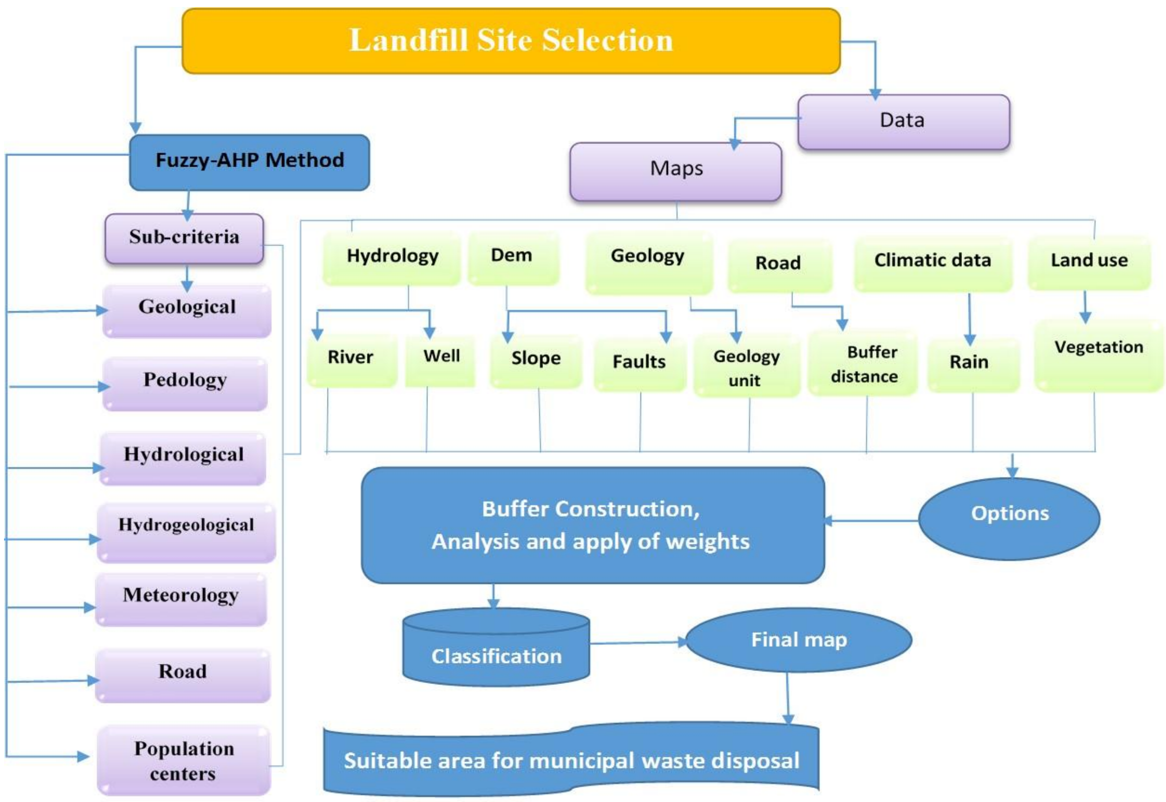

Figure 2: Flowchart of the methodology used in this study.

In this study, we applied GIS in managing and planning landfill selection. Unfortunately, some shortcomings were reported in the model selection or the data implementation phase in a GIS environment [36, 37]. To fix these shortcomings, fuzzy-AHP models were combined to give more precise results. In this study, an algorithm was developed for the proposed fuzzy-AHP approach in three phases of retied, aggregation, and selection parts. The following equation was used to compare pair-wise between criteria, sub-criteria, and options. (Equation 1).[38, 39]

$$ni_j = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}} \qquad (1)$$

Where, the value of each criterion (r_{ij}) in the decision matrix is divided into the total values of r_{ij}, in each column.

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Table 1: The preference values in fuzzy-AHP method.

Importance	1	2	3	4	5	6	7	8	9
Definition	Equal	Weak	Important	Moderate	Strong importance	Strong	Very strong	Very, very strong	Extreme importance

In present study, the consistency index (CI) was computed using equation (2) to ensure that the priority ratio is consistent. Afterwards, based on the CI and a random index (RI), the consistency ratio (CR) was calculated using equation (3):

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (2)$$

$$CR = \frac{CI}{RI} \quad (3)$$

Where, n is the number of items compared in the matrix; λm_{ax} is the largest eigenvalue and RI is a random CI obtained from a large number of simulation runs that varies upon the order of matrix (Table 2) [40, 41].

Table 2: Random index

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Results

Geological parameters

Soil texture, alluvial thickness, slope, and distance from the main and minor faults, earth instability, and seismic hazard were studied as geological parameters. For each soil texture parameter, the distance from faults and slope was from 0.082 to 0.129 according to the importance of the investigated area in locating the waste disposal site (Table 3).

Parameters of soil

In determining the soil factors, the vegetation layer was used. At this stage, five layers including soil erosion, permeability, land use, vegetation, as well as land suitability and capability were considered as soil parameters. At this stage, the minimum and maximum weights of 0.049 and 0.075 were considered for soil factors.

Hydrological parameters

According to Siddiqui, an 800 m buffer is a suitable protective boundary to avoid contamination of surface waters by solid wastes [42]. However, Chang suggests that a distance in 0–1 km from rivers is not suitable and distances more than 1 km are suitable for landfill because more distance from surface water resources such as rivers decrease the risk of river contamination[43-45]. To avoid surface water contamination, we considered a buffer of 600–3,000 m from rivers (Table 4).[46, 47]. Nas suggests that a boundary less than 0.3 km from wells is not protective because toxic gases are released at landfills, which can be a serious threat to these water resources [48]. Therefore, we considered a protective boundary of 0.3–3.5 km from groundwater as an appropriate buffer for Ilam landfill.

Meteorological factor

In the first stage, two layers of evaporation and rainfall data were considered. At this stage, the minimum and maximum total weights were 0.013 and 0.017 for the meteorological parameters, respectively.

Table 3: Comparative weight of sub-criteria in fuzzy-AHP method.

Geological	Pedology	Hydrological	Hydrogeological	Meteorology	Road	Population centers
0.471	0.274	0.144	0.073	0.055	0.047	0.039

Table 4: Brief characterization of the 6 sites of interest identified in the area.

Areas	Land use	Topography	Penetrable	Distance to Fault(km)	Rain(mm)	Distance to drainage(km)
Area 1	Arid	Lowland	High	3	425	5
Area 2	Arid	Lowland	Moderate	1.5	400	4
Area 3	Arid	Moderate	Moderate	1.7	370	3.5
Area 4	Pasture	Moderate	Moderate and low	1.5	370	3
Area 5	Pasture	Moderate	Low	1.5	370	2.7
Area 6	Pasture	High	Low	1	480	600m

Residential areas

Qanavati and Sorkhi suggested that the municipal landfill should be located at a distance of over 300 m from the main residential areas (including towns and villages). Sener considered that a distance of 1,000 m from the rural residential areas was inappropriate, while a distance of more than 1 km was appropriate [49]. Since our study area was small, we considered 300 and 2,000-meter distance of landfill from residential areas as the minimum and maximum distances, respectively. Allen believed that the appropriate threshold for landfill from towns with a population of more than 500 people was 1–5 km. However, Sener found that a distance of 5–30 km from the main city was a suitable boundary from landfill. We considered a distance of 1–5 km as a suitable boundary of landfill from Ilam. Due to the high costs of facilities required for sanitary landfill, allocating a common landfill for several small cities and towns would be a much better option. At this stage, the total maximum and minimum weights of 0.009 and 0.007 were considered for the Residential parameters (Table 5). After selecting appropriate sites for the landfill using fuzzy-AHP, different regions were classified according to their suitability (Figure 3). Based on the fuzzy-AHP model, 6 sites were identified as suitable areas for municipal waste disposal. Among the selected sites, one site was highly suitable, two were suitable, and three sites were moderately suitable (Figure 4).

Table 5: Comparative weight of options in fuzzy-AHP method.

Distance to fault	Variation	Landslide	Erosion	Penetrable	Land use
0.129	0.087	0.082	0.075	0.069	0.57
Vegetable	Capability land use	Distance to drainage	Distance to main stream	Distance to dam	Distance to well
0.051	0.049	0.037	0.033	0.029	0.026
Depth ground water	Quality ground water	Flow direction	Evaporate	Rain(mm)	Speed wind
0.024	0.021	0.019	0.017	0.015	0.013
Distance to main road	Distance to secondary road	Distance to line convection	Distance to village and city	Distance to industry city	Protected area
0.012	0.011	0.010	0.009	0.008	0.007

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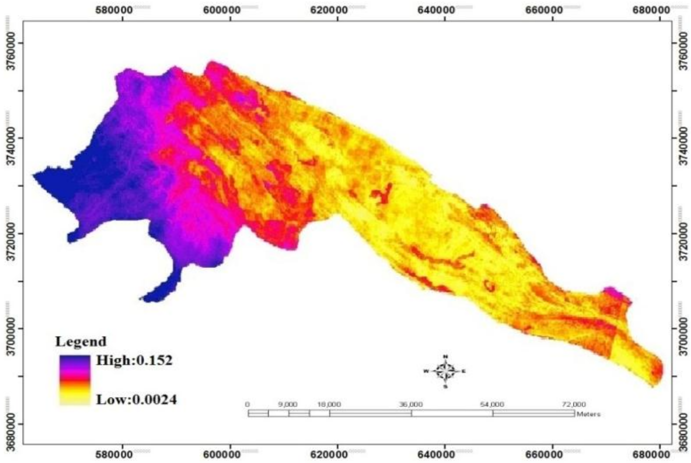

Figure 3: Suitable areas to landfill based on fuzzy-AHP model

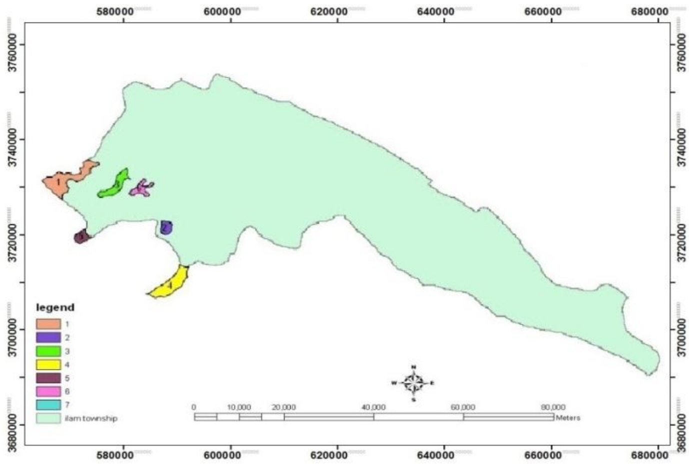

Figure 4: Selected sites to landfill using fuzzy-AHP model

Discussion

Suitable areas for landfill were located in the northwest of Ilam. Considering that this area is located in a high rainfall area, it is covered with agricultural lands and forests. These areas have poor vegetation with suitable bedrock, good distance from surface waters, communication paths, and residential areas. These regions with an area of 83.8 km^2 are located along the west of the city and adjacent to the Iraqi border. The height of this area is between 347 and 425 meters. The aggregates are calcareous sediments along with silt and clay. The gradient of these areas is appropriate. Most of the range is composed of limestones of the Asmari. A very small part of the range 3 in the south is the periodicity of red to gray gravel and limestone with gypsum mildew.The landfills (n = 6) mainly located in the western part of the city Ilam were appropriate considering the environmental characteristics, special environmental, and natural conditions. The selected sites were studied more precisely than others. At this stage, 3 selected areas, including sites 3, 2, and 1 were studied using maps with a scale of 1: 25000 and field observations were studied in more details. Among the selected sites, site 1 was more suitable for landfill. The current conditions of the waste disposal site in Ilam City show that the site does not meet the necessary criteria for waste disposal, such as distance from the fault and water sources. Proximity to the fault increases the likelihood of earthquake-induced contamination [50]. The proximity of the landfill to the drainage increases the likelihood of contamination of water sources [51]. Comparing the characteristics of the selected sites with the environmental criteria of the waste disposal sites of the Environmental Protection Organization [52] shows that the sites selected based on the fuzzy-AHP model have the maximum level of suitability and are good for a period of ten years. Given that the selected sites are located in the western part of the region and away from the residential areas, they are suitable. Land use study shows that the selected sites are located in areas with poor land use and have suitable conditions for waste disposal based on the environmental criteria. West of Ilam Township has a suitable condition for waste disposal in a long period. This area has appropriate environmental standards such as hydrology, geology, land use, meteorology, and distance from residential facilities. So, it can be used to dispose wastes in Ilam for a period of ten years without negative environmental impacts. The current landfill in Ilam is located in a forested area near the city and poses an environmental threat; so, the selected sites can replace the current site and reduce the environmental hazards.

Conclusion

The urban development of Ilam city during recent years was due to combination of villages and natural growth of the city. In the process of this demographic shift, the needs and consumption of natural and artificial materials were in the form of waste materials (waste) in quantity and quality and daily production of more than 220 tons of waste in a natural environment. In locating the landfill of Ilam City, many environmental factors were considered such as fault, agricultural lands, human settlements, soil, and urban development process based on fuzzy-AHP. Finally, the areas in the West of the city were selected as the best sites for landfill. A combination of fuzzy-AHP methods was used in this study and the findings proved the validity of this method. Based on the findings, 6 areas were appropriate for waste landfill. Most areas were located in regions with poor pasture land and away from agricultural and urban areas. However, applying fuzzy-AHP model provides the necessary conditions for assessing effective relationships among discrete criteria. In the end, combining these models and their findings represented advantages of this kind of modeling and improved scoring in all of these pixels.

Acknowledgment

The authors are grateful to all those who have supported the production and publication of this article, the authors are grateful to Dr. Nabin Baral from University of Washington for providing helpful comments and reviewing the manuscript.

Funding

There were no funding sources for this study.

Conflict of Interest

The authors confirm that there is no conflict of interest regarding the publication of this article.

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