

Research Article

Noor Hashim Hamed*, Haifaa Nasser Husein and Oday Zakariya Jasim

Suitability location for landfill using a fuzzy-GIS model: A case study in Hillah, Iraq

<https://doi.org/10.1515/eng-2022-0493>

received June 14, 2023; accepted July 20, 2023

Abstract: One of the most significant issues facing local governments and municipalities worldwide is choosing an appropriate location for landfills. In order to suggest appropriate places for waste sites, this study proposes a strategy using a fuzzy logic model and spatial analytic tools. The proposed approach utilized five parameters extracted from Geographic Information System (GIS) layers in Hillah city in Iraq, which include distances from hydrology features, residential or urban areas, transportation, and historical locations. These parameters were used as standards to construct a geodatabase for generating suitability maps. These indicators are relevant factors in determining the suitability of a site for an urban landfill. It is important to consider the distance from residential or urban areas when selecting a landfill site. A significant distance helps reduce the potential negative impacts on nearby communities, such as odors, noise, traffic, and health concerns associated with waste disposal, and for the other indicators. The fuzzy logic model is more accurate than conventional methods such as the weighted overlay approach. Based on a fuzzy logic model, the total surface area of acceptable locations is 1.1 km². According to the fuzzy logic model, some frequent adequate places were discovered to be beyond the city borders, to the west and south of the research region. To minimize the negative impacts on the environment and its residents, this study demonstrated how the fuzzy logic model and GIS might be combined for waste management decision concerns connected to landfill site selection.

Keywords: fuzzy logic model, geographic information system, weighted-based model, landfill, solid waste

1 Introduction

Throughout the solid waste management process, the location of landfills for solid waste operations is frequently chosen based on various factors, such as the area's geographic characteristics. The selection of landfill sites depends on public institutions in the city [1]. Because of the expense, the challenges of reversal, the financial implications, the challenges of reversal, and the necessary long-term obligations, decision-makers frequently operate landfill site selection [2,3]. Several challenges are facing finding suitable landfill sites, such as population growth, health risk, environmental impacts, increasing waste amount, and decreasing available land for landfill sites [4]. Therefore, traditional and manual site selection should be developed for an automatic or semi-automatic process for finding a suitable area for landfill sites. Choosing an appropriate landfill site is complex and involves several considerations, criteria, and circumstances. Below are some primary considerations, standards, and restrictions usually made while choosing a landfill location. First, the site should be located away from residential areas, water bodies, and environmentally sensitive areas. It should also be easily accessible for waste disposal vehicles. Second is the topography, which is the site that should have a suitable topography that is not prone to landslides, flooding, or erosion. Third is the soil which is the site, should have soil suitable for waste disposal, and does not have a high water table or contain contaminants. Fourth is geology, which should be free from geological hazards such as fault zones and sinkholes. Fifth is the climate: the site should have a climate suitable for waste disposal, with low rainfall and low humidity to reduce the risk of leachate generation. Sixth is land use and environmental impacts, which is the site, should not conflict with existing land use or future development plans. The ultimate considerations involve the financial aspects and adherence to regulatory requirements, which the site should be economically feasible, with low costs for acquisition, construction, and operation. Also, the site should meet all local, state, and federal regulations and obtain all necessary permits. The fuzzy approach had other applications, such as modeling a vehicle crash test [5] and assessing ecosystem innovation risks [6].

* **Corresponding author: Noor Hashim Hamed**, Civil Engineering Department, University of Technology, Baghdad, Iraq, e-mail: Noor.H.Hamed@uotechnology.edu.iq

Haifaa Nasser Husein: Civil Engineering Department, University of Technology, Baghdad, Iraq, e-mail: Haifaa.N.Husein@uotechnology.edu.iq

Oday Zakariya Jasim: Civil Engineering Department, University of Technology, Baghdad, Iraq, e-mail: Oday.z.jasim@uotechnology.edu.iq

In many Middle East countries such as Iraq, traditional methods and techniques to find the optimal location to establish landfill sites are ongoing. Therefore, these countries require developing models and frameworks to improve the suitability analysis related to landfill sites. This study may introduce a new approach or framework for selecting a suitable urban landfill site using a fuzzy-Geographic Information Systems (GIS) model. This methodology could provide a more comprehensive and objective means of decision-making compared to traditional approaches and also may demonstrate the successful integration of fuzzy logic techniques with GIS for site selection purposes. This study may provide a real-world case study, showcasing the application of the proposed fuzzy-GIS model in a specific urban context.

2 Related works

The most fundamental method for appropriateness analysis is multi-criteria decision-making (MCDM), based on the analytic hierarchy process [7,8]. This process has the

ability to solve complicated decision-making issues in many applications [9–11]. Based on weighting approaches that can be learned from experts or past trials, MCDM is used. This combination appropriately manages imprecision criteria and combines qualitative and quantitative aspects.

Despite the fact that several studies have covered the application of fuzzy MCDM methods, several studies have recommended combining these tactics to solve issues with disposal site selection. To find acceptable places for a landfill site in Shahr, Iran, Torabi-Kaveh *et al.* [12] suggested combining a Geographic Information System (GIS) with a fuzzy analytical hierarchy process. At Al-Hashimiyah Qadhaa, Babylon, Iraq. Chabuk *et al.* [13] utilized GIS analysis and MCDM to choose landfill locations. When choosing landfill areas, various techniques have been used [14–16]. These authors concluded that a combined review utilizing MCDM techniques is essential when choosing a landfill site. This is because the features of the issue domain determine the relative benefits of various techniques. The south of Baghdad area in Iraq is considered a good location for a landfill site, but finding the optimum area is still a challenge. Therefore, this study proposed a fuzzy logic model that can

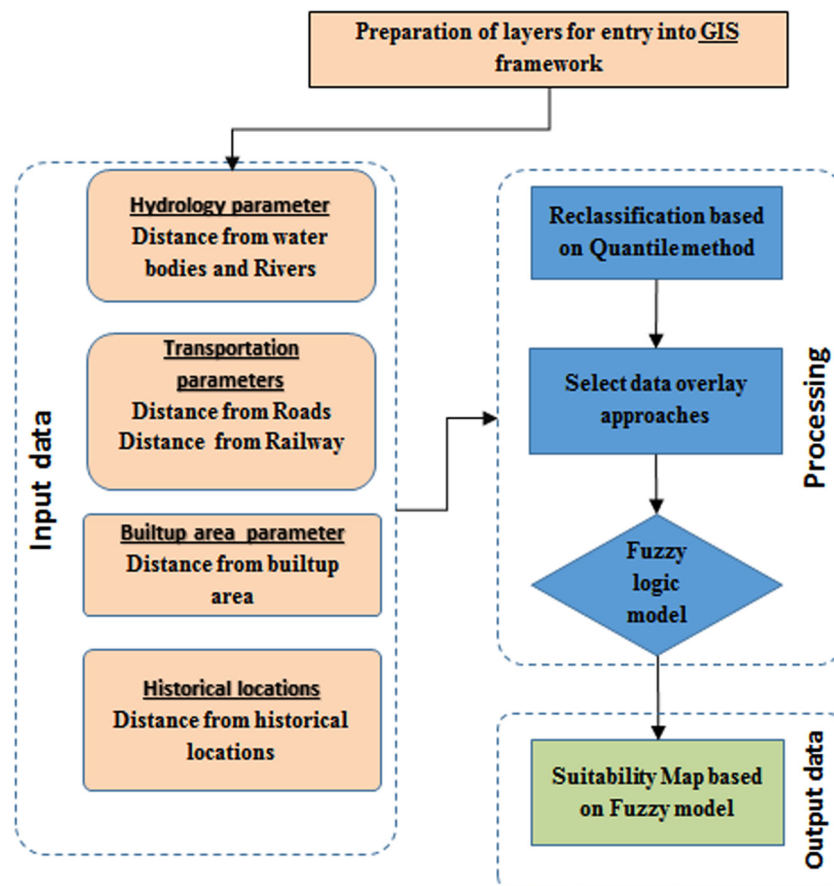


Figure 1: Study's conceptual methodology.

be integrated with GIS to find an optimal area for a landfill site in Babylon province near the south of Baghdad. There is now no landfill site available in the region of Babylon, and the one does not meet the necessary environmental and scientific criteria. This article's main objective is to suggest a technique for choosing landfill sites. That suits Babylon Province, south of Baghdad City, and fulfills the required standards. Five criteria were considered in the fuzzy logic model to achieve this goal.

3 Methodology and data set

The proposed geodatabase uses GIS, which shows the five most standards to find a suitable geographic location for the landfill site in the region of our study. The geodatabase and the layouts of the maps of all the standard conditions for the landfill siting were generated using geomatics techniques. Modeling analysis was applied using quantile method in MATLAB software. Each raster image was separated into

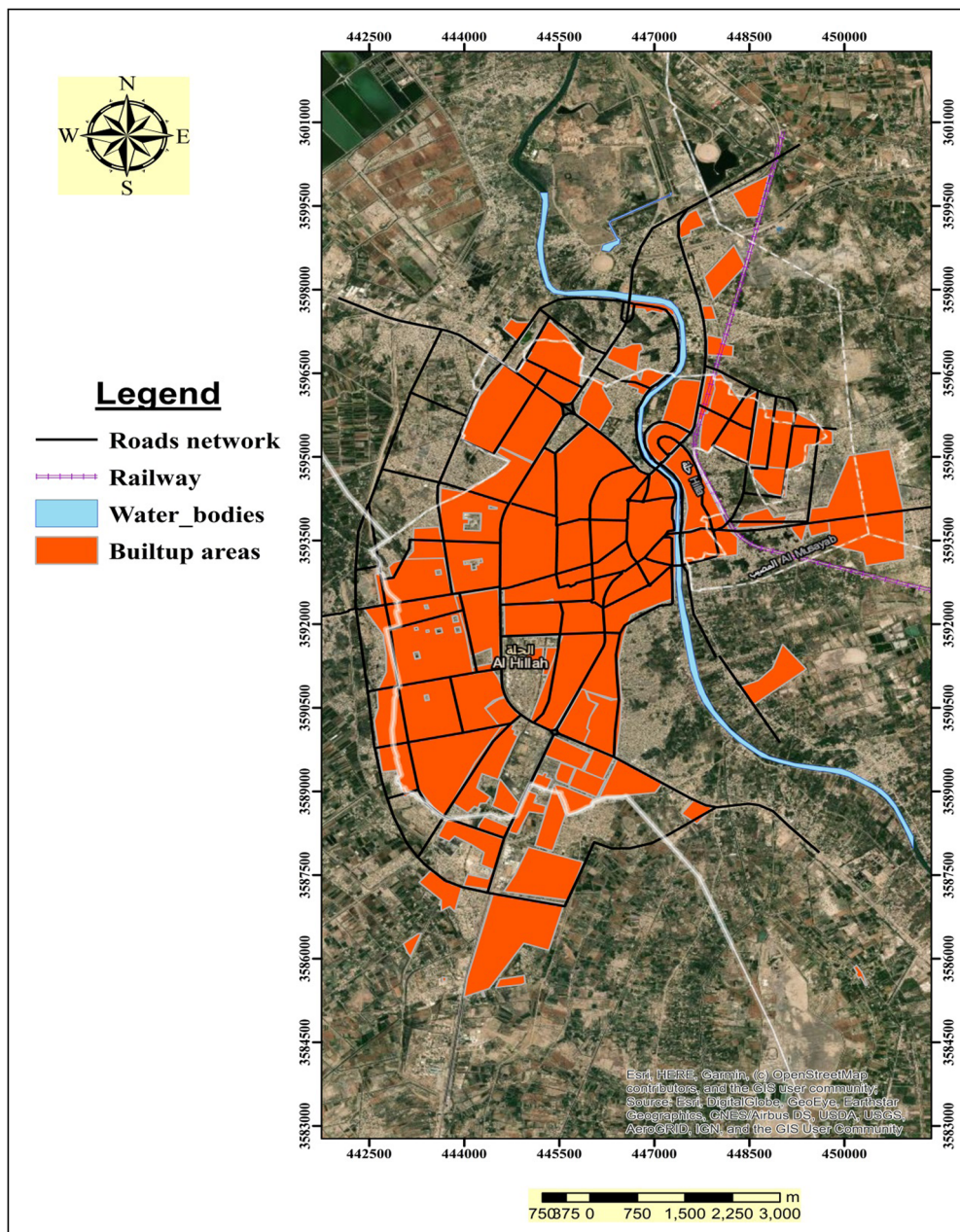


Figure 2: Study area of Hillah/Iraq.

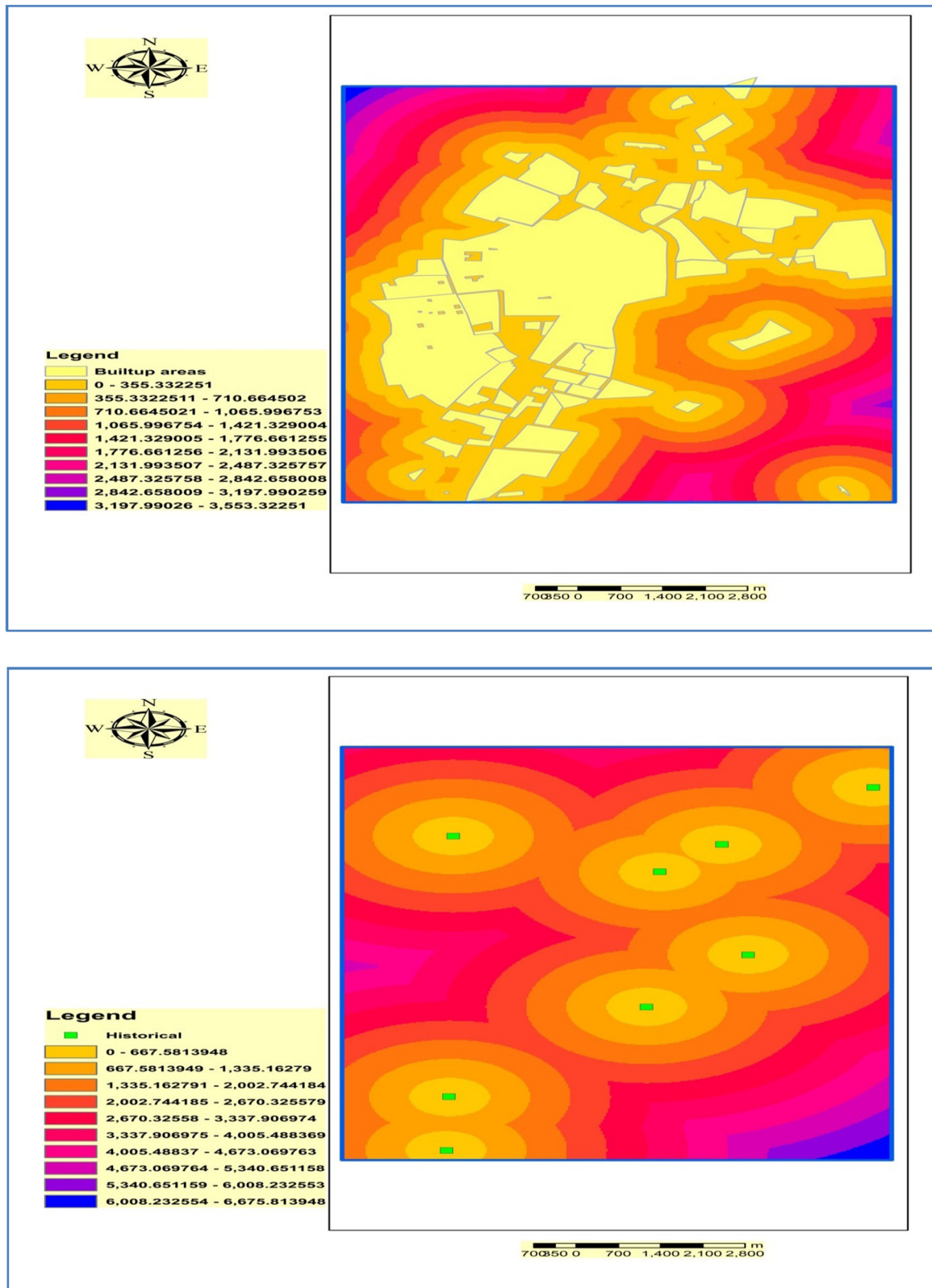


Figure 3: Distance from residential areas and historical locations.

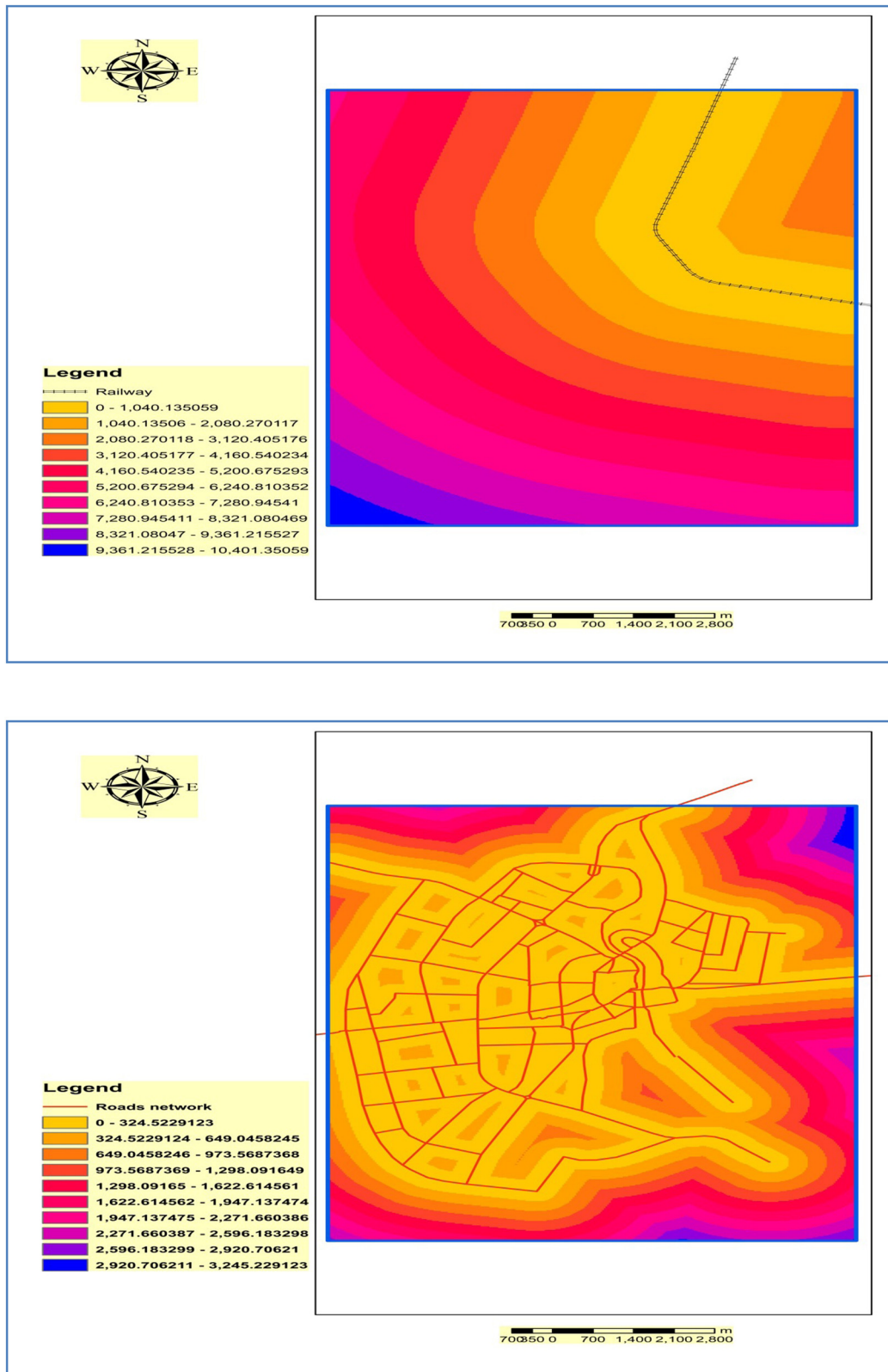


Figure 4: Distance from transportation.

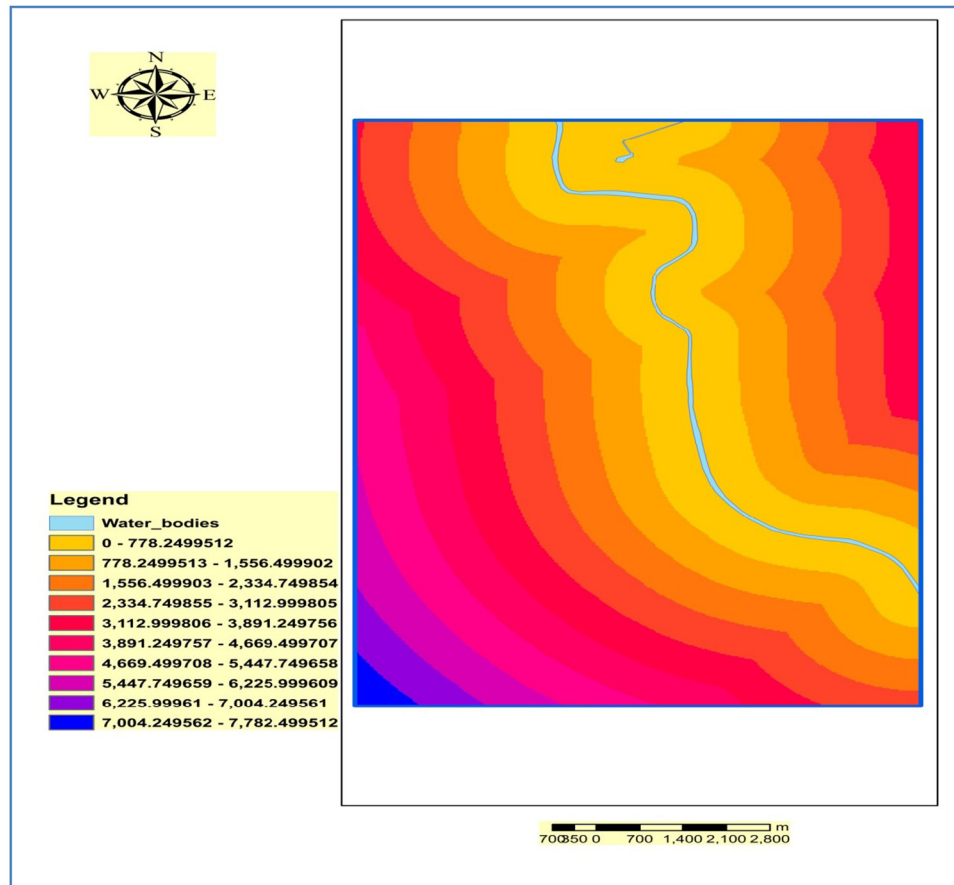


Figure 5: Distance from hydrogeology.

sets according to the chosen standard and criteria, and each set was given the proper weight. The final landfill site map and geodatabase were made using GIS. This study's approach and structure are illustrated in Figure 1.

3.1 Study area

Babylon is situated between the latitudes 32°24'24" and 32°31'58" North of equator and the longitudes 44°22'13" to 44°28'13" East of Greenwich, south of the Iraqi capital Baghdad. According to Figure 2, the satellite image (WV3) of the city Hillah with spatial resolutions (0.31 m) and dated in 31/01/2020, which serves as the provincial capital of Babylon, is located around 89 km south of Baghdad. Babylon has an area of about 5,200 km² and 2,174,783 in population as of 2020. This region's distinctive features include a variety of land uses, including industrial, commercial, and residential ones, as well as a number of newly expanded human activities and infrastructures. Also, the city is surrounded by a number of historical sites, such as Old Babylon City, making this region a popular tourist destination. And for these

reasons, a study area was chosen to apply all the five indicators for selecting the suitability location for landfill. The province of Babylon was mainly covered with agricultural fields (Chabuk et al. [13]).

3.2 Suitability criteria

In this article, five criteria were extracted from different sources to determine the best areas for establishing landfill sites: a distance from hydrogeology, distance from transportation to minimize transportation costs and reduce the environmental impact of transporting waste, distance from railways, distance from historical locations, and distance from residential areas. These criteria were determined utilizing GIS techniques. In our investigation, spatial analysis techniques were employed to assess five characteristics: distance from hydrogeology, distance from transportation, distance from railways, distance from historical locations, and distance from residential areas. On the other hand, parameter weights were applied based on fuzzy logic tools in spatial analysis techniques (Figures 3–5).

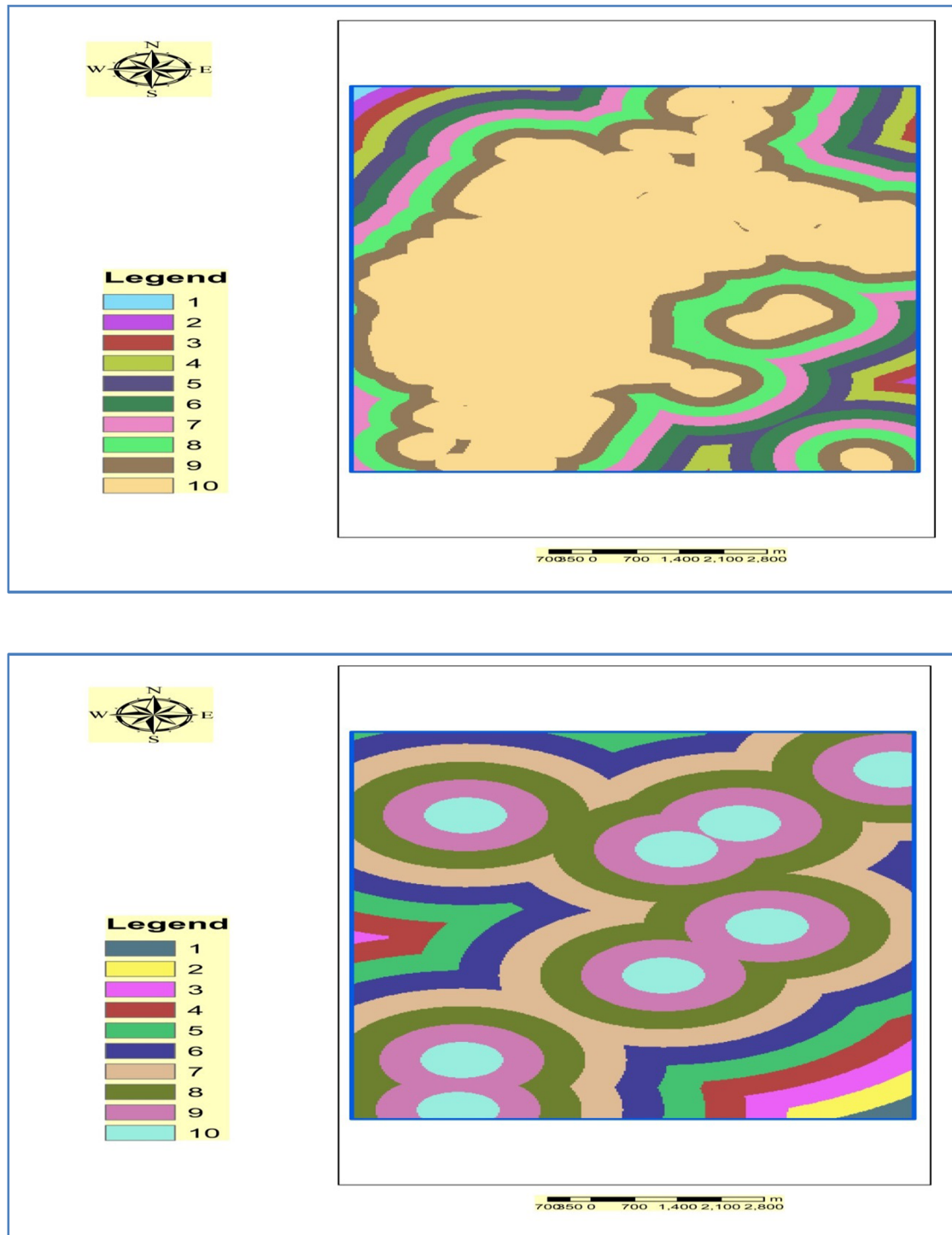


Figure 6: Reclassified distance from residential areas and historical locations.

Using a number of methodologies, the reclassification procedures often involve altering cell values to alternate values. Reclassification in GIS involves assigning new values to existing data based on specific criteria or rules. Reclassifying individual values or groups of values at once

based on criteria like preset intervals (divide the data into 10 intervals) or area is possible (group the values into 10 groups containing the same number of cells). A reclassification is a powerful tool in ARC GIS software that allows you to assign new values to exist data based on certain criteria or rules

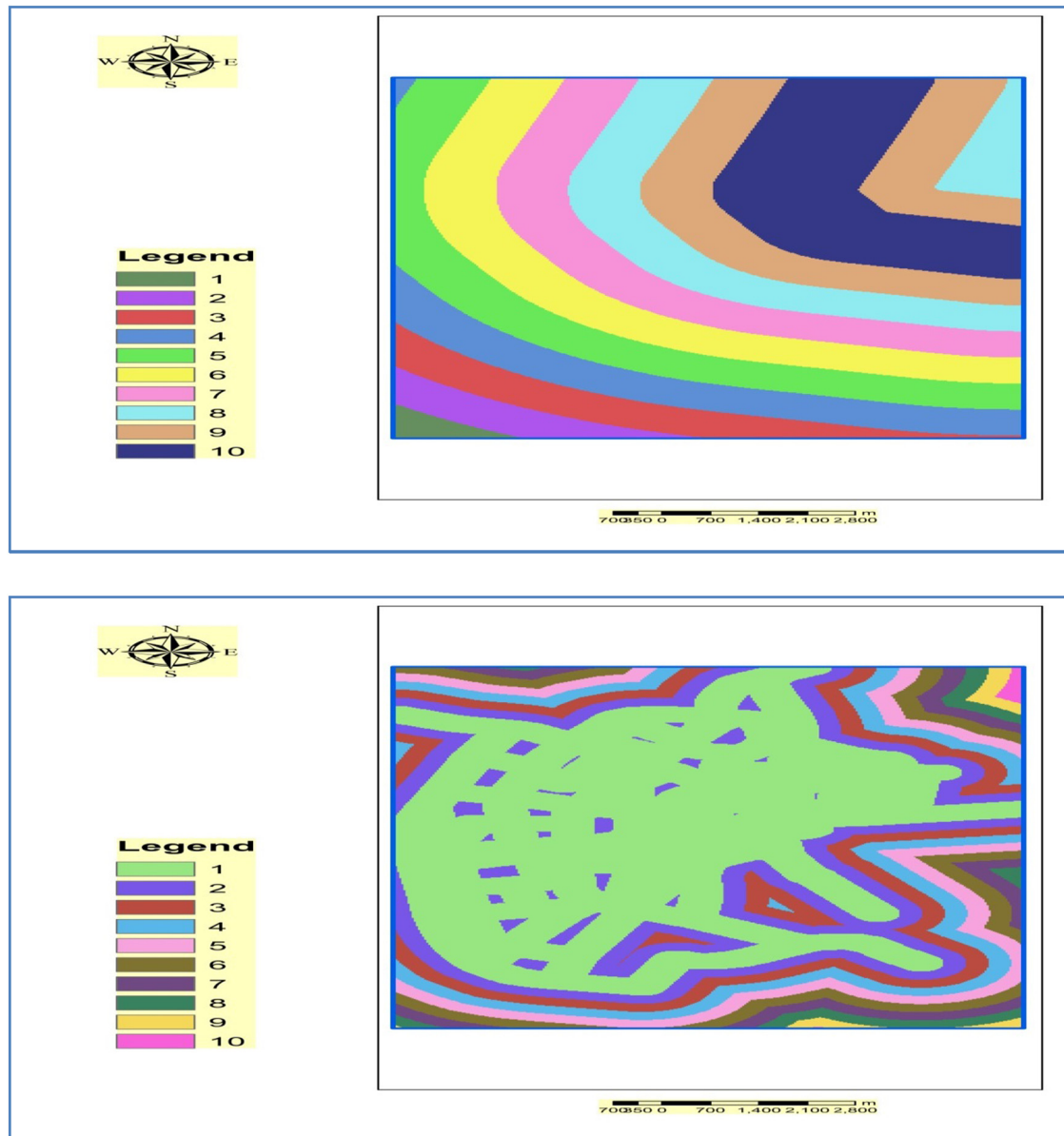


Figure 7: Reclassified distance from transportation.

and group values into intervals or classes for further analysis and visualization. Figures 6–8 illustrate the reclassification results.

3.3 Use of the fuzzy logic model

In a fuzzy technique, pixels from causal factor layers map land suitability. The numerical pixel values, which range from 0 to 1, are generated as “not suitable to very suitable.” There are no practical restrictions on the value selection; however, pixel values must be between zero (0) and one (1).

Based on subjective assessment, values might be selected to indicate the extent of a set’s membership [17] or can be obtained from various reality-representing functions [18]. In this work, the reality function was represented using linear functions because it can quantify the appropriateness of land use continuously, which reduces ambiguity and uncertainty. Three processes make up a site suitability application using fuzzy logic, as shown below:

The first step in the process involves employing fuzzy set models to normalize or standardize land attributes. The user can utilize fuzzy logic to assess whether a site is suitable. This procedure assigns values between 0 and 1, where 0 is inappropriate and 1 is appropriate. The higher

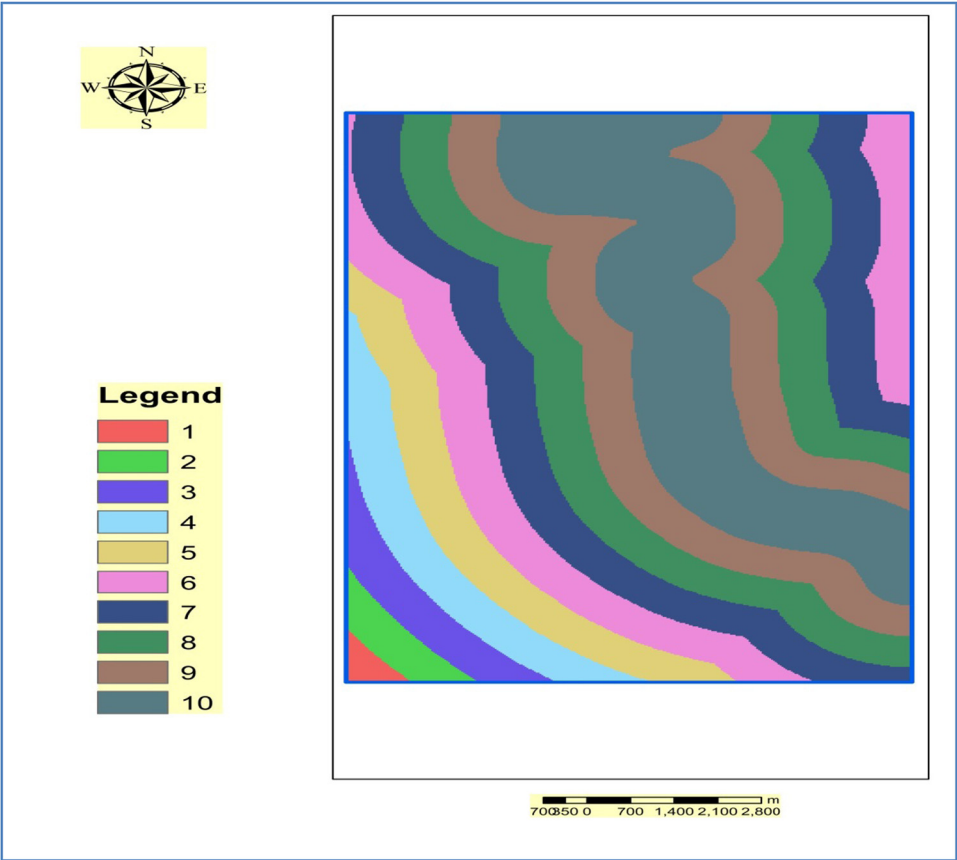


Figure 8: Reclassified distance from hydrology.

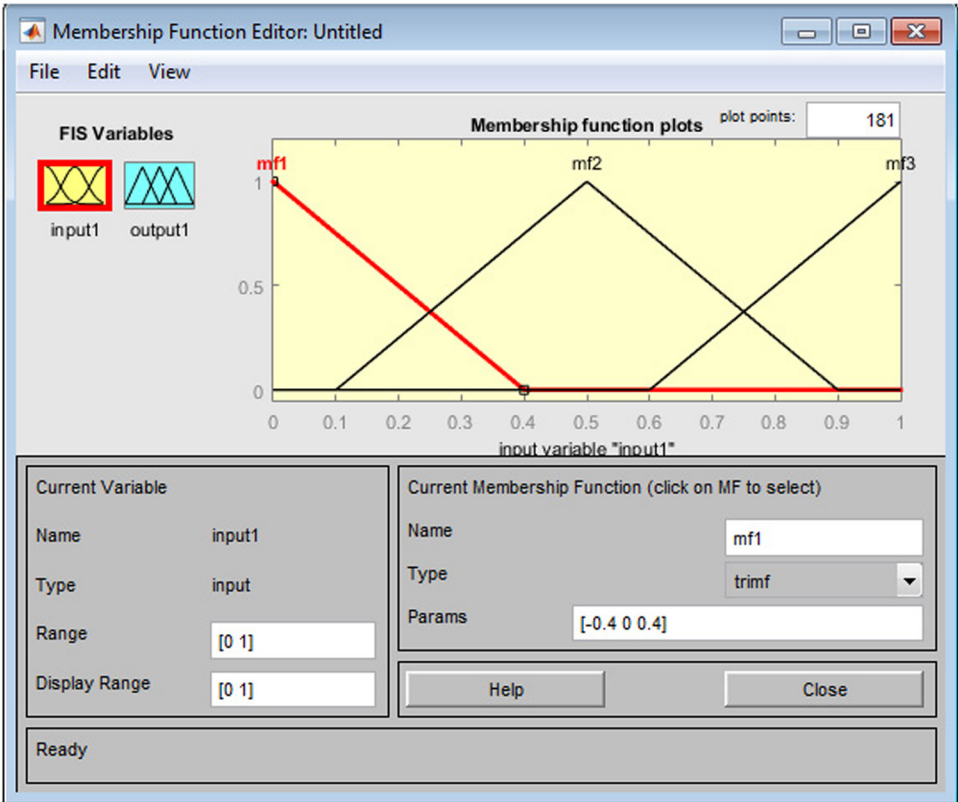


Figure 9: MATLAB input variables.

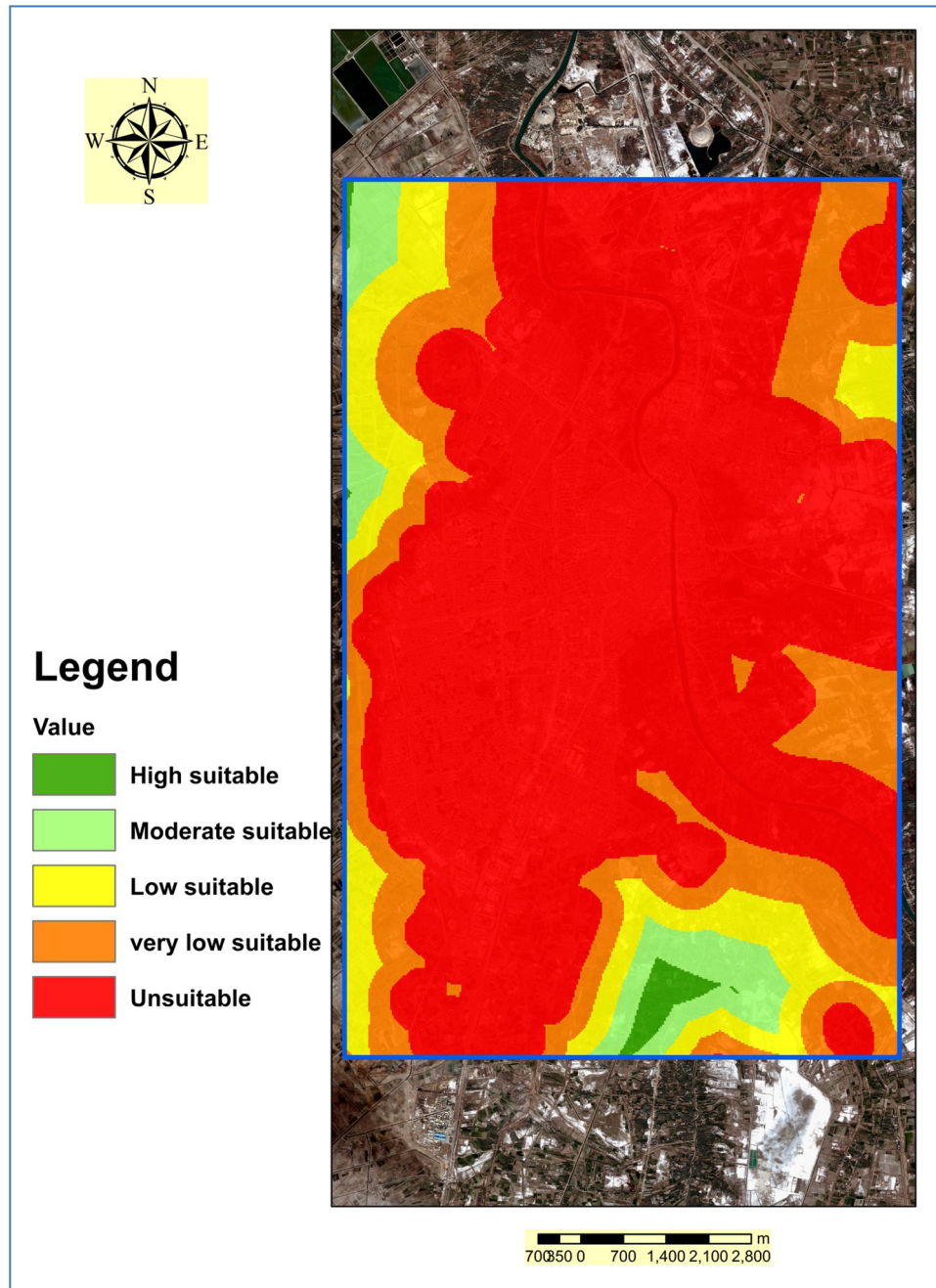


Figure 10: Suitable location for landfill site map using a fuzzy logic model.

fuzzy value implies the ideal of the site. The second step in the process is the development of the criteria map features. A different scaling method using language variables to communicate both quantitative and qualitative requirements is provided by fuzzy logic [17,19]. For quantitative criteria, such as return on resources, representation by a linguistic variable needs the creation of word sets (meager, low, medium, high, and very high). The final step in the process is the production of the overall land suitability

map layers. This study applied a fuzzy logic model based on two software packages (MATLAB and ARC GIS), where MATLAB was used for fuzzy modeling and GIS was used for fuzzy logic overlay and building geodatabase and map production. Parameters were converted to tables that include “distance to parameters” that were converted to tables in order to be easily used in MATLAB software. This article used a fuzzy logic designer to build a fuzzy model. Unique functions in the fuzzy logic designer are employed to

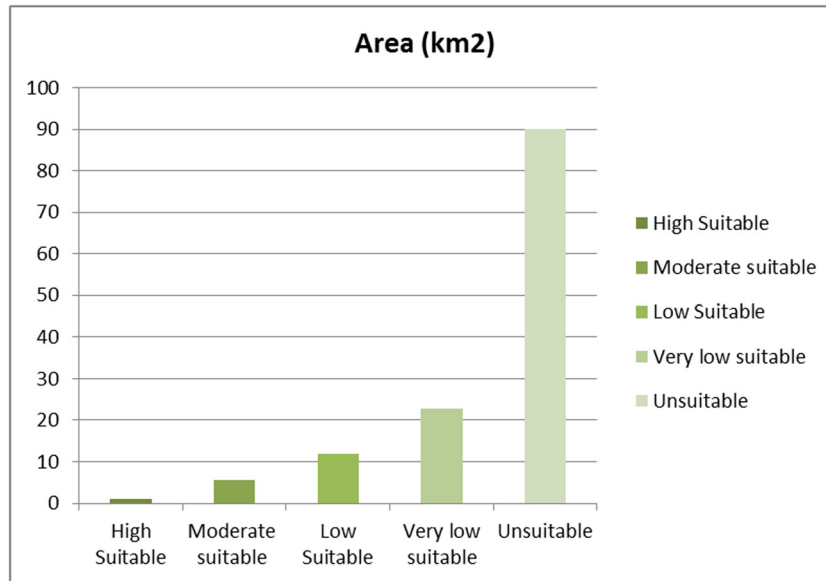


Figure 11: Disparities in coverage between high suitable class and problematic areas.

construct a fuzzy inference system. Open fuzzy logic designer is the initial step. Type the input at the MATLAB® command line. Then, provide the number of inputs and outputs of the fuzzy system, such as creating custom membership functions and replacing the built-in membership functions with them. Replace the built-in inference routines with your custom inference functions. The AND, OR, implication, aggregation, and defuzzification procedures are examples of inference techniques. This action generates the output values for the fuzzy system. Then, the results were used as input parameters in a fuzzy overlay to generate a suitability map based on a fuzzy logic model, as in Figure 9.

4 Results and discussion

4.1 Suitability analysis using a fuzzy logic model

Figure 10 shows the geodatabase for the suitability data generated by the fuzzy logic model. The final results will be presented as a map highlighting the research area's suitable and unsuitable locations based on five criteria for landfill suitability analysis. The map indicates that the high-appropriate regions are situated in the southernmost portion of the research area. On the other side, it was discovered that there was no recognized good place for solid waste in the research areas' northern, eastern, western, and center portions. Hence, during the field visit, they

should be disregarded. The total amount of suitable land is projected to be 1.1 km². The suitability map produced using the fuzzy logic model shows the geographical distribution of the appropriate places and their patterns in the research region. According to Figure 11, the high-suitable class covers the smallest area, approximately 1.1 km². At the same time, the most significant area was covered by problematic areas that roughly equaled 90.1 km². High-suitable regions can be grouped into two distinct groups rather than randomly dispersed in various directions. This suggests that the suitable locations found are homogeneous and have traits in common. This is crucial for decision-makers since it facilitates and improves the accuracy of the final choice. With this technique, decision-makers may quickly find locations in a certain region acceptable for solid waste landfill construction. On the other hand, Figure 10 shows the variation in area quantities for the suitability classes.

It is crucial to compare the outcomes of the weighted-based model with fuzzy logic models to spot any parallels and possible differences. Comparing the maps developed by these models showed that the fuzzy model produced a map with clustered small areas. Yet, the weighted-based maps showed the optimal locations to be dispersed regions with vast expanses. It was noted that the fuzzy map only discovered two acceptable places in the southern sections of the study region. Yet, the weighted-based map identified appropriate locations within the research region. The fuzzy model selected 1.1 km² for a landfill site, whereas the weighted-based model found 31.5 km² highly suitable. Consequently, the fuzzy

model outperformed weighted-based model due to the relatively small final results and can reduce the cost, time, and efforts for the field investigations to find the exact location to establish a landfill site. To consider extra factors not considered by the model, such as population density and environmental changes, a field investigation is necessary to determine the landfill's final location.

5 Conclusion

Five criteria were employed in an overlaying study of possible sites utilizing a GIS to find a suitable landfill site in Hillah City, Iraq. Fuzzy logic models were used in this article; layers such as distance from hydrology, distance from transportation, distance from residential, and distance from historical sites were considered. The locations that met the criteria for environmental, economic, and residential features were discovered to be outside of cities, mainly in the research area's south. The common regions found using both approaches demonstrated that the best landfill sites were located sufficiently away from populated areas. The results suggested that a fuzzy model including a range of scientific and environmental elements might be used to develop an effective and efficient system for selecting suitable landfill sites in Hillah, Iraq.

Funding information: We declare that the manuscript was done depending on the personal effort of the author, and there is no funding effort from any side or organization.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: Most datasets generated and analyzed in this study are in this submitted manuscript. The other datasets are available on a reasonable request from the corresponding author with the attached information.

References

- [1] Hanine M, Boutkhoul O, Tikniouine A, Agouti T. Comparison of fuzzy AHP and fuzzy TODIM methods for landfill location selection. *SpringerPlus*. 2016 Dec;5:1–30.
- [2] Gorsevski PV, Donevska KR, Mitrovski CD, Frizado JP. Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: a case study using ordered weighted average. *Waste Manag*. 2012 Feb;32(2):287–96.
- [3] Liu HC, You JX, Fan XJ, Chen YZ. Site selection in waste management by the VIKOR method using linguistic assessment. *Appl Soft Comput*. 2014 Aug;21:453–61.
- [4] Srivastava AK, Nema AK. Fuzzy parametric programming model for multi-objective integrated solid waste management under uncertainty. *Expert Syst Appl*. 2012 Apr;39(5):4657–78.
- [5] Pawlus W, Karimi H, Robbersmyr K. A fuzzy logic approach to modeling a vehicle crash test. *Open Eng*. 2013 Mar;3(1):67–79.
- [6] Abreu A, Martins JM, Calado JM. A fuzzy reasoning approach to assess innovation risk in ecosystems. *Open Eng*. 2018 Dec;8(1):551–61.
- [7] Beskese A, Demir HH, Ozcan HK, Okten HE. Landfill site selection using fuzzy AHP and fuzzy TOPSIS: a case study for Istanbul. *Environ Earth Sci*. 2015 Apr;73:3513–21.
- [8] Moenaddini M, Khorasani N, Danehkar A, Darvishsefat AA. Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj). *Waste Manag*. 2010 May;30(5):912–20.
- [9] Saaty TL. A scaling method for priorities in hierarchical structures. *J Math Psychol*. 1977 Jun;15(3):234–81.
- [10] Tavares G, Zsigraiová Z, Semiao V. Multi-criteria GIS-based siting of an incineration plant for municipal solid waste. *Waste Manag*. 2011 Sep 1;31(9–10):1960–72.
- [11] Uyan M. MSW landfill site selection by combining AHP with GIS for Konya, Turkey. *Environ Earth Sci*. 2014 Feb;71:1629–39.
- [12] Torabi-Kaveh M, Babazadeh R, Mohammadi SD, Zaresefat M. Landfill site selection using combination of GIS and fuzzy AHP, a case study: Iranshahr, Iran. *Waste Manag & Res*. 2016 May;34(5):438–48.
- [13] Chabuk A, Al-Ansari N, Hussain HM, Knutsson S, Pusch R, Laue J. Combining GIS applications and method of multi-criteria decision-making (AHP) for landfill siting in Al-Hashimiyah Qadhaa, Babylon, Iraq. *Sustainability*. 2017 Oct;9(11):1932.
- [14] Gbanie SP, Tengbe PB, Momoh JS, Medo J, Kabba VT. Modelling landfill location using geographic information systems (GIS) and multi-criteria decision analysis (MCDA): case study Bo, Southern Sierra Leone. *Appl Geogr*. 2013 Jan;36:3–12.
- [15] Khorram A, Yousefi M, Alavi SA, Farsi J. Convenient landfill site selection by using fuzzy logic and geographic information systems: A case study in Bardaskan, East of Iran. *Health Scope*. 2015;4(1):e19383.
- [16] El Baba M, Kayastha P, De Smedt F. Landfill site selection using multi-criteria evaluation in the GIS interface: a case study from the Gaza Strip, Palestine. *Arab J Geosci*. 2015 Sep;8:7499–513.
- [17] Marks LA, Dunn EG, Keller JM, Godsey LD. Multiple criteria decision making (MCDM) using fuzzy logic: an innovative approach to sustainable agriculture. In *Proceedings of 3rd International Symposium on Uncertainty Modeling and Analysis and Annual Conference of the North American Fuzzy Information Processing Society*. IEEE; 1995. p. 503–8.
- [18] Eastman JR. *IDRISI Kilimanjaro: guide to GIS and image processing*. Idrisi Production, Clark University; 2003.
- [19] Pawlus W, Karimi H, Robbersmyr K. A fuzzy logic approach to modeling a vehicle crash test. *Open Eng*. 2013 Mar;3(1):67–79.