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Raid Mahmood FAISAL, Mohammed Fakhraldeen AHMED
College of Environmental Sciences and Technology, Mosul University

GIS and AHP based modeling for landfill site selection (case study: west side of Mosul city)

Key words: GIS, Solid waste landfill, AHP, optimality

Introduction

In spite of the municipal management efforts, large quantities of solid waste accumulate each day in Mosul city and causes a real problem. The reasons of this problem are: firstly, most of collection vehicles became out of service as a result of aging; secondly, the huge people migration from villages to the city; thirdly, most of current dumps were randomly selected within the city boundaries; finally, the absence of real effort to use scientific plans to select a suitable landfill site complying with national standards. For all these reasons, a planned municipal landfill for Mosul city becomes enormously needed.

There are few researches to select the optimal landfill site within Iraq, for example, Chabuk, Al-Ansari, Hassain and Knutsson (2017) attempted to determine a suitable landfill site for Al-Musayiab Qadhaa, Babylon. They used two methods to derive weights for criterion map on GIS, AHP and simple additive weighting (SAW). Two of candidates' sites were identified for landfill site selection in the final map.

Worldwide attempts for landfill site selection were numerous, for example, Isalou, Zamani, Shahmoradi and Alizadeh (2012) attempted to locate a suitable place to dispose the municipal solid wastes hygienically in Kahak town, Qom, Iran. They designed a model that can be applied in site selection for solid waste landfill by using fuzzy logic and analysis network process (ANP).

Kirimi and Waithaka (2014) developed landfill site selection method by employing GIS and AHP technique for evaluating the suitability for landfill site selection in Nakuru town in Kenya. Through integrating GIS with AHP, a final suitability map was drawn with eleven candidate sites ranked from the most to the least suitable site.

Rahmat et al. (2016) used GIS and AHP technique to select the suitable solid waste landfill site for Behbahan, Iran. They used SAW method to evaluate landfill suitability index. The results showed that five sites within the region under study were suitable for landfilling.

This study aims at designing a model to determine the optimal solid waste landfill site using GIS and AHP technique at west side of Mosul city.

Materials and methods

Study area

The study area is located at west side of Mosul city. The study area contains different agricultural and industrial sites surrounding the outer municipal boundary of city center. It lies approximately between longitudes 42°52′54″ E and 43°11′51″ E, while latitudes 36°11′57″ N and 36°24′21″ N. Total study area is 1,646 km^2 as in Figure 1.

Data analysis

A group of base maps including satellite imagery and district maps are utilized to derive the used variables. A number of tabulated and statistical data are used such as climate, population and groundwater data. A database is built utilizing the used variables with input map data as in Table 1.

The studied data can be classified according to specified processing method into two types: the first type is discrete data which includes the following variables (transportation routes, airport, residential sections, pipelines, power lines, river, villages, military base), as in Figure 2. The second type is continuous data which includes certain variables (soil, geological information, land use, slope, topography, groundwater depth, wind direction), as in Figure 3.

TABLE 1. Input map data

No	Data	Objects
1	WorldView-2 satellite image gallery high-resolution 30 cm, for Mosul city, 2016	Roads and power lines
2	Topographic maps scale 1 : 100 000 for Mosul, Iraq, 1989	Villages, pipelines
3	Landsat 7, ETM+, raw path (170, 35), 2014	Land use
4	Residential sections map of Mosul city, 2012	Residential sections
5	Districts map of Mosul (the agricultural districts), 2009	Location
6	Geological map (Mosul), scale 1 : 250 000, 1995	Geological
7	Soil condition in Iraq, Ministry of Agriculture (Buringh, 1961)	Soil
8	Raster Dem 30 m ASTGTM_N36E043, ASTGTM_N36E042	Slope, elevation, stream
9	Data of meteorological stations – Iraq, 1992–2012	Wind direction
10	Wells data – Iraq, 2014	Groundwater depth and wells locations
11	Iraqi Ministry of Planning, 2007	Statistical data

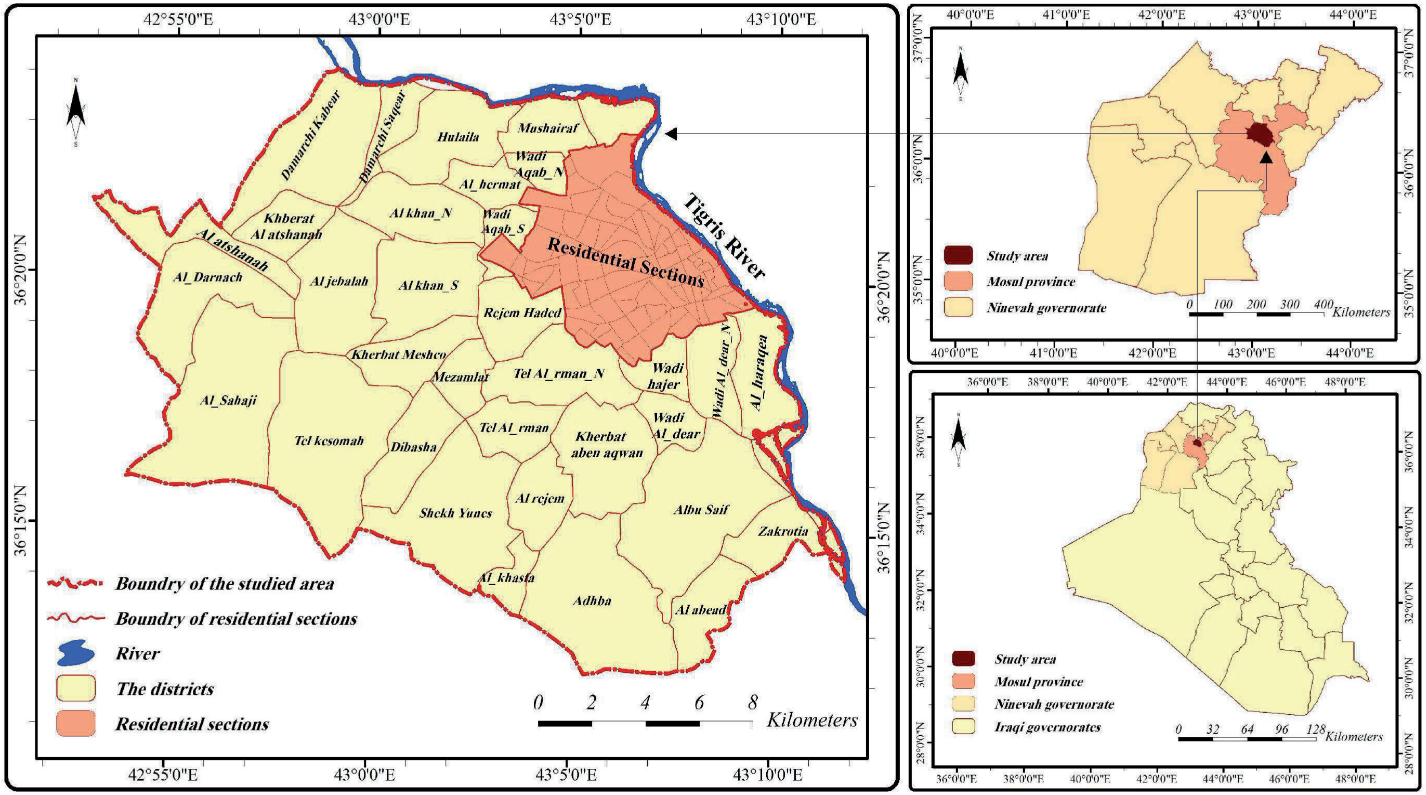

FIGURE 1. Map of the studied area

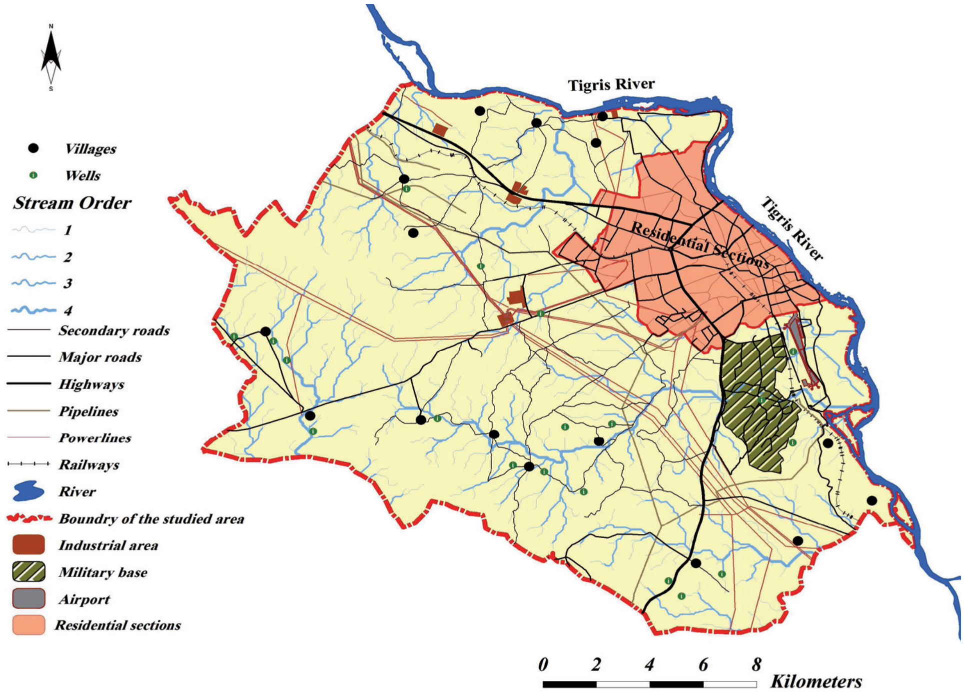

FIGURE 2. Discrete data variables map

Methodology

Geographic information system (GIS)

ARC GIS 10.2.2 software was is used in this study to create a proper model through applying multiple variables.

Analytical hierarchical process (AHP)

The AHP is a technique used to derive priority weights through pair wise comparisons (Saaty, 1980, 2008). The AHP has been used on three main stages. Firstly, developing a systematic hierarchy of extracted variables. Secondly, the compared pair wise matrix is applied by setting the variables, and these variables are analyzed to develop a series of relative weights, as in Table 2. Finally, the consistency ratio (CR) is calculated to determine the accuracy of weighting. In case of the CR's value is ≤ 0.1, the weighting is accurate; if not, the variables' relative weights must be re-weighted. Pair wise comparison matrix for selecting variables and its CR is listed in Table 3. Super Decision SD software 20.8 is an extension of AHP

TABLE 2. Scale of relative importance for pair wise comparison (Satty, 1980, 2008)

importance	Definition
1	equal importance
2	equal to moderately importance
3	moderate importance
4	moderate to strong importance
5	strong importance
6	strong to very strong importance
7	very strong importance
8	very to extremely strong importance
9	extreme importance

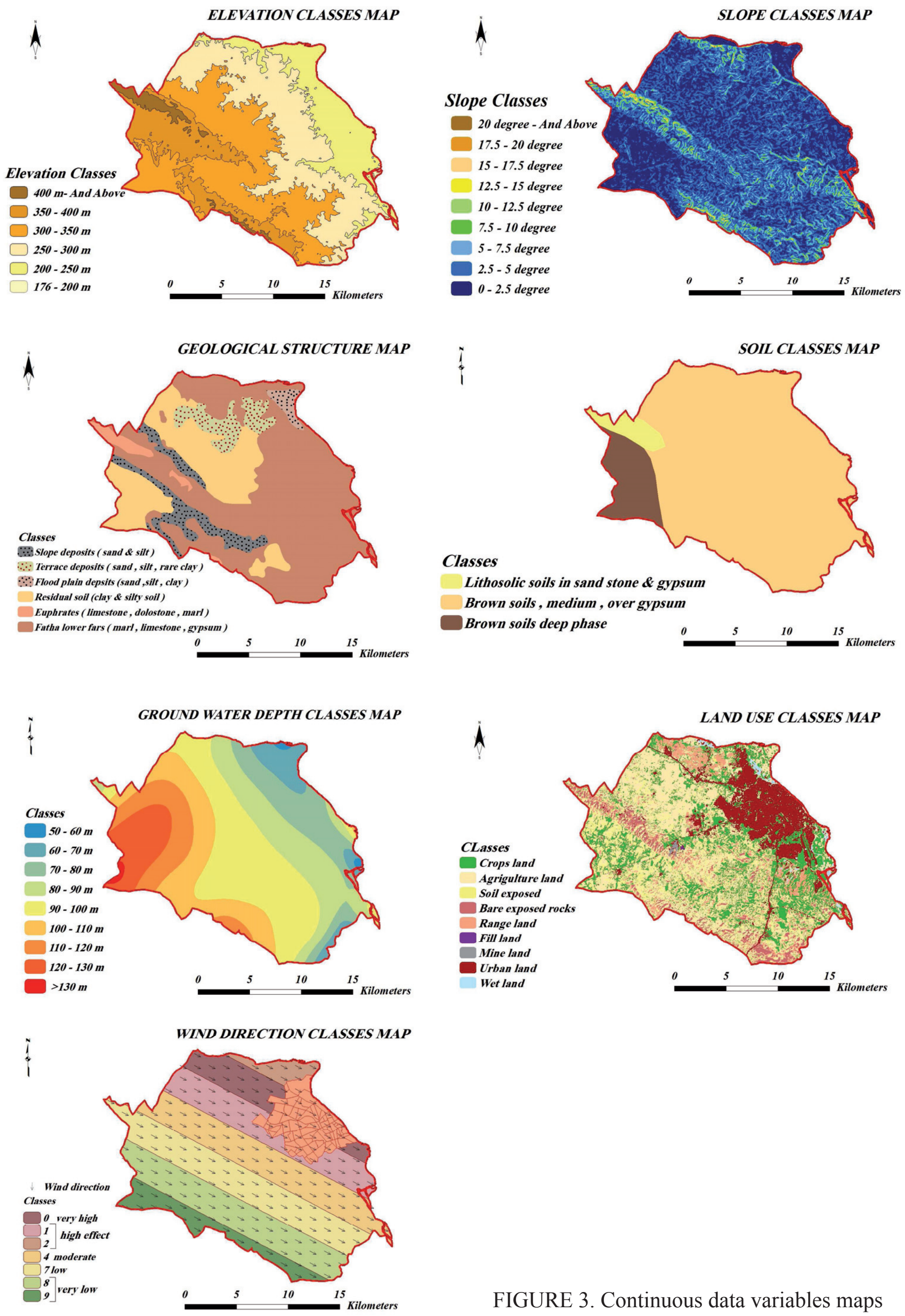

FIGURE 3. Continuous data variables maps

technique used to simplify the weight calculations, as in Table 4. This extension has the ability to analyze a problem into its elements (Kirytopoulos, Voulgaridou & Rokou, 2011).

Landfill required area

It is necessary to have a sufficient landfill area to cover the total solid waste enough for at least five years (Tchobanoglous, Theisen & Eliassen, 2007). Therefore, it is obligatory to have an estimation of the expected future population increasing rate and the average daily solid waste generation. The following formula is used to estimate the population of west side of Mosul city in 2017 based on the reference data taken from (Iraqi Ministry of Planning, 2007): $P_f = P_o (1 + r)^n$, where: n is number of years; P_o is population in 2007 which was estimated as 423,241 citizens; P_f is popula-

TABLE 3. Pair wise comparison matrix for selecting suitable landfill site

Factors	Residential sections	Highways	Water depth	Major roads	Secondary roads	Railway	Villages	Land use	Streams	River	Wells	Slope	Elevation	Wind direction	Soil	Geological	Airport	Military base	Industrial area	Power lines	Pipelines
Residential sections	1	2	3	3	7	9	6	2	5	6	6	2	5	2	3	3	6	9	9	8	6
Highways	0.5	1	2	2	4	7	3	0.5	3	2	3	1	2	1	1	2	3	7	7	8	4
Water depth	0.33	0.5	1	1	3	5	2	5	2	3	3	0.5	3	1	1	2	2	5	6	4	3
Major roads	0.33	0.5	1	1	3	5	2	0.33	2	2	3	0.5	2	0.5	1	1	2	5	6	4	3
Secondary roads	0.142	0.25	0.33	0.33	1	2	1	0.12	0.5	0.5	1	0.2	0.5	0.25	0.33	0.5	1	2	3	2	0.5
Railway	0.111	0.14	0.2	0.2	0.5	1	0.33	0.11	0.33	0.5	0.5	0.11	0.33	0.14	0.16	0.2	0.33	1	1	1	0.333
Villages	0.167	0.33	0.5	0.5	1	3	1	0.2	1	1	2	0.33	1	0.33	0.5	0.5	1	3	3	2	1
Land use	0.5	2	2	3	8	9	5	1	5	6	6	2	4	2	2	3	4	9	9	9	6
Streams	0.2	0.33	0.5	0.5	2	3	1	0.2	1	1	2	0.33	1	0.33	0.5	0.5	1	3	4	3	2
River	0.167	0.5	0.33	0.5	2	2	1	0.16	1	1	2	0.33	1	0.33	0.5	0.5	1	3	4	3	2
Wells	0.167	0.33	0.33	0.33	1	2	0.5	0.16	0.5	0.5	1	0.2	0.5	0.25	0.33	0.33	0.5	2	3	2	1
Slope	0.5	1	2	2	5	9	3	0.5	3	3	5	1	3	1	2	2	3	9	9	8	5
Elevation	0.2	0.5	0.33	0.5	2	3	1	0.25	1	1	2	0.33	1	0.33	0.33	0.5	1	3	4	2	1
Wind direction	0.5	1	1	2	4	7	3	0.5	3	3	4	1	3	1	1	2	3	7	8	6	4
Soil	0.33	1	1	1	3	6	2	0.5	2	2	3	0.5	3	1	1	2	2	6	6	5	2
Geological	0.33	0.5	0.5	1	2	5	2	0.33	2	2	3	0.5	2	0.5	0.5	1	2	5	5	5	2
Airport	0.167	0.33	0.5	0.5	1	3	1	0.25	1	1	2	0.33	1	0.33	0.5	0.5	1	3	3	2	1
Military base	0.111	0.14	0.2	0.2	0.5	1	0.33	0.11	0.33	0.33	0.5	0.11	0.33	0.14	0.16	0.2	0.33	1	1	0.5	0.33
Industrial area	0.11	0.14	0.16	0.16	0.33	1	0.33	0.11	0.25	0.25	0.33	0.11	0.25	0.12	0.16	0.2	0.33	1	1	0.5	0.33
Power lines	0.125	0.12	0.25	0.25	0.5	1	0.5	0.11	0.33	0.33	0.5	0.12	0.5	0.16	0.2	0.2	0.5	2	2	1	0.5
Pipelines	0.167	0.25	0.33	0.33	2	3	1	0.16	0.5	0.5	1	0.2	1	0.25	0.5	0.5	1	3	3	2	1

Consistency ratio = 0.01057.

TABLE 4. Variable buffer zones (Iraqi Environmental Legislation, 2011) and AHP extracted weights

No	Variable	Buffer zones	*R*	AHP weight	No	Variable	Buffer zones	*R*	AHP weight
1	Residential distance	0–4 000 m	0	0.147369	9	Streams	0–350 m	0	0.030793
		4 000–5 000 m	9				> 350 m	9	
		5 000–6 000 m	8		10	River	0–2 000 m	0	0.030006
		6 000–7 000 m	7				> 2 000 m	9	
		7 000–8 000 m	6		11	Wells	0–350 m	0	0.019411
		8 000–9 000 m	5				> 350 m	9	
		9 000–10 000 m	4		12	Slope	0–2.5°	9	0.091454
2	Highways	0–1 000 m	0	0.079151			2.5–5°	7	
		1 000–2 000 m	9				5–7.5°	6	
		2 000–3 000 m	6				7.5–10°	4	
		3 000–4 000 m	3				10–12.5°	3	
		> 4 000 m	1				12.5–15°	2	
3	Water depth	50–60 m	1	0.06065			> 15°	0	
		70–60 m	2				0–2.5°	9	
		80–70 m	3				2.5–5°	7	
		90–80 m	4		13	Elevation	176–200 m	9	0.029048
		100–90 m	5				200–250 m	7	
		110–100 m	6				250–300 m	6	
		120–110 m	7				300–350 m	4	
		130–120 m	8				350–400 m	2	
		> 130 m	9				400–485 m	0	
4	Major roads (R1)	0–500 m	0	0.0528	14	Wind	High effect	2	0.079223
		500–1 000 m	9				Middle effect	4	
		1 000–1 500 m	7				Middle effect	5	
		1 500–2 000 m	5		15	Soil	S1	5	0.061559
		2 000–2 500 m	3				S2	7	
		> 2 500 m	2				S3	9	
5	Secondary roads (R2)	0–100 m	0	0.019798	16	Geological	G1	2	0.048073
		100–200 m	9				G2	9	
		200–300 m	7				G3	4	
		300–400 m	5				G4	6	
		400–500 m	3		17	Airport	0–1 500 m	0	0.027795
		> 500 m	2				> 1 500 m	9	
6	Railways	0–500 m	0	0.010736	18	Military base	0–1 000 m	0	0.010203
		> 500 m	9				> 1 000 m	9	

TABLE 4, cont.

No	Variable	Buffer zones	*R*	AHP weight	No	Variable	Buffer zones	*R*	AHP weight
7	Villages	0–1 000 m	0	0.02753	19	Industrial area	0–500 m	0	0.009306
		> 1 000 m	9				> 500 m	9	
8	Land use	Urban	0	0.128512	20	Power lines	0–100 m	0	0.012792
		Mine land	0				> 100 m	9	
		Crops	4		21	Pipe lines	0–100 m	0	0.023826
		Agriculture land	5				> 100 m	9	
		Range land	7		×				
		Bare exposed rocks	9						

S1 – Lithosolic Soils in Sand Stone & Gypsum, S2 – Brown Soils, Medium, over Gypsum, S3 – Brown Soils Deep Phase, G1– Slope Deposits & Terrace Deposits, G2 – Residual Soil (Clay & Silt), G3 – Fatha Lower Fares (Marl, Limestone, Gypsum), G4 – Euphrates (Limestone, Dolostone, Marl).

tion in 2017, population growth rate (*r*) was (3.2%), based on estimates of Directorate of Municipal in Nineveh (2009). The population number is 579,943 citizens in 2017.

The yearly accumulative weight of solid waste is calculated based on the population (579,943 citizens) multiplied by solid waste generation (0.61 $kg \cdot capita^{-1} \cdot day^{-1}$) (Al-Rawi & Al-Tayar, 2012). The compacted density of solid waste in landfill is 450 $kg \cdot m^{-3}$ (Al-Anbari, Kadum & Taha 2008).

The yearly accumulative volume of solid waste is calculated by dividing the total weight by compacted solid waste density. The resulted calculated area is extracted by dividing the total accumulative volume by the depth lift (3 m). Then, the required area is computed by multiplying the calculated area by 1.4 factor (Tchobanoglous et al., 2007). The final required area is 133,907 m^2 for one year. For five years the required area is 669,535 m^2.

Drawing the ranking and final map

Based on the collected data, buffer zones of each variable are derived and then converted into a thematic map. The ranking map has been created after multiplying each variable with its extracted weight. The degree of suitability for the ranking map is divided into a number of ranks according to the relative importance to the candidate sites starting from the least importance to the highest importance, as in Figure 4. The final map has been created by converting the highest value obtained from the ranking map from raster to vector format and calculating the optimal landfill site area, as in Figure 5.

Model building

The model has been built through applying ArcGIS 10.2.2 software tools. These tools are arranged as follows: ras-

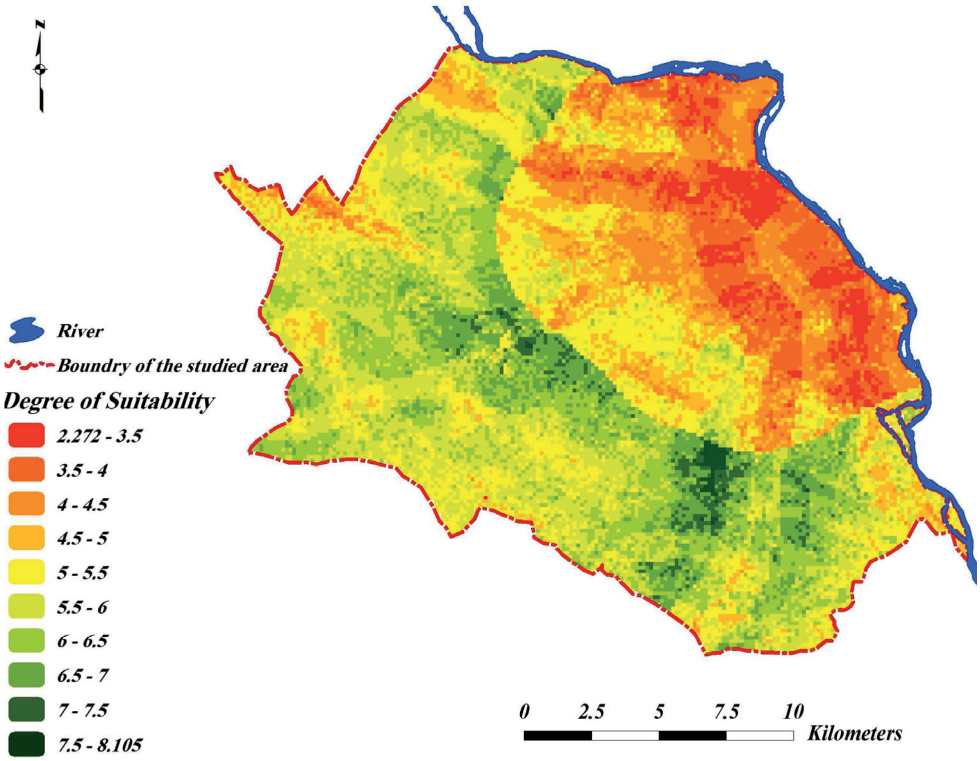

FIGURE 4. Ranking of weighted variables map

terization converts the vector format to raster format. Euclidean distance gives the distance for discrete data from each cell in the raster to the closest source, noting that this tool is only used with raster format. Reclassification tool is used to reclassify each variable into classes according to environmental standard scale which produces a new layer, and this layer can be used to generate data to be processed by map algebra. Raster calculator is used to perform geographic analysis as raster data processed in Arc GIS 10.2.2. Other supporting tools are used to derive a number of variables such as (hydrology tools analysis and geostastical analysis) to generate wind directions and underground water depth, as in Figure 6.

Results

According to Iraqi Environmental Legislation (2011) accompanied with economical factors, a variety of variables have been used with their extracted weights for landfill sites. The most important variables are the distance to residential sections, the group of transportation roads and land use, come in the first order. A group of variables with medium importance come in the second order, such as slope, groundwater depth, soil

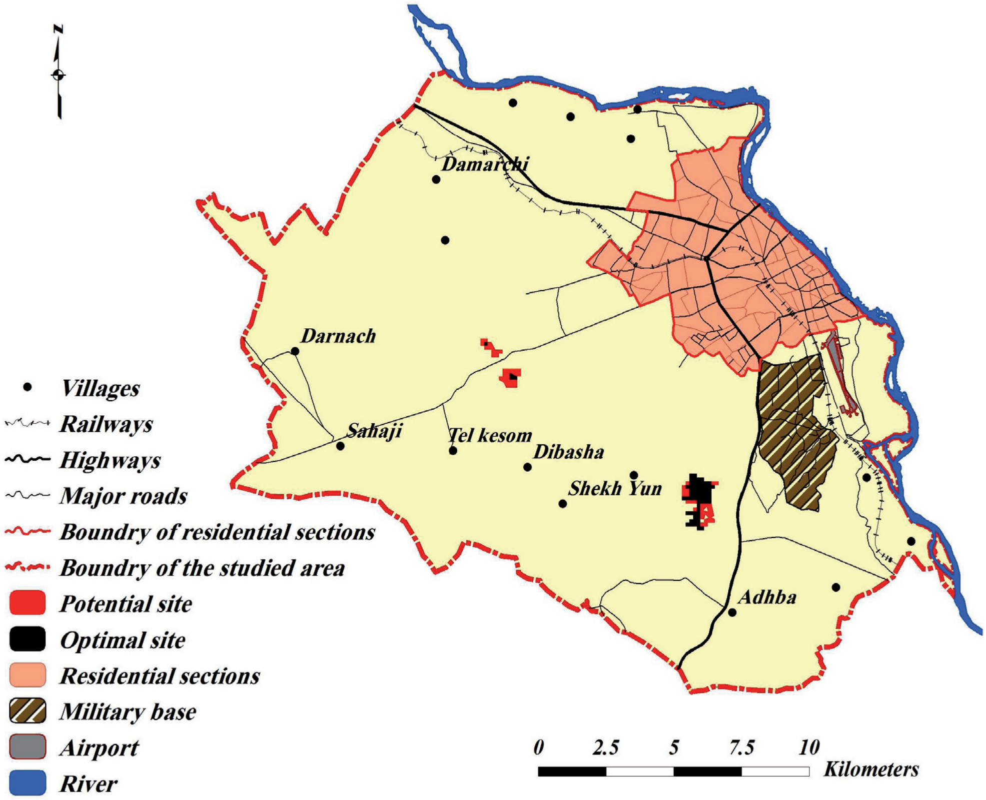

FIGURE 5. The final map

type and geological structure. The rest of the variables take the lowest order.

The study is based on building a model using GIS and AHP technique to extract the weights through applying Super Decision SD software to draw the final map for the optimal landfill site. The optimal site is situated to the south-west of the west side of Mosul city with longitude as 43°5′25″ and latitude as 36°15′ 52″, and the total area is 1,114,303 m^2. While the other site comes in the second rank, noting that it consists of two sections, the first section surrounds the first site (531,652 m^2) which is sufficient for extra future four years of expansion, and the second section is located at the west of the city with longitude as 43°0′43″ and latitude as 36°8′12″ with an area of 408,159 m^2 and sufficient for future three years of expansion. The second section is useful for future expansion plans for the optimal site, and it is near the current dumping site.

Conclusions

This study attempts to locate the optimal solid waste landfill site in the west side of Mosul city. A number of variables are

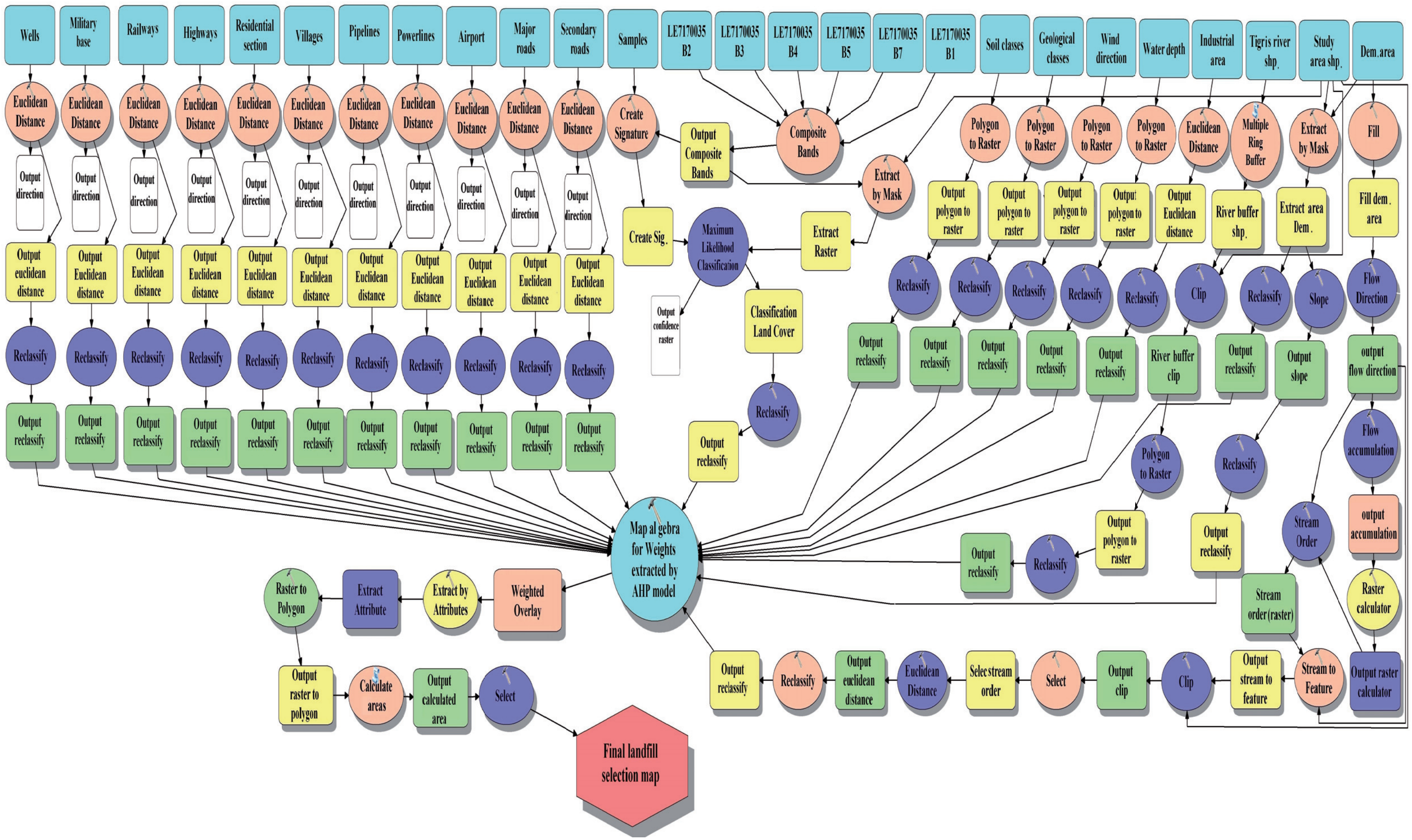

FIGURE 6. The hierarchy of the model

used and obtained in GIS. AHP technique is used to determine the relative weights of variables. The results show that among the studied variables, the distance to residential sections, the group of transportation roads and land use are the most essential variables. The optimal site has an area of 1,114,303 m^2 and is sufficient for eight years and enough for one lift.

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Summary

GIS and AHP based modeling for landfill site selection (case study: west side of Mosul city). The accumulation of large quantities of solid waste inside Mosul city becomes a real residential and municipal management problem. There are many reasons including the existence of unplanned dumping sites within the city boundaries, and the absence of scientific researches which applies modern techniques for selecting the optimal solid waste landfill. This study uses geographic information system (GIS) and analytic hierarchical process (AHP) which is used to extract the weights with the help of Super Decision SD software. The studied variables data can be classified according to specified processing method into two types: continuous data, and discrete data. The ranking map has been designed after multiplying each variable with its extracted weight, then the final map has been created based on the values obtained from the ranking map. The results show that the optimal landfill area is located at south west Mosul city. This study aims at building a model by using GIS to determine the optimal and potential solid waste landfill site.

Authors' address:
Raid Mahmood Faisal Al-Moula
Mohammed Fakhraldeen Ahmed
Mosul University – IRAQ
College of Environmental Sciences
and Technology
e-mail: raidalfaisal2017@yahoo.com
mfakher1962@gmail.com