Sustainable Geographic Information System-Based Map for Suitable Landfill Sites in Aley and Chouf, Lebanon

Allaw Kamel, Bazzi Hasan

Abstract**—**Municipal solid waste (MSW) generation is among the most significant sources which threaten the global environmental health. Solid Waste Management has been an important environmental problem in developing countries because of the difficulties in finding sustainable solutions for solid wastes. Therefore, more efforts are needed to be implemented to overcome this problem. Lebanon has suffered a severe solid waste management problem in 2015, and a new landfill site was proposed to solve the existing problem. The study aims to identify and locate the most suitable area to construct a landfill taking into consideration the sustainable development to overcome the present situation and protect the future demands. Throughout the article, a landfill site selection methodology was discussed using Geographic Information System (GIS) and Multi Criteria Decision Analysis (MCDA). Several environmental, economic and social factors were taken as criterion for selection of a landfill. Soil, geology, and LUC (Land Use and Land Cover) indices with the Sustainable Development Index were main inputs to create the final map of Environmentally Sensitive Area (ESA) for landfill site. Different factors were determined to define each index. Input data of each factor was managed, visualized and analyzed using GIS. GIS was used as an important tool to identify suitable areas for landfill. Spatial Analysis (SA), Analysis and Management GIS tools were implemented to produce input maps capable of identifying suitable areas related to each index. Weight has been assigned to each factor in the same index, and the main weights were assigned to each index used. The combination of the different indices map generates the final output map of ESA. The output map was reclassified into three suitability classes of low, moderate, and high suitability. Results showed different locations suitable for the construction of a landfill. Results also reflected the importance of GIS and MCDA in helping decision makers finding a solution of solid wastes by a sanitary landfill.

Keywords—Sustainable development, landfill, municipal solid waste, geographic information system, GIS, multi criteria decision analysis, environmentally sensitive area.

I. Introduction

WASTE production is linked to human activities, lifestyles and environmental awareness. Rapid urbanization, increasing consumption and limited environmental awareness have a cumulative effect on waste generation [1]. Municipalities' waste is formed from different sources starting from houses, trading, and many other public institutions [2]. Municipal wastes are collected by the interest of municipal authorities, and they get rid of them by the waste management system [2].

As defined by the Unite74d States Environmental Protection Agency (USEPA), the materials that are not considered as MSW include construction and diemolition materials, municipal wastewater treatment sludge, and non-hazardous industrial wastes, otherwise materials known as trash or garbage are known as MSW.

Solid wastes have hazardous effects on both environment and human health. Improper MSW disposal and management causes all types of pollution: air, soil, and water. The U.S. Public Health Service identified 22 human diseases that are linked to improper MSW management [3]. Solid waste management remains an important worldwide environmental task. Proper solid waste management techniques should be implemented to avoid the transmission of infectious diseases and prevent the contamination of various environmental resources. Several methods and techniques are used such as recycling, compositing and landfilling. According to the USEPA, integrated waste management consists of a hierarchy of four components involving, in order of preference, source reduction, recycling, combustion with energy recovery, and disposal through landfilling.

With a population of 5.6 million people in 2013, Lebanon produces 2,040,000 tons of MSW per year [4]. The MSW generation per capita varies from around 0.85 kg/person/day in rural areas to around 0.95 to 1.2 kg/person/day in urban areas, according to waste management data obtained from the Ministry of Environment (MOE) as well as studies undertaken in Lebanon. The foreseen increase in waste generation is estimated at an average of 1.65% across the country; this growth is however highly unevenly distributed. Almost all of the MSW generated in Lebanon is collected by public or private haulers (99% in rural areas, 100% in urban); however, management varies from one area to another: 8% is recycled, 15% is composted (several treatment plants already constructed will be put in operation soon, hence increasing percentage), 51% is landfilled and 26% is disposed of in open dumps [4]. A study conducted by the World Bank [5] on the state of environmental degradation in Lebanon, quantified the cost of degradation caused by pollution from illegal dumping and waste burning to be around $10 Million per year, and rising. Outside Great Beirut Area (GBA), municipalities and federations are responsible for the collection, treatment and disposal of municipal waste and assume all related costs [5].

Within summer 2015, Lebanon has suffered a crucial solid

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waste management problem. For eight months, Lebanon and especially Great Beirut and Governorate of Mount Lebanon had no solution to manage solid wastes except leaving them stacked on the road side [6]. The existing landfills were closed due to environmental and political problems. The proposed solution by the Lebanese government was to construct a new landfill. Although managing solid wastes using landfills is not the most appropriate way for waste management, it is still an important solution in Lebanon. As a developing country, Lebanon suffers from many political problems, making it difficult to find better waste management solutions. Solid waste management solutions require a long-term vision and a political and collective commitment. To date, in the absence of both, the Government of Lebanon (GOL) has adopted emergency response procedures. In addition, most Lebanese companies are not familiar with recycling strategies (known as "waste sorting"), making these advanced solutions more difficult. In the absence of serious and sustainable environmental education programs in schools, universities and the media, people tend to consume relentlessly, reuse less, and throw more [1]. For these reasons, the choice of a landfill as a solution for the existing problem seems to be the most acceptable solution in Lebanon. Choosing landfilling as a solution is much better than stacking wastes on the road side. Even though this is not the best environmental solution, but it is a way to have management more friendlily with the environment. In this way, we are trying to save the Lebanese environment with least negative consequences. Also, when locating a landfill, the sustainable development part existed to create a landfill that serves for present and future demands.

Landfill site selection is a serious problem in urban and rural areas due to the dangerous impacts of the landfill on the ecology, environmental health, and economy of the area. The selection of the landfill site should be controlled by several factors and criterion that identify the most suitable places for a landfill. Several indices were defined to determine suitability factor and sustainable development had an important part in the selection process. This selection is managed by several data being mapped and organized using GIS to get an output showing different suitability classes. The process of Landfill site selection will be accomplished on Aley and Chouf Districts, two districts of Mount Lebanon Governorate, and currently suffering from a severe waste management problem.

II. Study Area

Aley and Chouf are two neighbour districts of the six districts of Mount Lebanon Governorate. The area stretches from the Mediterranean coast west, reaching the peaks of Barouk Mountains at the east (2000 m). Located between 35°24'(E) and 35°44'(E) longitudes and 33°30'(N) and 33°50'(N) latitudes Aley and Chouf covers an area of 758 km^2 (Chouf 495 km^2, Aley 263 km^2) consisting of total 169 village (97 village in Chouf, 72 village in Aley) and forming 7.2% of Lebanon total area. Altitudes in the area range between few meters on the coastal line and 2000 m at the Barouk Mountains. The area has a rainfall average widely ranging between 600 and 1400 mm due to different climatic areas in the zone. The total population is estimated at 310000 inhabitants (Aley 135000, Chouf 175000) forming approximately 7% of the Lebanese population.

The study area is crossed by Al-Awali River and Al-Damour River both originating from the Barouk and Niha Mountains flowing westward to the Mediterranean Sea. The eastern part of the area contains part of Al Chouf Cedar Reserve located on the slope of Barouk Mountains. Al Chouf Cedar Reserve is one of the largest natural reserves in Lebanon and most popular destination for tourists. Both Aley and Chouf contain important touristic sites.

The two districts are suffering now from the waste management problem, and authorities in the region are using an improper open dumpsite as a partial solution waiting for the construction of a new landfill.

III. Methodology

A. Principle

GIS is capable of providing SA including manipulating and analyzing geo-referenced digital form maps. Site selection or suitability analysis is a type of analysis used in GIS to determine the best place or site for a project. The research methodology is based on using different GIS SA tool integrated with multi criteria analysis to produce a landfill siting in the study area. The selection of a landfill site has been done by many researchers around the world, such as [7]-[11]. Moreover, the chosen factors were different depending on the study area. Thus, several factors have been first identified, based on the study area analysis, which defines the four main indices: Soil Index, Geology Index, LUC Index, and Sustainable Development Index. Indices defined manage several impacts a landfill can cause and especially takes into consideration the sustainable development sector which is important for future demands. Each factor has been classified into different classes according to the suitability range. The value 0 was given for the unsuitable class, and different values were given to different suitability classes ranging from least suitable, suitable to most suitable. Factors of each index were weighted according to their relative importance. The indices were then given different weights reflecting the importance of each index. The intersection of different factors related to the same index produces the suitability map relative to this index. The Simple Additive Weighting (SAW) method in (1) was used to calculate the suitability value of each area. This method can be considered as an efficient method and most commonly used in creating maps for suitable landfill sites; it has been used by [11]-[14] and Weighted Linear Combination (WLC) was used by [9]. Based on the analysis of these bibliographies, it was observed that the study area in Aley and Chouf resembles, to a great extent, the study areas of the referenced bibliography, thus the SAW method was chosen to be applied on our study area. Each index map was then classified into four classes; unsuitable, low, moderate, and high. A final intersection of the four index maps was done. The implementation of SAW in (1) also showed regions having different suitability values. The produced values were reclassified to get four major classes: unsuitable, low suitability, moderate suitability, and high suitability.

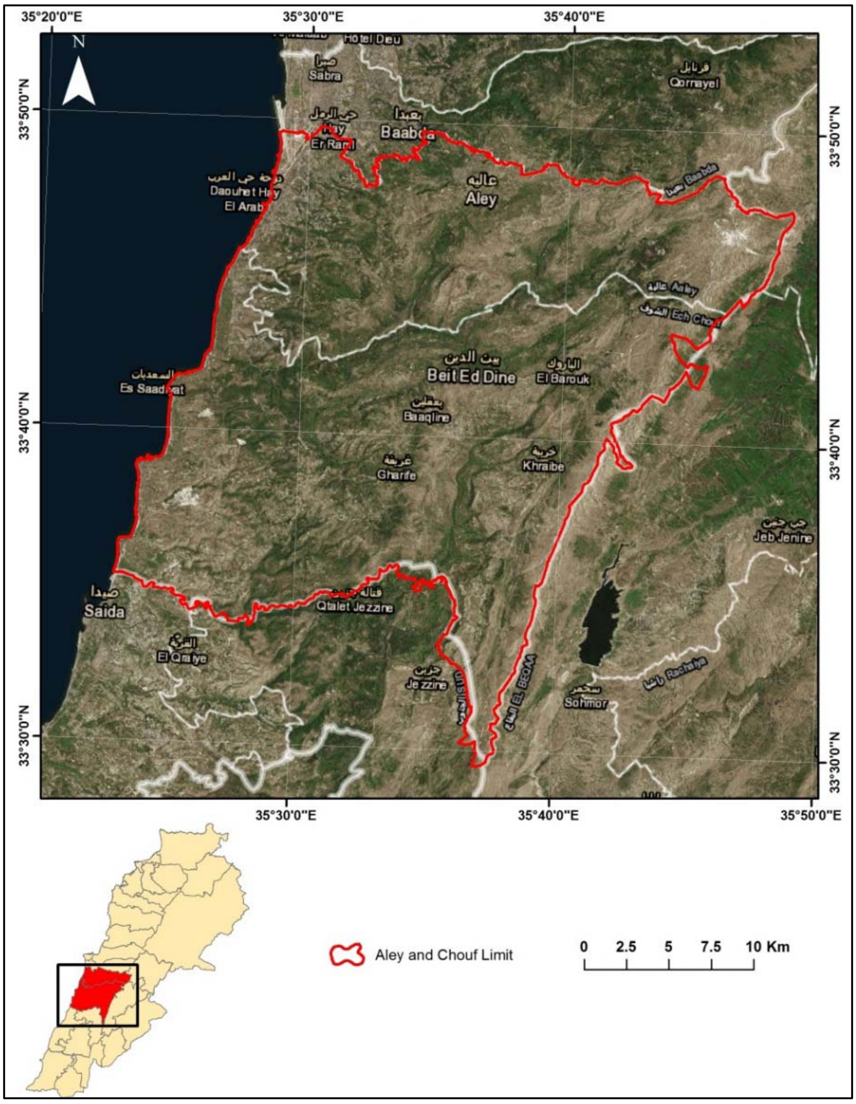

Fig. 1 Location of the study area

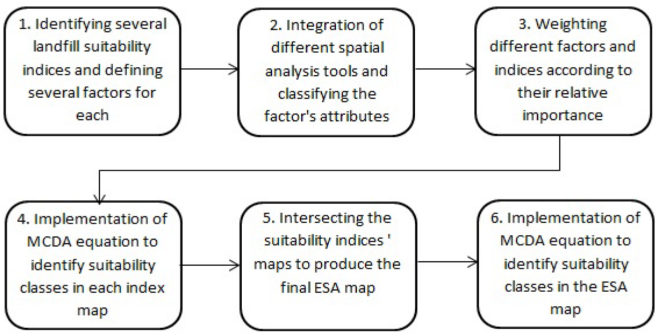

Fig. 2 Landfill selection process guide

B. Data and Methods

Several factors are implemented in the selection criteria to obtain the optimum results. In planning, landfill site selection occupies extremely important place. It has been widely mentioned in literature that the landfill site selection is mainly affected by environmental, economic, and social factors [11], [13], [14]. Based on the analysis of the study area with its natural, social and economic features that exists, and taking into consideration the sustainable development, 13 factors were extracted and classified into four main indices to generate the final output map. Soil, Geology, LUC and Sustainable Development were chosen as indices defining the ESA related to landfill site. Fig. 3 shows the main indices with their relative factors. Full classification of the defined factors and indices with their contributing weights is shown in Table I.

Slope: Ground slope is an important environmental factor for landfill siting. A too steep slope would make it difficult to construct and maintain the stability of wastes, and a too flat slope would affect the runoff drainage. High slopes can favor leachate drainage to flat areas and water bodies and cause contamination [7], [14]. Also, economically very steep slopes bring higher excavation costs. There are many suggestions about slope, and areas with slopes greater than 15° should be avoided for a landfill site. According to [15], the appropriate slope for constructing a landfill is about 8-12%. Therefore, areas with high slope are considered unsuitable for landfill sites. The slope map was generated from DEM (Digital Elevation Model) created using 50 m contour lines of the study area. Contour map is taken from SDATL (Schéma Directeur d'Aménagement du Territoire du Liban) at a scale 1:10,000. The slope values ranged from 0° to 47°. The slope is then classified into four main classes according to [12] (Fig. 4).

Drainage: It is widely mentioned in literature that landfill sites should be located on the remote areas from surface water resources [7], [8], [16]. The landfill site should take into consideration the surrounding surface water. To avoid contamination of the surface water, the farther the site is, the more it is suitable for a landfill. Since the area is crossed by two main rivers, Al-Awali River and Al-Damour River, it was important to avoid being in an area that affects these two important rivers. The river map of scale 1:10,000 was taken from SDATL. Buffer zones of 300, 500 and 1000 meters were created and classified into four suitability classes [13] (Fig. 5).

Geological Transmissivity: Transmissivity is an important hydraulic property of aquifers and water-bearing materials. In common with permeability, transmissivity affords a notion about the water-bearing characteristics of hydrological bodies. The possibility of ground water abstraction is estimated by transmissivity values. Therefore, knowledge of transmissivity distribution helps us to draw important conclusions from hydrogeological studies, and for this reason, prevailing transmissivity values are often represented in hydrogeological maps [17]. The classification of transmissivity varies between high, moderate and low with small differences in their numeric values usually measured in meter square per sec. The geological transmissivity map of scale 1:10,000 was taken from SDATL. Three classes where classified. As the transmissivity decreases, the suitability increases. Values between 10^{-2} and 1 sq. m/sec are considered high and given low suitability, values ranging between 10^{-4}, and 10^{-3} sq. m/sec are moderate to low and are classified as suitable, and all the other values less than these ranges are considered of very low transmissivity and classified as most suitable (Fig. 6).

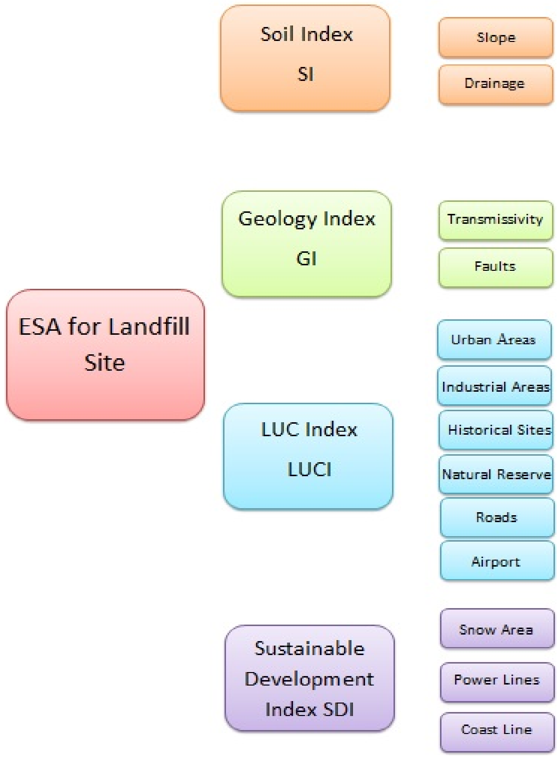

Fig. 3 Criteria of ESA for landfill site

Fault Lines: A landfill site must be away from fault lines; otherwise, the wastes can pollute the groundwater or damage the surrounding engineering structures in case of an earthquake [18]. Faults increase permeability of rocks so groundwater may be polluted with leachate of the landfill. Areas having no fault lines or at a safe distance from fault lines are considered suitable for landfill construction. A safety distance of 200 meters from fault lines is required [11]. Fault lines map was taken from SDATL of scale 1:10,000. Distance from faults and suitability of landfill are directly proportional. Areas within 200 meters of faults are classified as unsuitable (0). The suitability classes are then classified according to distances of 500 (1), 1000 (2) and >1000 (3) meters (Fig. 7).

Urban Areas: Landfill area should be located at a significant distance from settlement area. Due to the unfavorable odor and noise, a landfill should not exist in cities and villages. Also, to avoid the spread of diseases and contamination of the fresh water, the landfill should be sited at a distance from populated areas. According to [8], biggest cities over 200000 people may have a 5000-m buffer zone, while smaller cities over 1000 people may have 1000 m. A 1000-m distance from residential areas is generally considered unsuitable for allocating landfills [19]. The urban areas were extracted from Land Cover created by CNRS (National Council for Scientific Research - Lebanon) at a scale of 1:10,000. A buffer distance of 1000 meters was made and excluded as an unsuitable area for landfill siting. At a different area of study, the remained areas which are not excluded are classified according to their suitability, but since we are working with a much urbanized area, only two classes were identified, suitable and unsuitable by assigning values 3 and 0 respectively (Fig. 8).

Industrial Areas: As stated by [20], centers classified as private residences, businesses, social and community buildings should have a buffer of 250 meters. In general, being far away from an industrial area is not of a great importance for landfill site selection, but because of having industries producing food and medicine products it was important to obtain a safe distance. In fact, the study area contains many food, medicine and agricultural industries which should be protected in addition to the electrical power plant in Al Jiyeh-Chouf District. As stated by [20], a buffer distance of 100-500 meters around industrial areas (hazardous, manufacturing, food/agricultural) should be excluded. For this reason, a buffer distance of 250 meters was obtained around industrial areas. The layer was then classified into unsuitable and suitable by assigning values 3 and 0 respectively. The map of industrial areas was extracted from Land cover 2005 by CNRS-Lebanon at a scale of 1:10,000 (Fig. 9).

Historical Sites: Landfill sites should not be placed on a site close to historical or cultural sites [9], [10]. There are many cultural and historical sites that should be protected in Aley and Chouf District. Since these areas are considered touristic areas, a landfill should not be placed near any of these sites. This is done to avoid visual impact and other nuisances. USEPA also recommends a buffer of at least 500 m for cultural heritage sites. For these reasons, a buffer zone of 500 m was created around the historical and touristic sites in the area and defined as unsuitable (0) area for a landfill site. Historical site data were taken from SDATL maps of scale 1:10,000 (Fig. 10).

Natural Reserves: It is stated that landfill sites should not degrade natural ESA or areas of unique ecological aesthetic interest [7]. Considered as the largest natural cedar reserve in Lebanon, Al Chouf Cedar Reserve should not be damaged with a landfill site around it. Protecting this important environmental part, the natural reserve and a buffer zone of 500 meters were classified as unsuitable (0) for construction of a landfill according to [16]. The remaining part was classified as suitable (3). The natural reserve map was taken from SDATL maps of scale 1:10,000 (Fig. 11).

$$S = \sum W_i X_i \qquad (1)$$

where S=Suitability index, W_i = Weight of ith factor, X_i=Score of ith factor attribute.

Different weights are assigned to the factors. The determination of the weight is accomplished based on the consultation of scientists and professors (Table I).

TABLE I
CLASSIFICATION, RANKING, AND WEIGHTS OF INDICES AND FACTORS

	Index	Factor	Class	Rank	Suitability
ESA For Landfill Site	Soil Index SI [24%]	Slope (°) [40%]	0 – 5	3	Most Suitable
			6 – 10	2	Suitable
			11 – 15	1	Least Suitable
			> 15	0	Unsuitable
		Distance to Drainage (m) [60%]	0 – 300	0	Unsuitable
			300 – 500	1	Least Suitable
			500 – 1000	2	Suitable
			> 1000	3	Most Suitable
	Geology Index GI [30%]	Geological Transmissivity m^2/s [60%]	$10^{-2} < T < 1$	1	Least Suitable
			$10^{-4} < T < 10^{-3}$	2	Suitable
			Very Low $< 10^{-5}$	3	Most Suitable
		Distance to Faults (m) [40%]	0 – 200	0	Unsuitable
			200 – 500	1	Least Suitable
			500 – 1000	2	Suitable
			> 1000	3	Most Suitable
	LUC Index LUCI [30%]	Distance to Urban Areas (m) [30%]	0 – 1000	0	Unsuitable
			> 1000	3	Suitable
		Distance to Industrial Areas (m) [15%]	0 – 250	0	Unsuitable
			> 250	3	Suitable
		Distance to Natural Reserves (m) [22%]	0 – 500	0	Unsuitable
			<500	3	Suitable
		Distance to Historical Sites (m) [15%]	0 – 500	0	Unsuitable
			> 500	3	Suitable
		Distance to Roads (m) [9%]	0 – 100	0	Unsuitable
			100 – 500	3	Most Suitable
			500 – 1000	2	Suitable
			>1000	1	Least Suitable
		Distance to Airport (m) [9%]	0 – 3000	0	Unsuitable
			> 3000	3	Suitable
	Sustainable Development Index SDI [16%]	Snow [40%]	Heavy Snow Areas	0	Unsuitable
			Other	3	Suitable
		Coast Line [35%]	0 – 100	0	Unsuitable
			>100	3	Suitable
		Distance to Power Lines (m) [25%]	0 – 30	0	Unsuitable
			> 30	3	Suitable

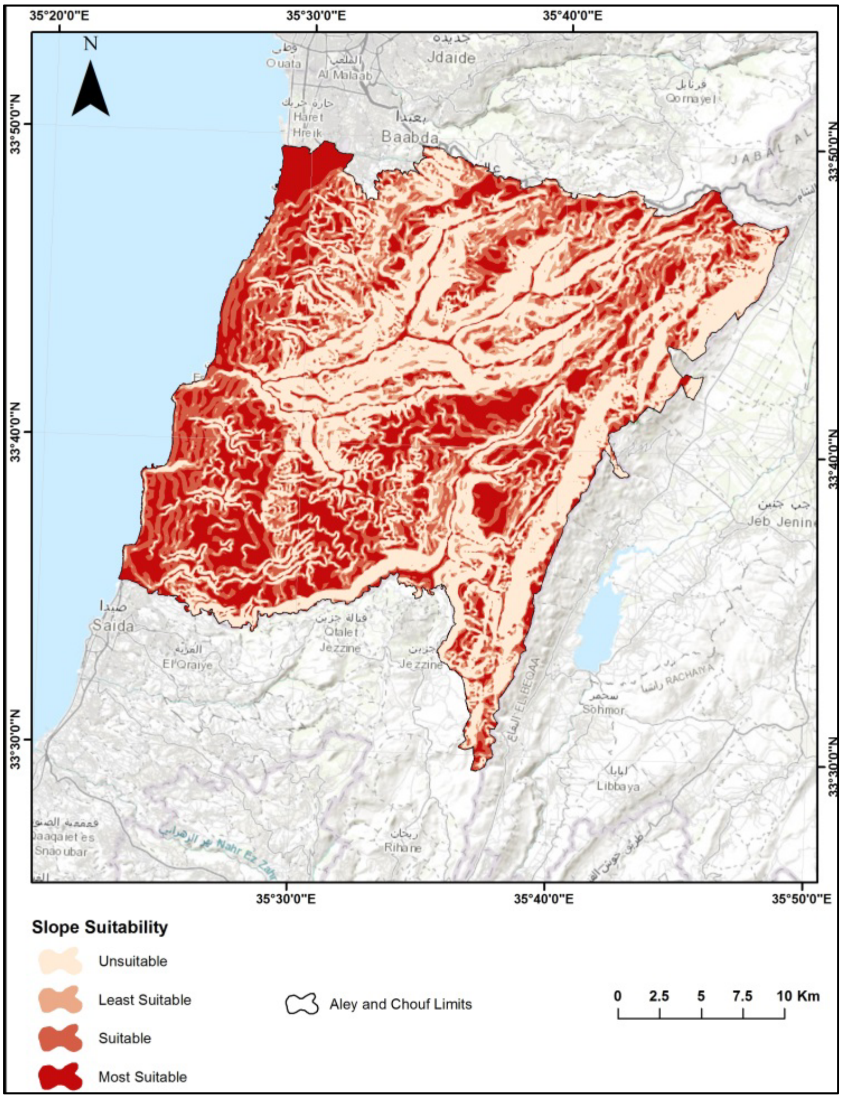

Fig. 4 Slope suitability map

Roads: The proximity to roads is another crucial criterion that must be considered for landfill site selection. Within economic perspective, it is suggested to use existing roads to avoid the high cost of constructing connection roads [10]. The Minimum distance from the network is imported in order to avoid visual impact and other nuisances. On the other hand, landfill should not exist far away from an existing road to facilitate transportation and consequently decrease the cost. Roads and 100 m around them should be applied as a buffer zone [21] The road map was taken from SDATL maps of scale 1:10,000. Three main buffer distances were created at 100, 500, and 1000 meters according to [12] and given values 1, 2, and 3 respectively (Fig. 12).

Airport: A safety distance from the airport should be taken for the landfill suitability. There are different values related to the safe distance from the airport for the landfill suitability as 3000 m according to [22], and 3048 m according to [23]. This distance is applied for the safety of airplanes while landing and taking off. Part of "Rafik Hariri International Airport" runways is located within the study area in Aley district. Airport runways map was taken from SDATL at a scale of 1:10,000. Considering all the suggested values for airport buffer, a distance of 3000 m was made as a buffer for "Rafik Hariri International Airport" and classified as unsuitable for landfill (Fig. 13).

Power Lines: The necessary buffer zone distance for electricity power lines according to [19] must be 30 meters on both sides to avoid defective infrastructure and all high voltage lines. An electrical power plant is located in Al-Jieh, and it is one of the important power generation plants in Lebanon, thus several power line connections exist within the area and should be protected to avoid any future problems such as fire risks. The power lines map was taken from SDATL at scale of 1:10,000, and a buffer of 30 meters was applied. The layer of power lines was classified as suitable or unsuitable for a landfill site by assigning values 3 and 0 respectively (Fig. 14).

Snow Areas: Barouk and Niha mountains, located in the eastern part of Aley and Chouf District, are considered the main source of water for Al-Awali and Al-Damour rivers.

Snow on these mountains remains until the end of March each year and is considered an important source of the groundwater. Also, it is not appropriate to locate a landfill in areas having permanent snow during winter season because this would affect the landfilling process and the transportation of wastes. Therefore, to protect these areas, any contamination of the groundwater should be avoided, and to insure a safe landfilling process, these areas were considered unsuitable for a landfill site as a sustainable development criterion. Snow areas were digitized from MODIS satellite imagery of resolution 500 m at a digitizing scale of 1:10,000 (Fig. 15).

Coastal Area: In order to avoid the pollution of the sea water, the coast line, extracted from the SDATL maps at scale 1:10,000 with a buffer distance of 100 meters, was considered as restricted areas for landfill site. Two landfills located on the Lebanese shore line, one located in Borj Hammoud-Beirut and the other is a dumpsite located in Saida-South Lebanon, damaged the coastal area and polluted sea water. To avoid falling in the same problem, the factor has been added as a sustainable development criterion (Fig. 16).

C. Implementation of Simple Additive Weighting Method

As discussed in 3.1, the Simple Additive Weighting method was used as multi attribute decision technique. A score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by decision maker followed by summing of the products for all criteria. The SAW was used in generating each index map taking the weight of each factor with its obtained score from several associated factors, as well as in producing the final map considering the index weight with the obtained score from each index map.

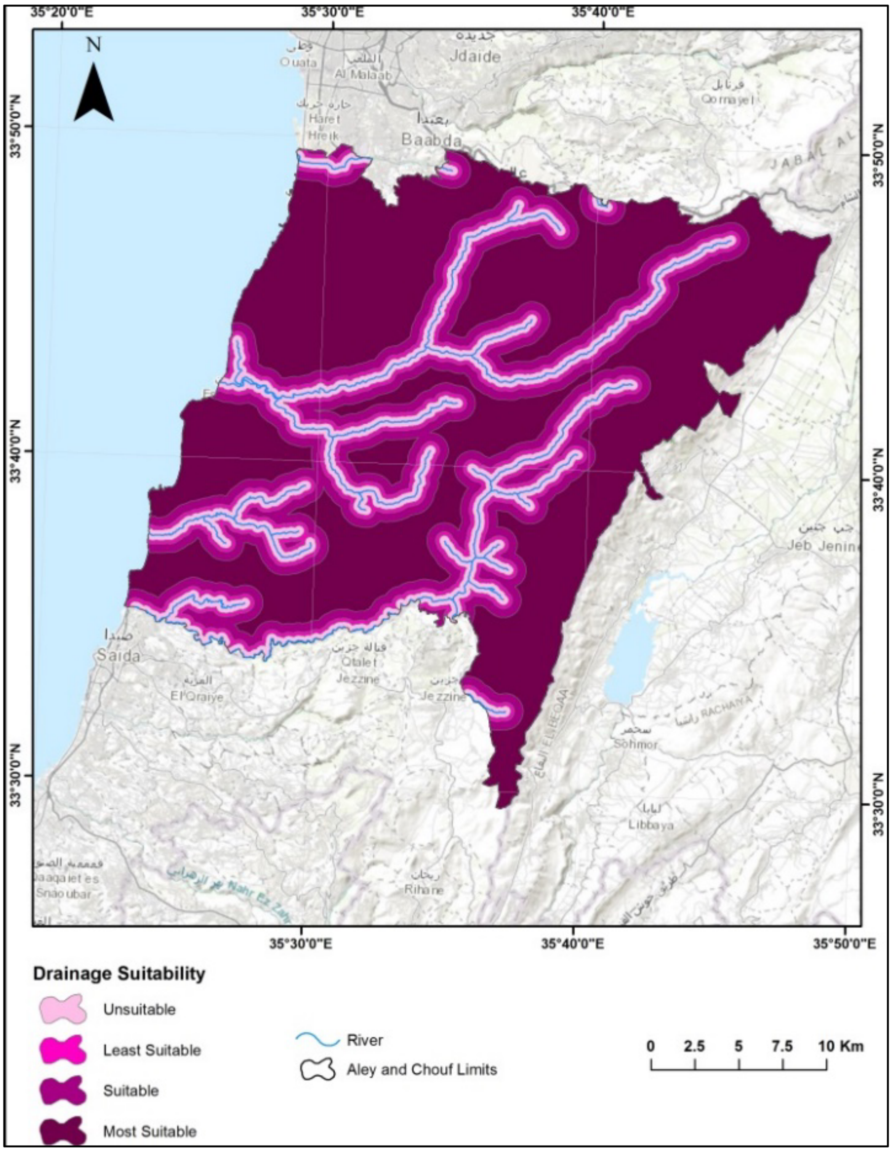

Fig. 5 Drainage suitability map

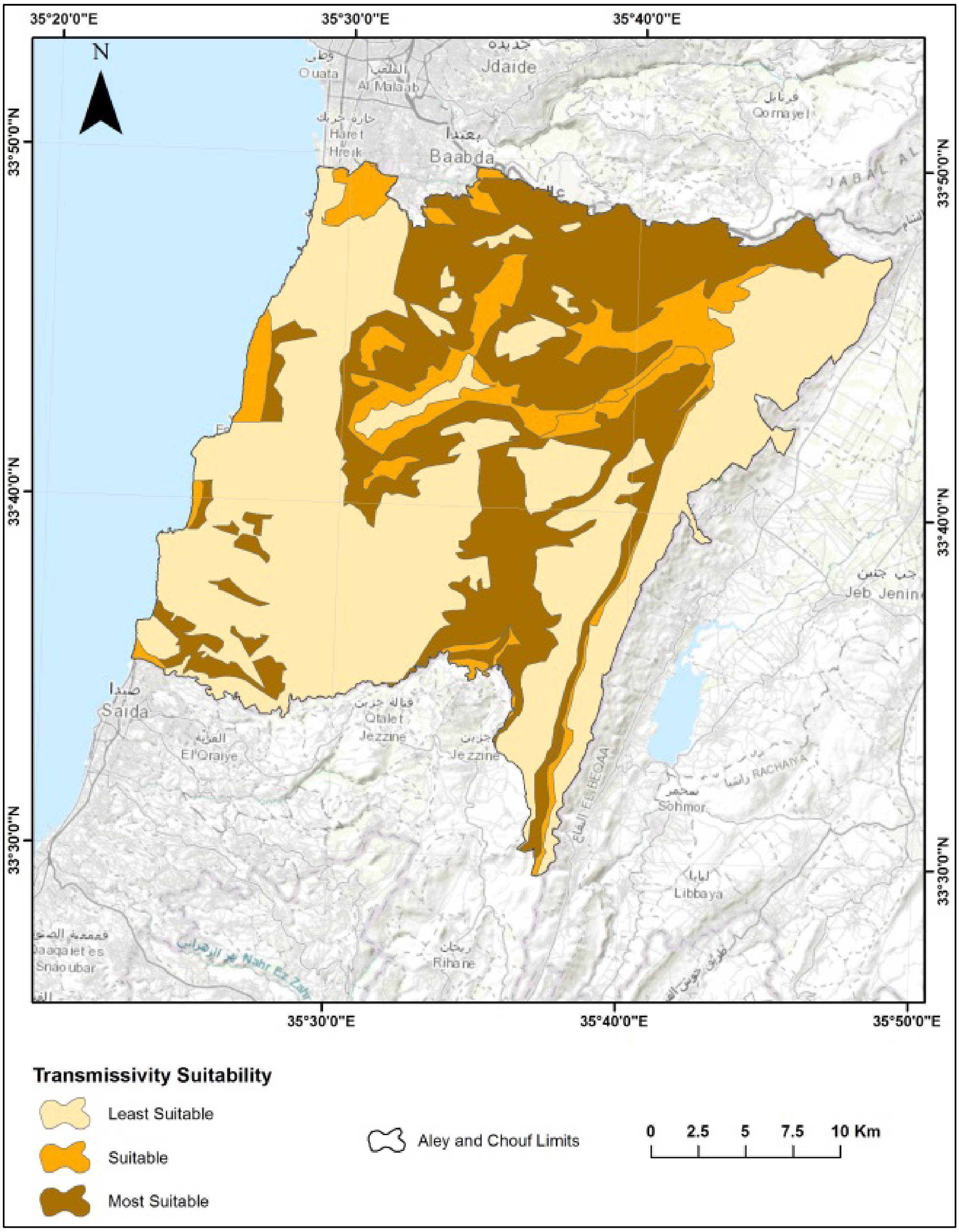

Fig. 6 Geological transmissivity suitability map

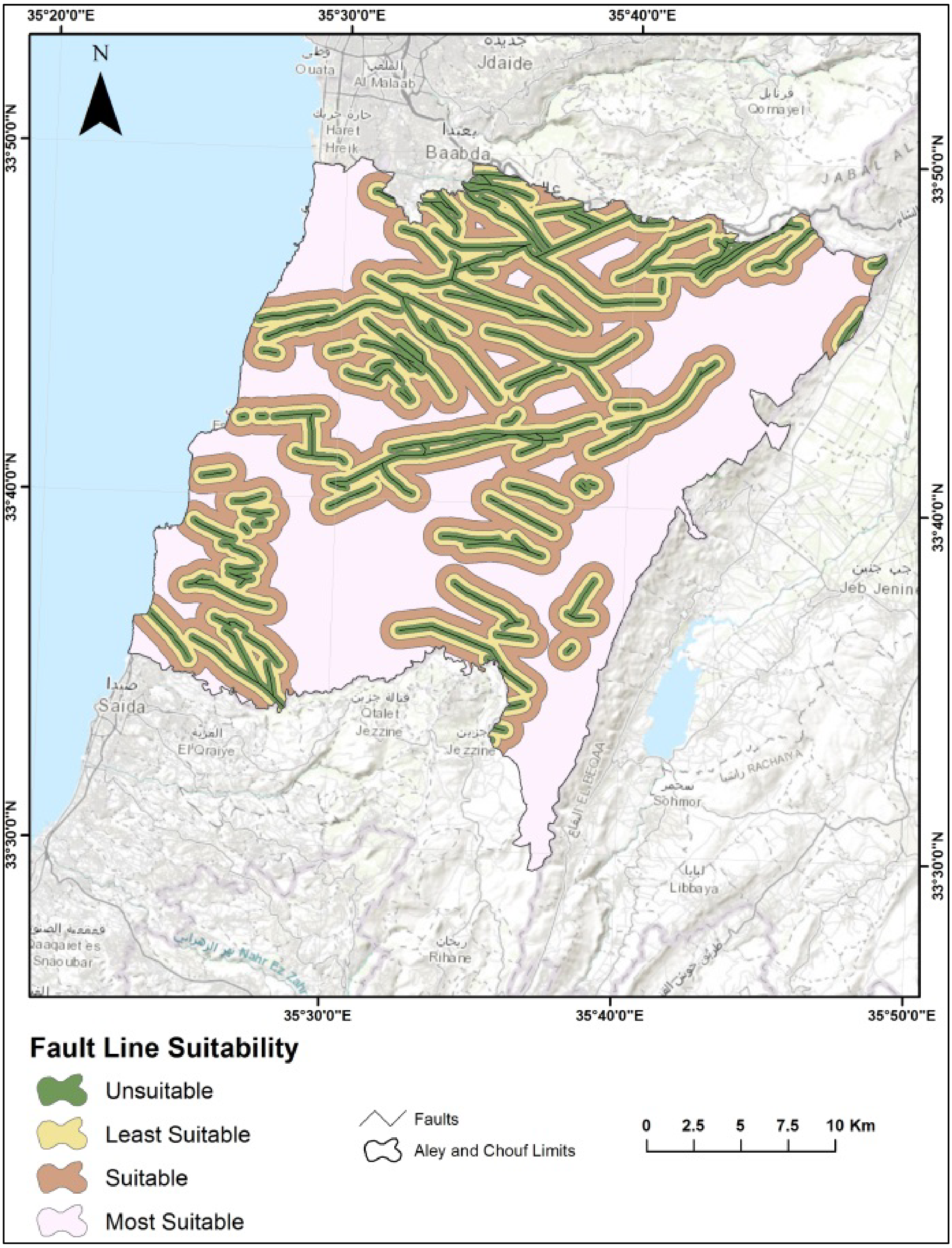

Fig. 7 Faults suitability map

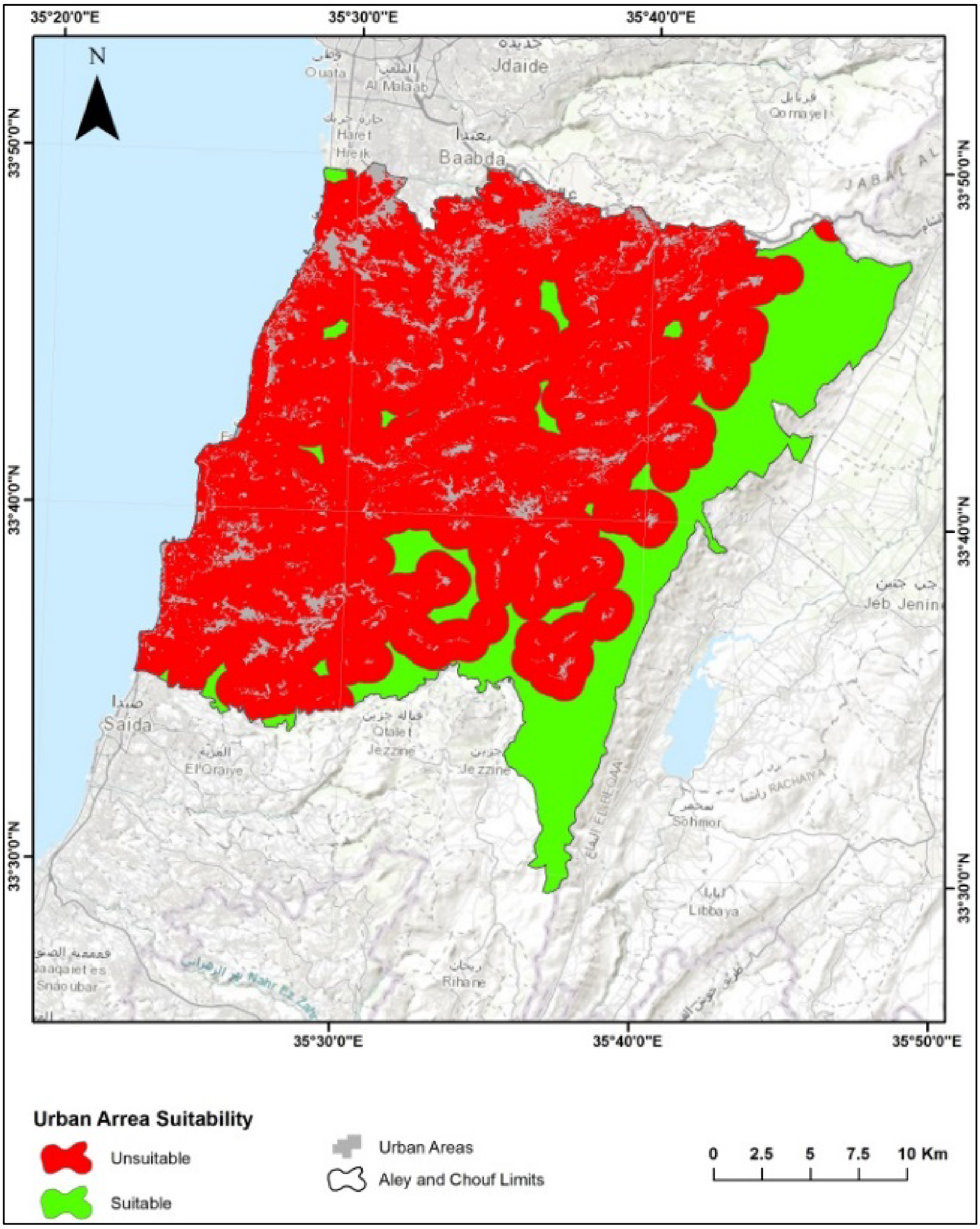

Fig. 8 Urban areas suitability map

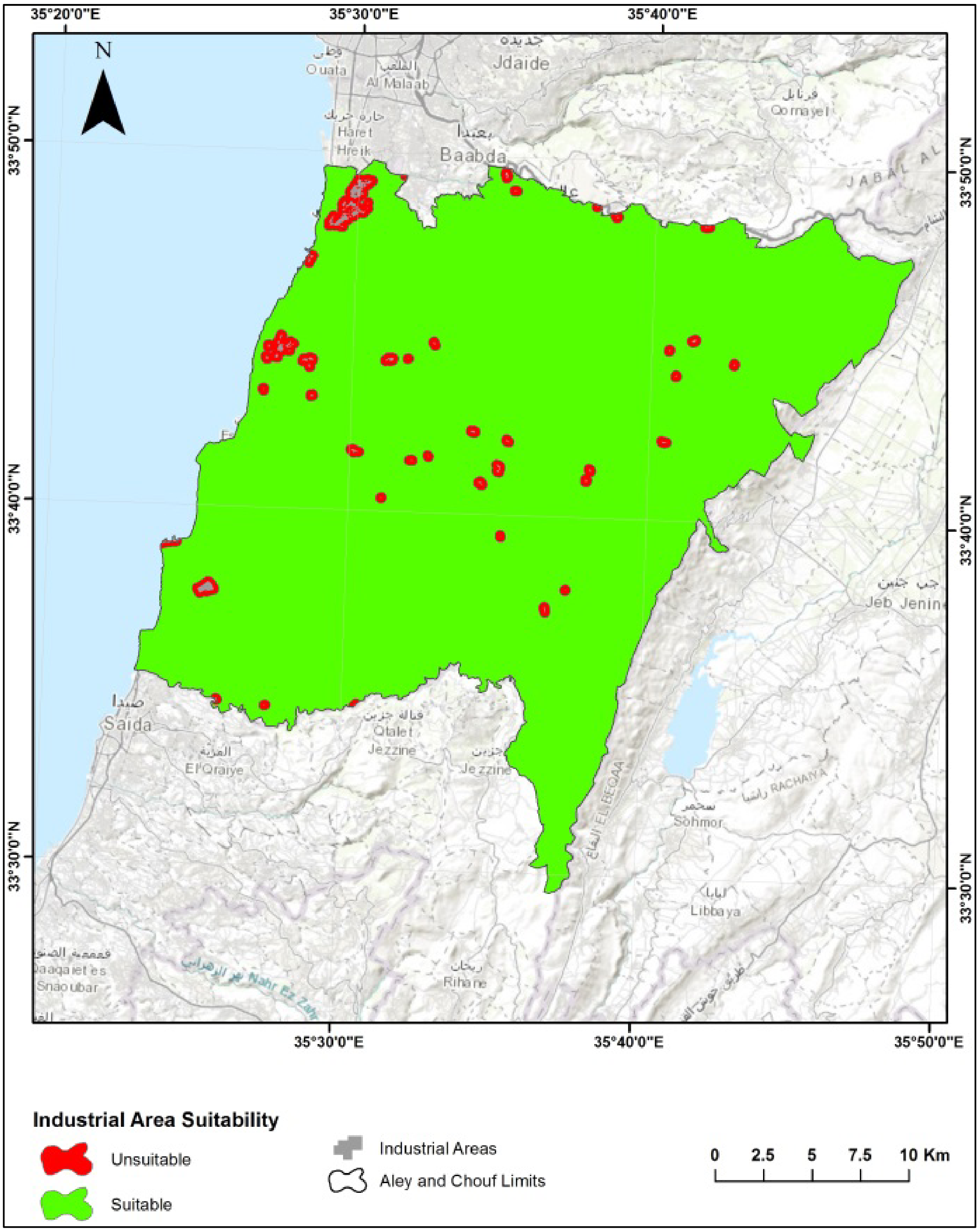

Fig. 9 Industrial area suitability map

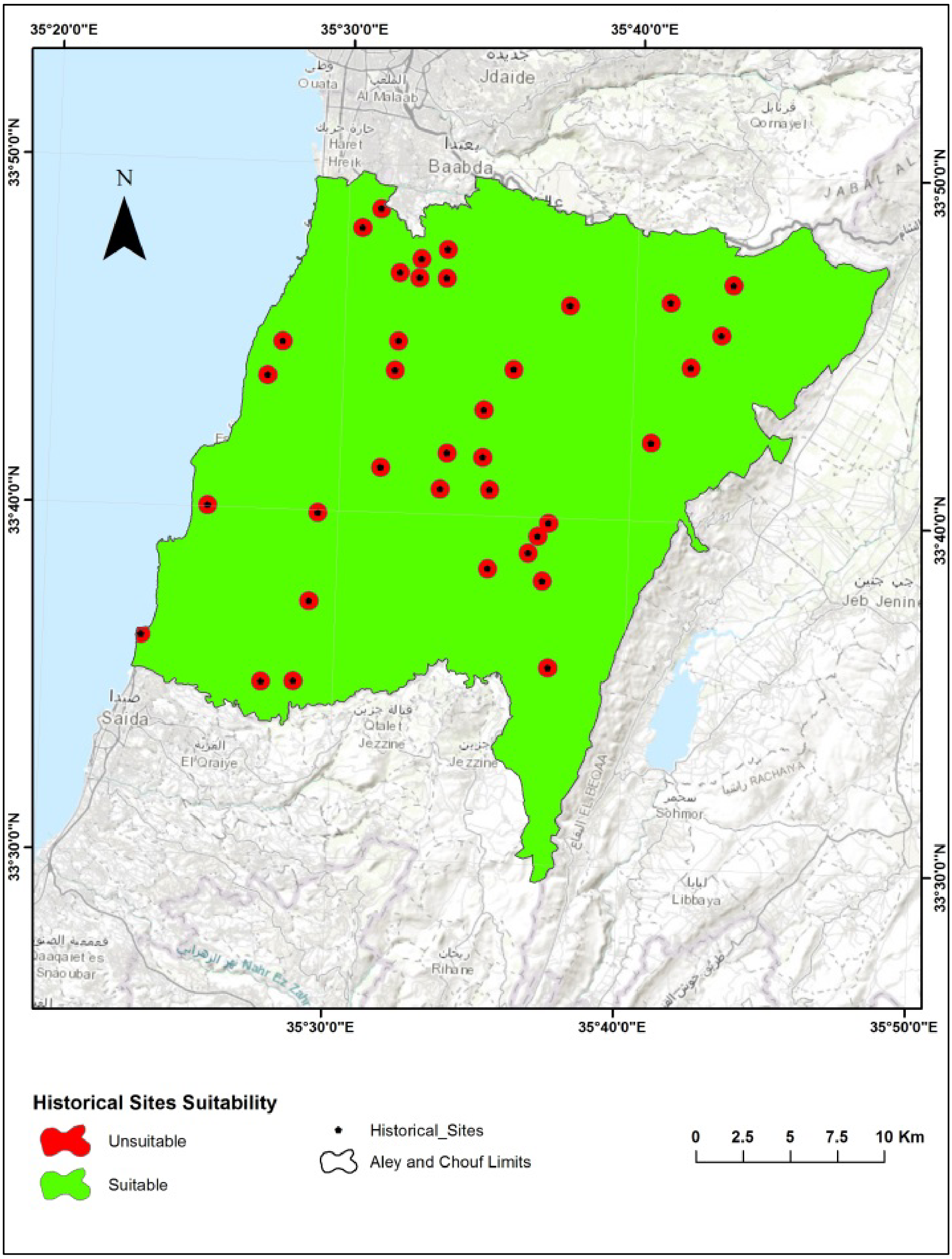

Fig. 10 Historical sites suitability map

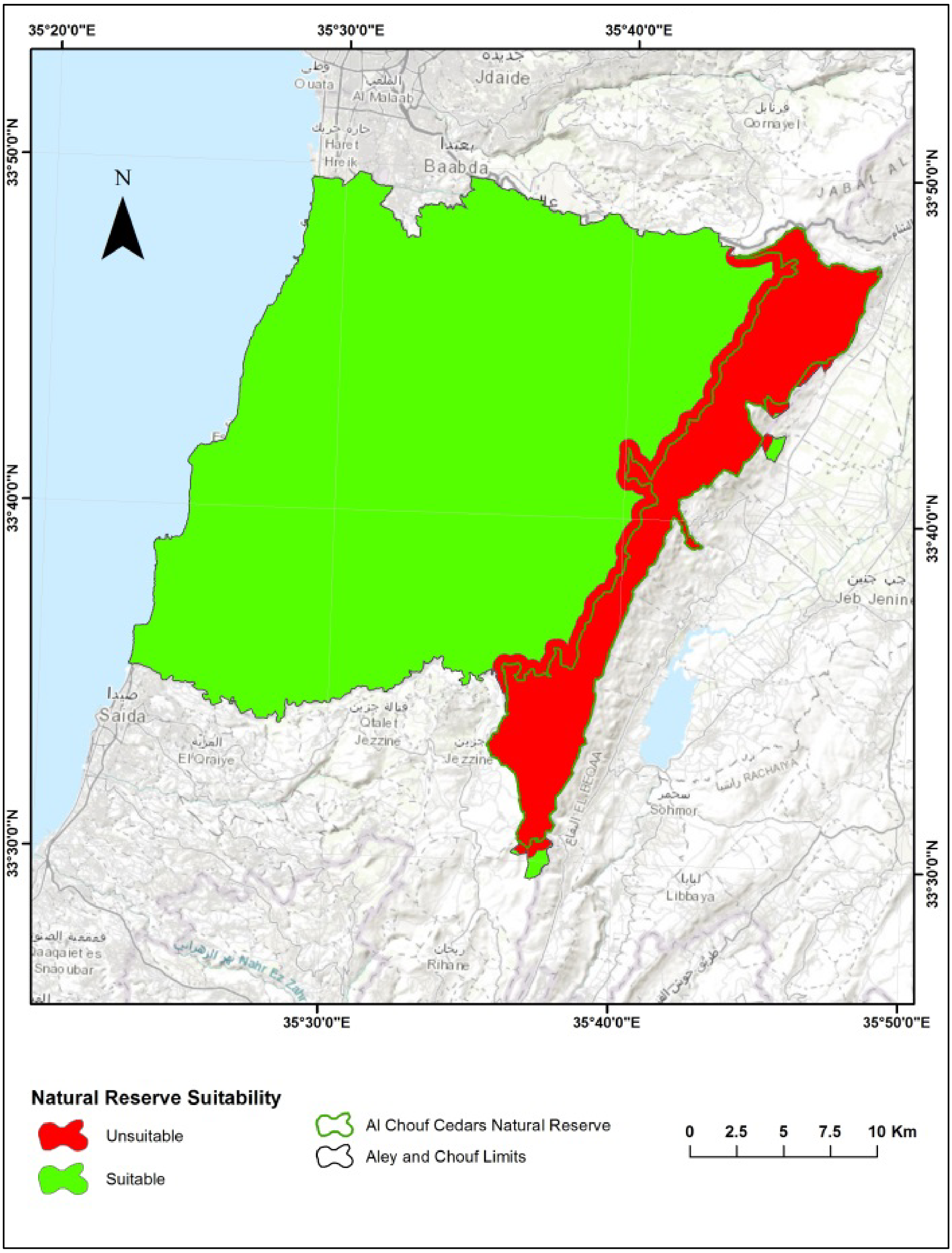

Fig. 11 Natural reserve suitability map

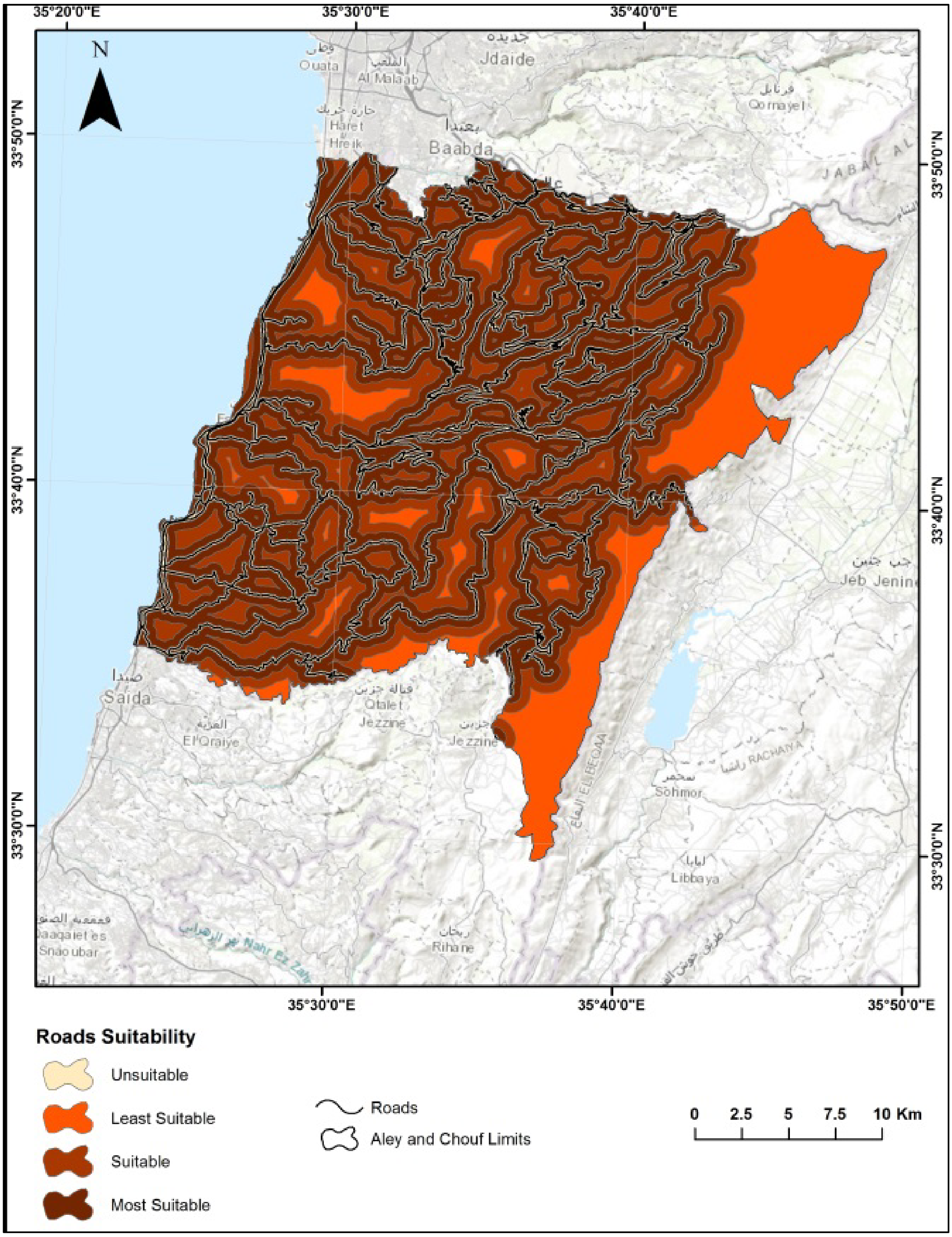

Fig. 12 Roads suitability map

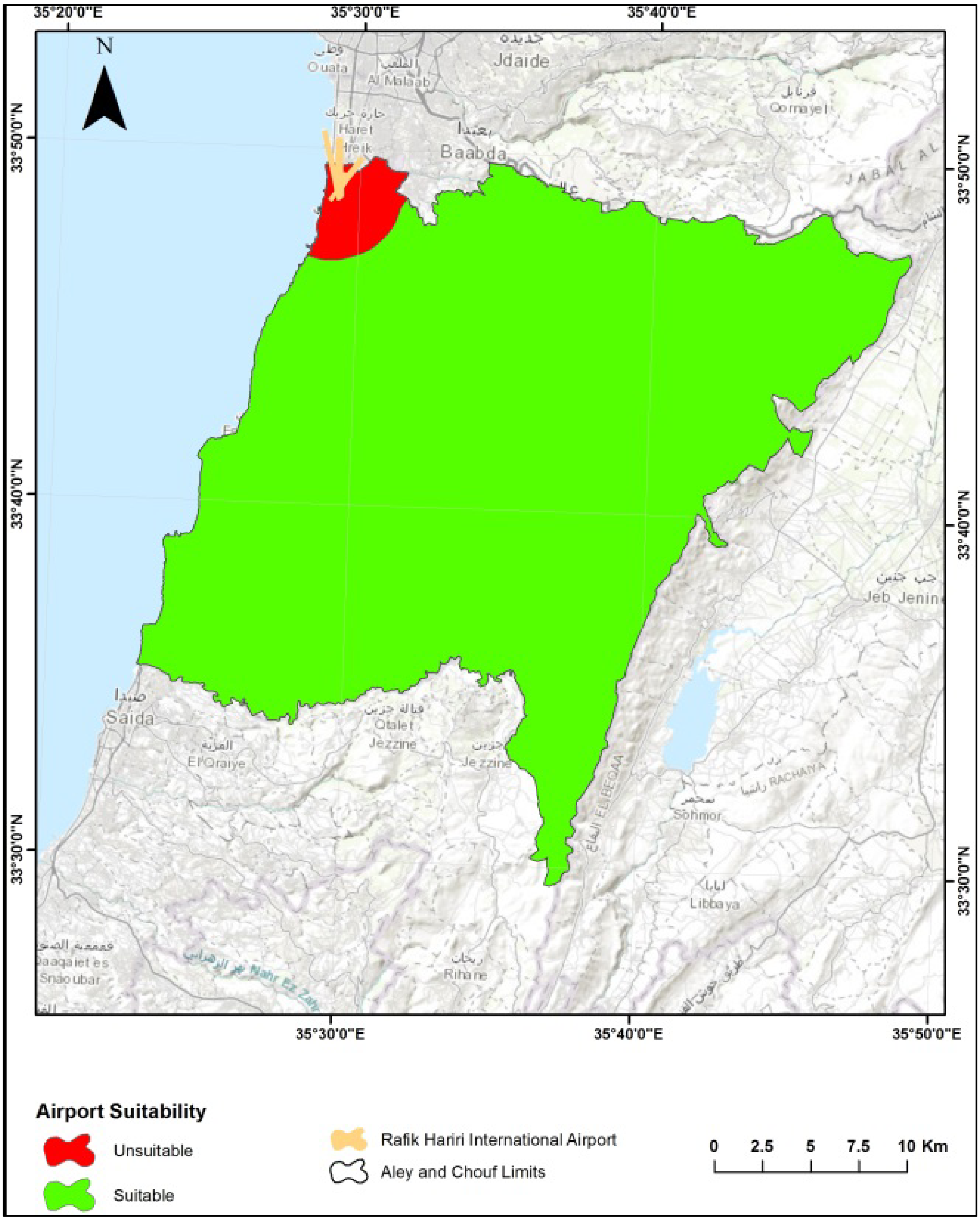

Fig. 13 Airport suitability map

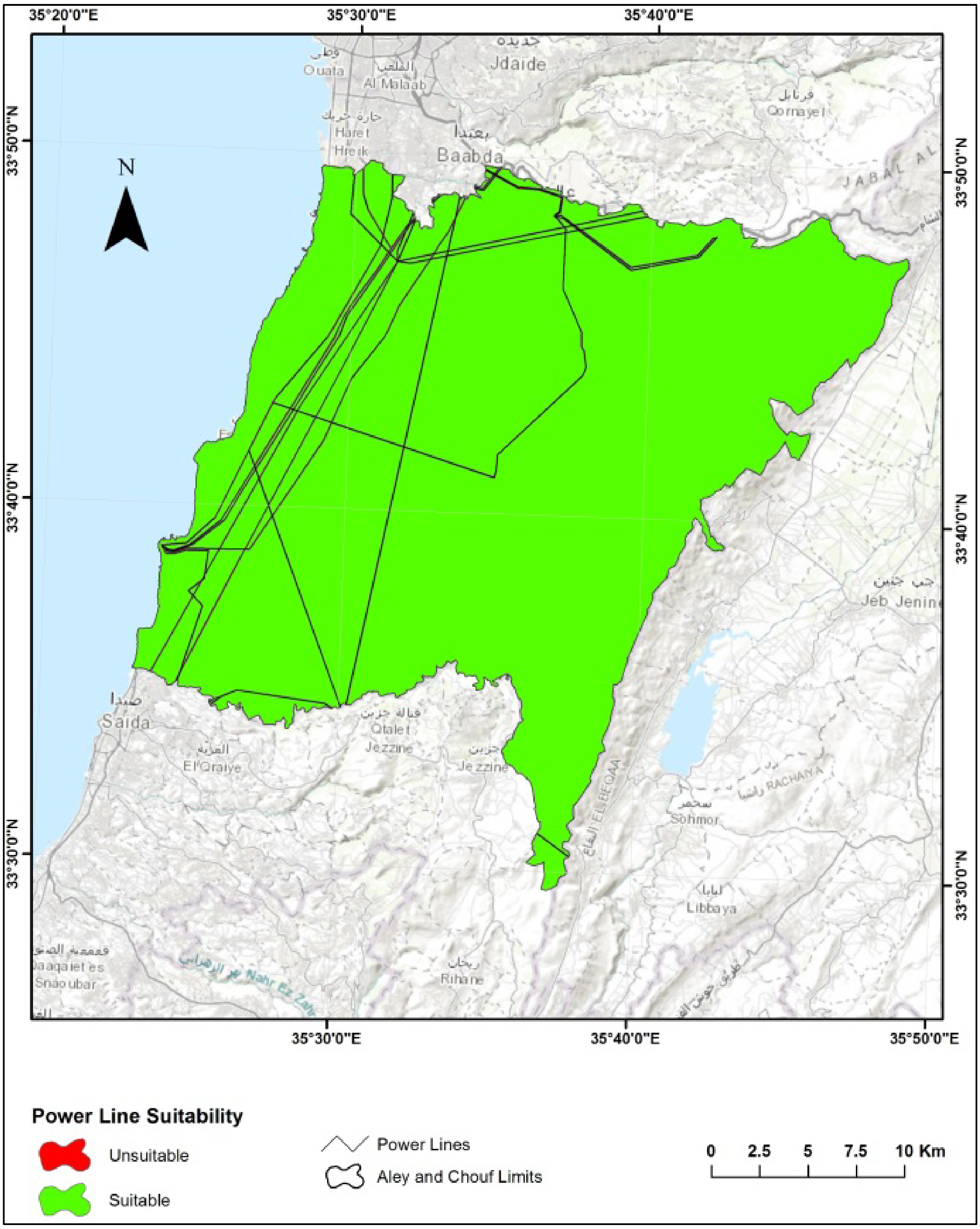

Fig. 14 Power lines suitability map

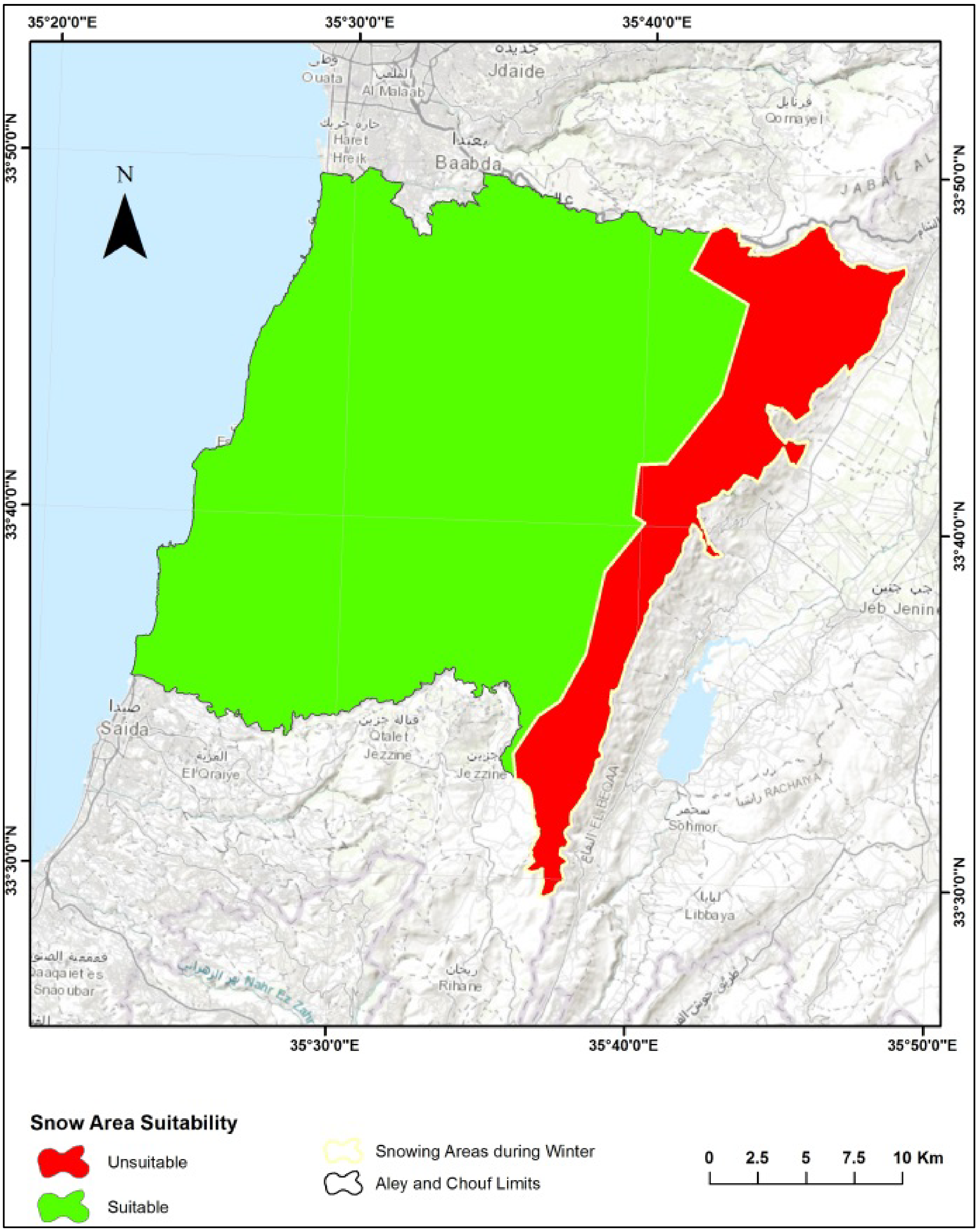

Fig. 15 Snow area suitability map

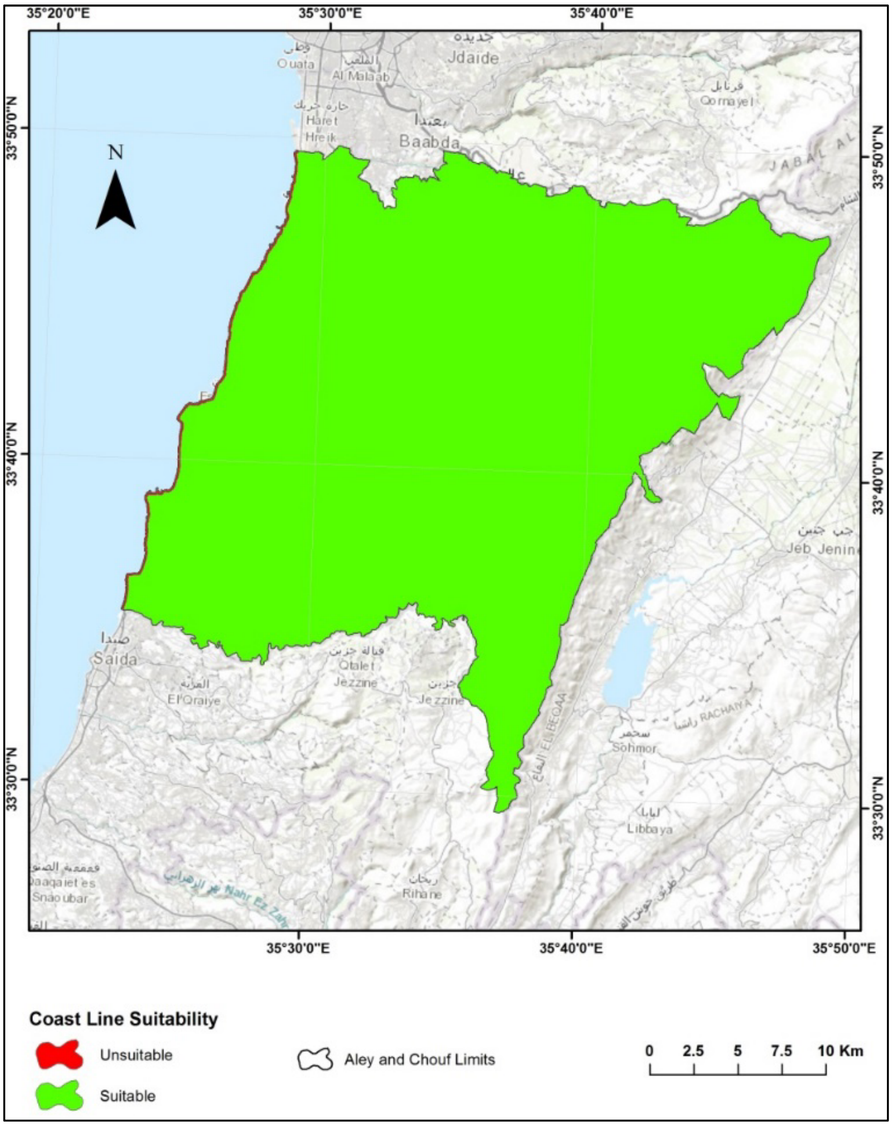

Fig. 16 Coastal area suitability map

IV. Results and Discussion

A. Results

Since many factors are incorporated in the landfill site selection, GIS is ideal for this kind of study to accomplish the analysis. The work was mainly accomplished using ArcGIS software and basically ArcMap. Vector data type was used as a data type for all layers. All factors' maps are of the same scale (1:10,000) which can generate maps of the same scale after the overlay. For each determined factor, a map was produced and classified according to suitability classes. Several geoprocessing tools (Buffer, Intersection, Merge, …) were applied to generate the map representing each factor. A classification was obtained for each map by assigning values from 0 to 3 to its own attribute table according to the suitability class. The factor's maps related to each index were used to produce the index map. Working with vector data type, the overlay of different layers defining each index produced the index map having several polygons, each receiving its own attributes from the basic factor map. Any polygon receiving at least one 0 attribute from any of the implemented layers is consequently unsuitable for a landfill and must be restricted and classified as unsuitable. The simple additive weighting method was then implemented to calculate the suitability index for each produced polygon (excluding polygons receiving 0 attribute value) based on the assigned weight of each factor. The generated index map was classified using the natural break classification, which was found to be the best method reflecting the reality of our area of study; as unsuitable (0 – restricted areas), low suitability (1), moderate suitability (2), and high suitability (3). The procedure was applied for the four main index maps, each related to its own index defined by several factors (Fig. 18). Indices maps are presented in Figs. 19-22. The four index maps were then used to create the final map at the same scale of the input index maps generating the final map at scale 1:10,000 with an accuracy of 10 meters estimated as a correspondence of 1 mm on the map. Intersection tool of the four indices layers is performed (Fig. 18). Also, polygons receiving attribute 0 from any index map are restricted. The SAW method was also implemented to calculate the suitability index of the final map based on the weight of each index map and natural break classification was used to produce suitability classes. Polygons having area less than 1000 sq. m were eliminated using the elimination tool because they are too small to fit for a landfill. Fig. 23 shows the produced map with different suitability classes. From Fig. 24, it can be seen that areas belong to low suitability class covers 30.0%, moderate suitability class 29.6%, and most suitable class 40.4% of the unrestricted areas.

B. Discussion

Results of this research help decision makers and authorities in Aley and Chouf district to choose sites suitable to construct a landfill and overcome the existing waste management problem. Working with a dense population area, we notice that the urban areas factor has its powerful effect on the site location. This important factor has made the high suitability sites present more in the eastern part which is the area of moderate to high elevations and considered less populated areas compared to the coastal and mid-height areas being favorable for urbanization. For sustainable development, authorities should take in consideration the urban sprawl that may occur towards the eastern part of the study area. This article affords authorities variety of options to be considered as a sanitary landfill location. Since the obtained map shows vast areas with high suitability, a site might be chosen to be dedicated only to Aley and Chouf districts, and also, a site may be chosen with wider area to be used for all Mount Lebanon districts. This could help to solve the problem not only in these two districts but also in the whole governorate. More factors such as land ownership type and land values must be studied in details. The acceptance of the site from municipalities in the district and political authorities in Lebanon should be also included. Further studies must be applied about population growth and waste generation rate to choose the most appropriate area. It is recommended to choose a landfill site which can help to solve the existing problem for a couple of years preparing to move into more advanced solutions for managing municipal wastes.

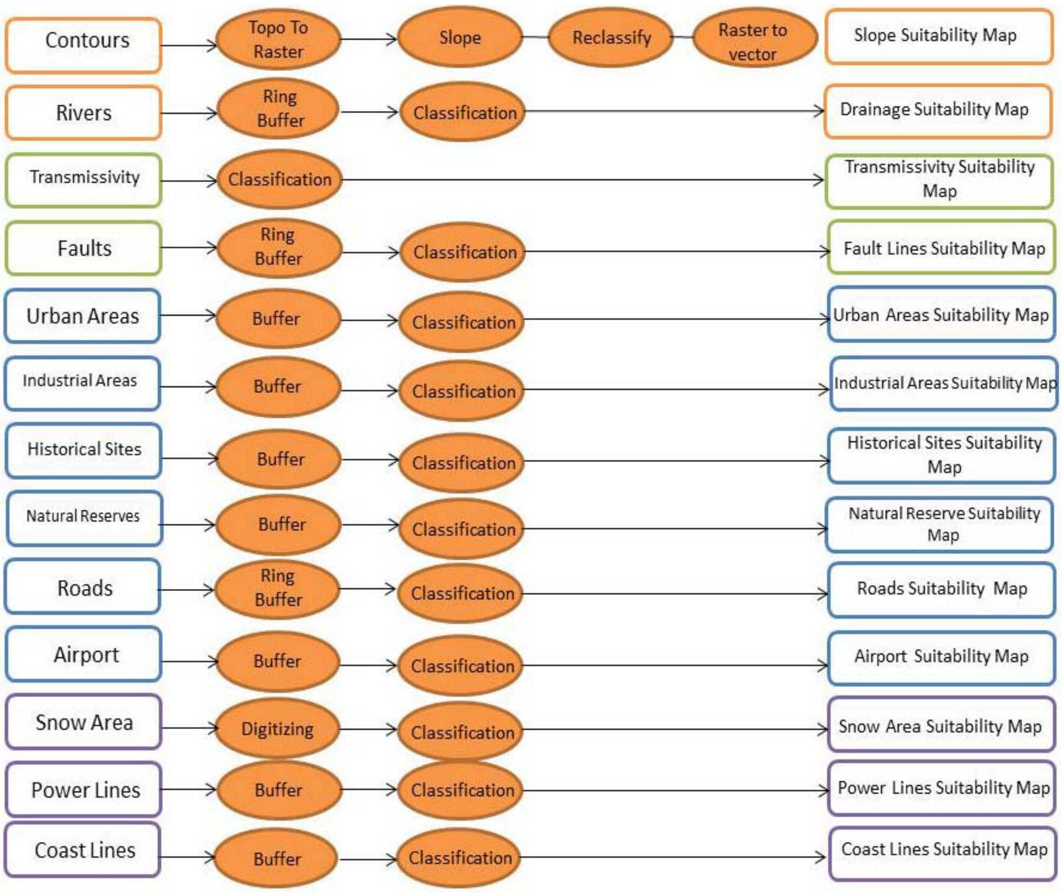

Fig. 17 Landfill factors' maps generation

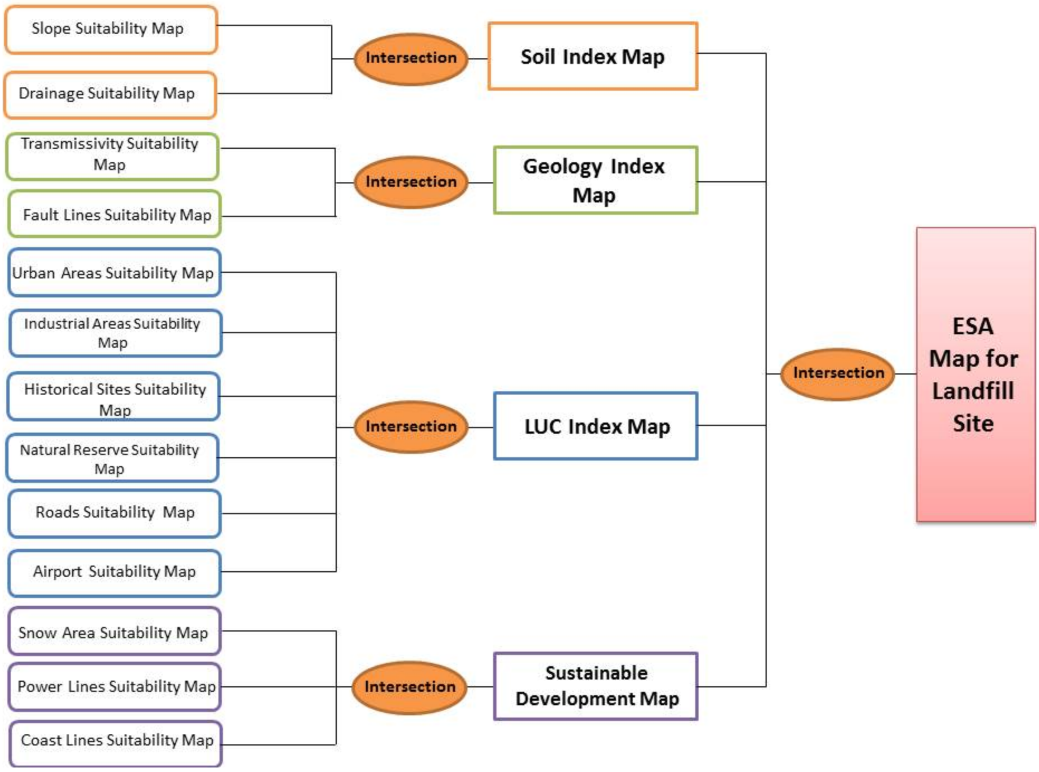

Fig. 18 ESA map generation

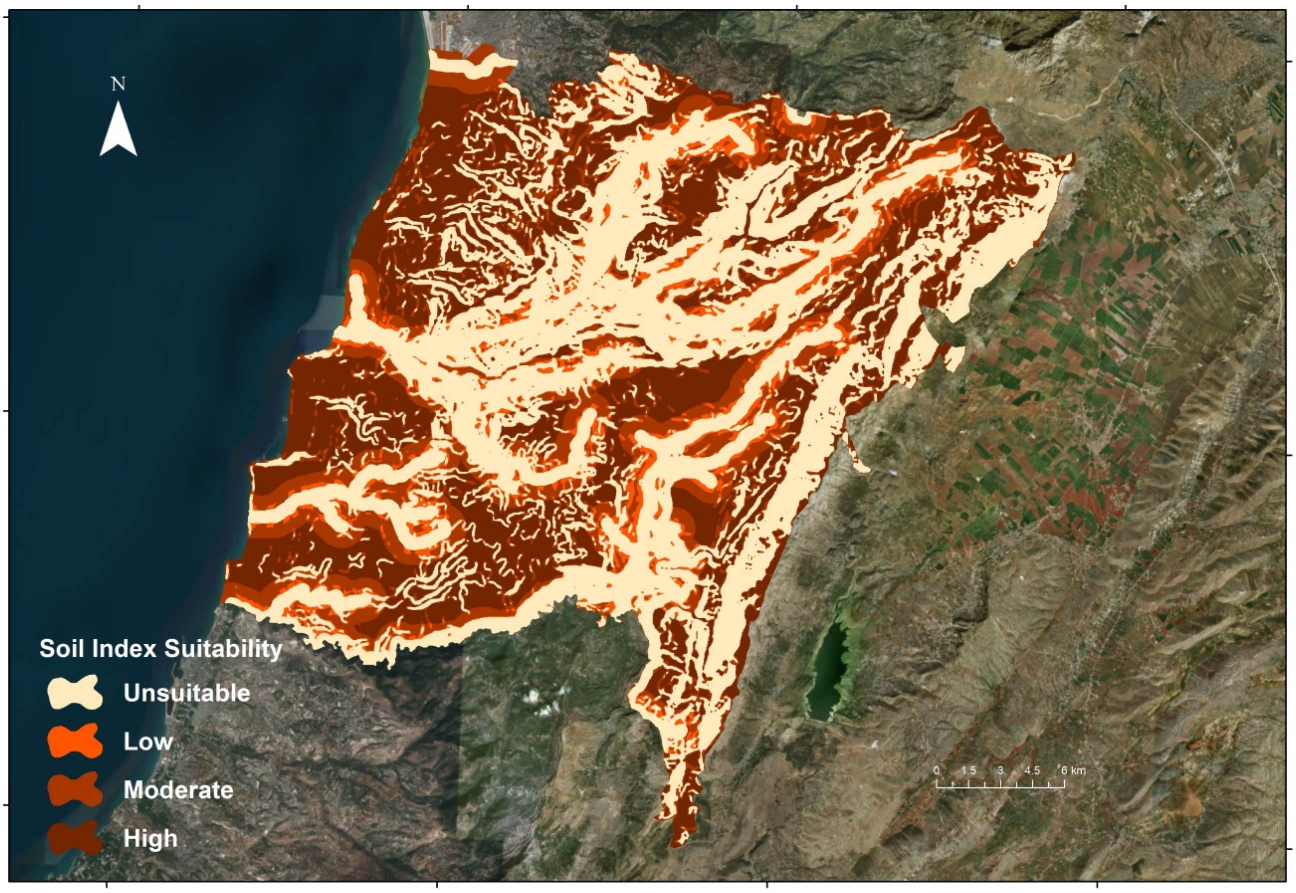

Fig. 19 Soil map index

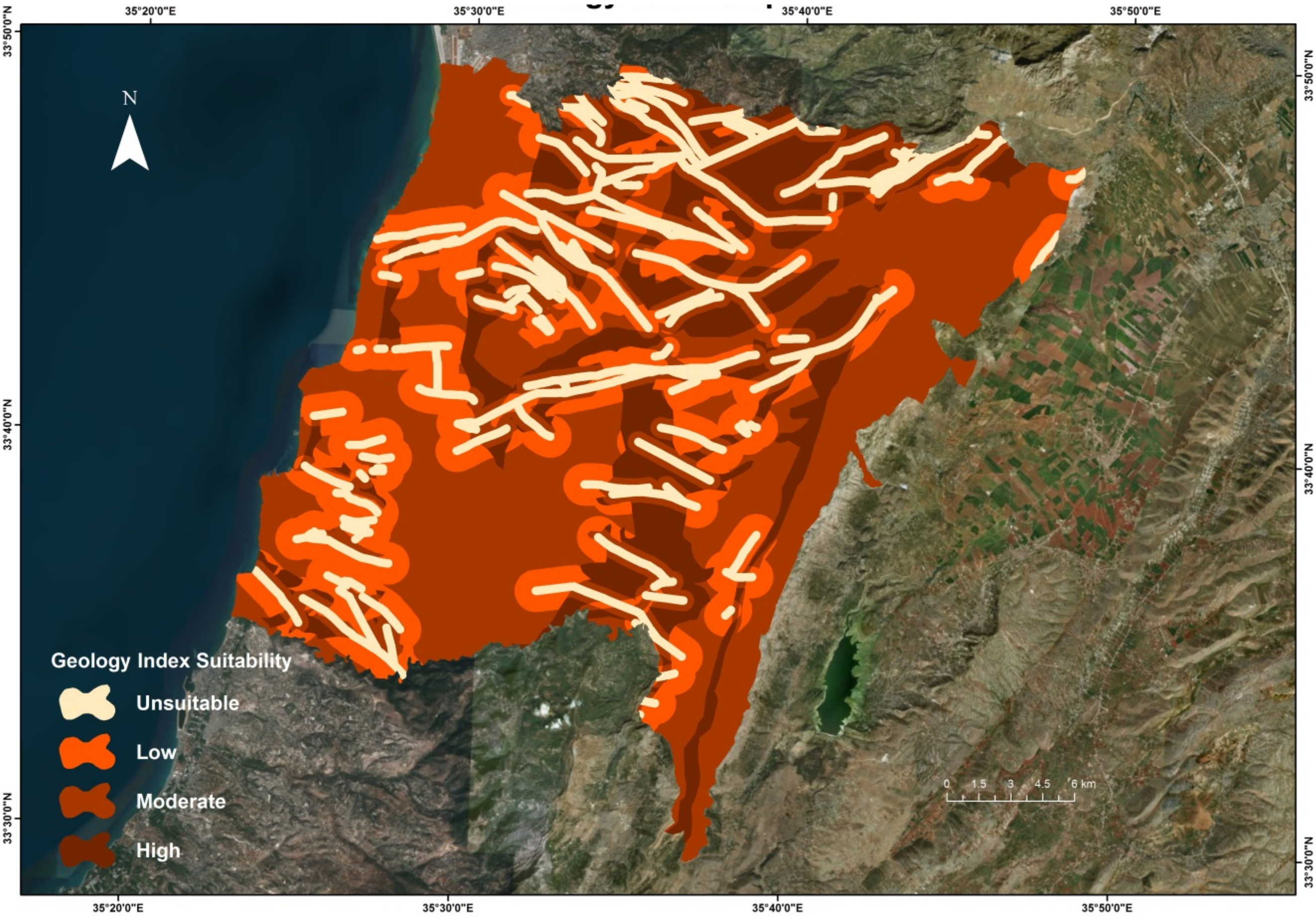

Fig. 20 Geological index map

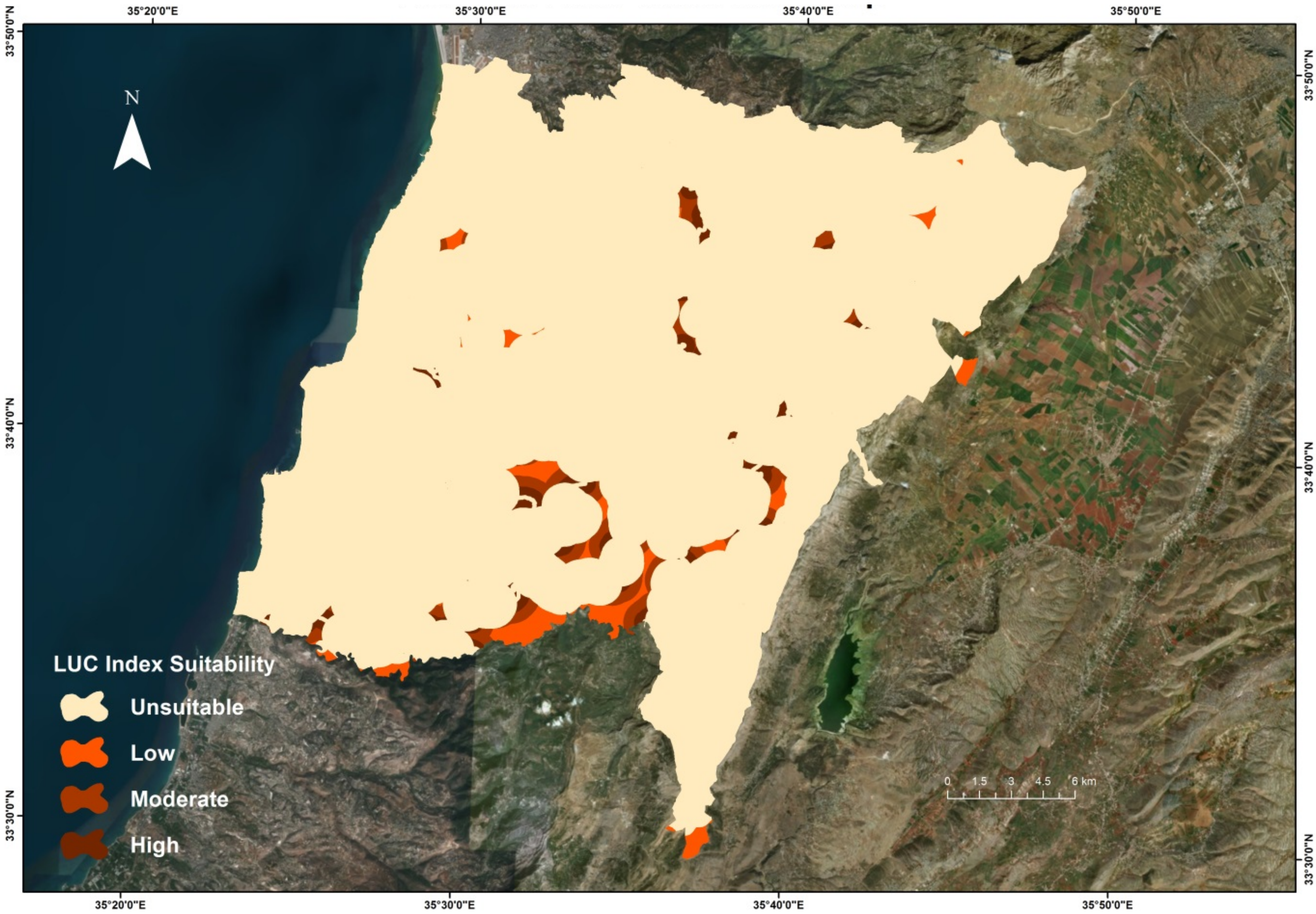

Fig. 21 LUC index map

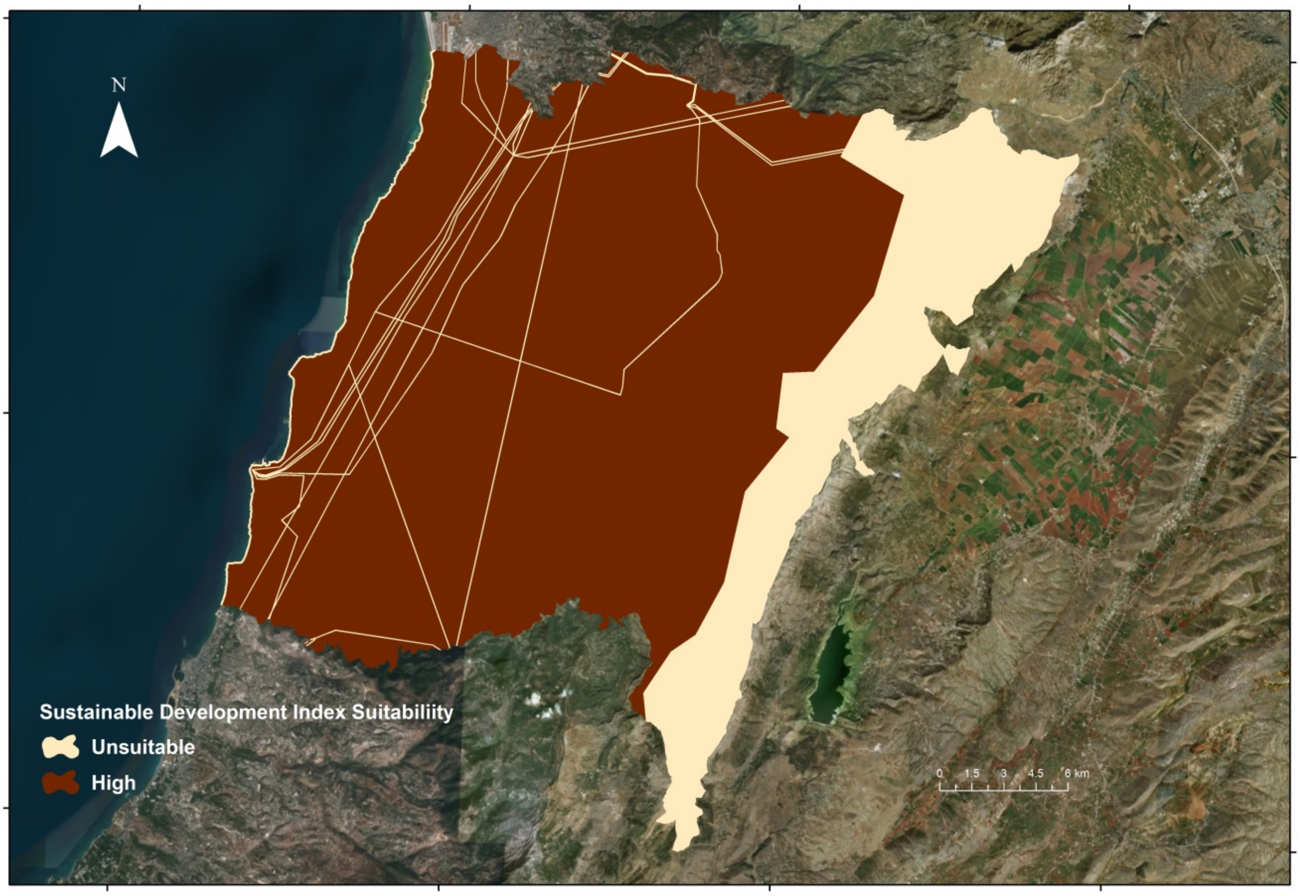

Fig. 22 Sustainable development index map

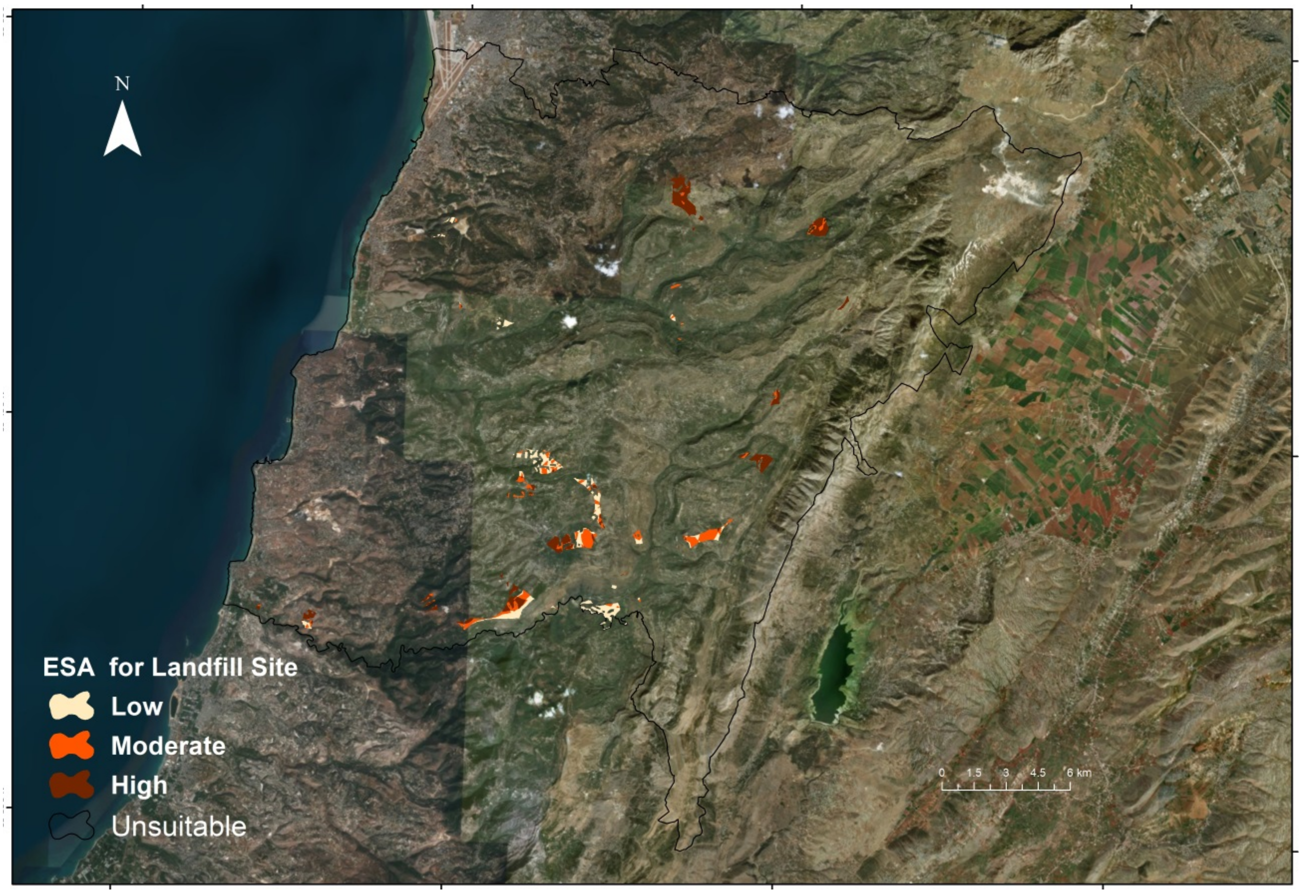

Fig. 23 Landfill suitable sites in Aley and Chouf district

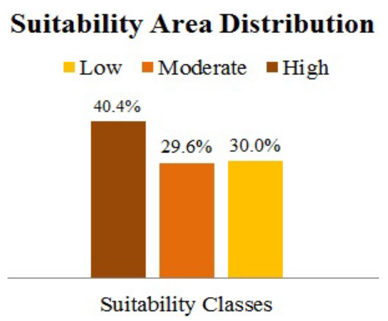

Fig. 24 Area distribution of different suitability classes

V. Conclusion

Trying to find a convenient solution for the Lebanese waste management problem which has deepened, it was proposed to find a suitable location for a sanitary landfill. Aley and Chouf district are both suffering from the severe problem, and a solution should be found to avoid more negative effects of the crisis. Landfill site selection is a complex procedure that needs involving several factors and constraints such as environmental, social, and economic factors. Using GIS is a practical way to produce high quality maps needed for the landfill site selection in a short time. In this study, several necessary criteria and indices were first determined through literature review. Using the available data, 13 suitability factors were defined, classified into four main indices and prepared as input maps to identify best landfill locations. Four indices maps were created from relative factors showing different suitability classes. Simple additive weighting method was used as a MCDA method. The implementation of the four indices maps produces the output map which was classified into four suitability classes; unsuitable, low, moderate and high suitability. This map is now considered a base for further studies related to landfill siting. Interfering GIS has made the selection easier by isolating the unsuitable areas and enabling selection from the suitable areas. It is important to realize that GIS analysis is not a substitute for field analysis. For this reason, more studies should be accomplished based on the field analysis to choose a landfill site from the suitable areas.

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