Iranian Journal of Environmental Technology
2nd Year, Vol. 2, No. 3, Spring & Summer 2016
Received: January 19, 2018/ **Accepted:** March 3, 2018. **Page:** 49- 67

Municipal Waste Landfill Site Selection based on Environmental, Geological and Geotechnical Multi-criteria: A Case Study

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Abstract

Waste management is a complex and detailed process that involves evaluation of certain important factors, such as a geological, geotechnical, hydrological, hydrogeological, climate, urban management, environmental, along with social, cultural, and psychological parameters. Unfortunately, in Iran, there is minimal evaluation of initial parameters and in some cases even don't exist. The purpose of this study is to conduct a landfill site selection based on engineering geological views. For this purpose, the Analytical Hierarchy Process (AHP), Multiple Criteria Decision Making (MCDM) and Geographic Information Systems (GIS) methods were used to select a suitable site for disposal of municipal solid waste (MSW) for the city of Maragheh, Iran. In order to make decision for landfill site selection, the focus was on multivariable function of the listed criteria. Each of these criteria is classified based on international guidelines (US environmental protection agency and technical committee on geotechnical landfill engineering), field studies, and laboratory tests. Based on the results, Three sites were recommended for municipal solid waste landfill (Sites 'A', 'B' and 'C'). From these sites, sampling and soil mechanics tests (sieve analysis and Atterberg limits) were conducted where categorised according to USCS classification system. Finally, with AHP and MCDM methods the 'Site A' was recommended as the best location for sanitary landfill.

Key words: Landfill, Environmental Engineering, Maragheh City, Site Selection, Analytical Hierarchy Process (AHP)

Highlights

- Using the AHP and Multi-criteria analysis for appropriated site selection of landfills.
- Investigation of important geo-environmental factors on engineering landfill site selection
- Geological engineering impacts of engineering landfill site selection on environments, soils, plants, groundwater, etc.
- Environmental effects on landfill site selections

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Introduction

The increasing population and developments in urbanised countries have led to huge consumption of non-renewable resources and an increase in the production of municipal waste (1). Pollution caused by improper disposal of municipal waste is a dangerous issue for today's world and has become the biggest environmental problem for communities (2). Based on studies and engineering experience, disposal of solid waste in a land is introduced as the most economical way with the least potential harm for the environment. The traditional (non-engineering) waste disposal is associated with many problems. These problems can be classified as follows:

- Air pollution,
- Biodiversity impacts,
- Groundwater pollution,
- Soil fertility effects,
- Visual and health impacts

In the developing countries, waste disposal traditionally has been conducted and this fact reflects the large-scale pollution on environment and biological ecosystems (3). Considering the importance of this issue, governments try to provide rules to ensure proper and engineering disposal of municipal waste (1). These management laws have been implemented by developed countries at international levels. These regulations are available through environmental protection agencies (4) and technical committee on geotechnical landfill engineering (5) of German geotechnical society. Iran, like other developing countries, has also faced with the waste problem and disposal is mostly conducted by traditional waste burial. Environmental impact of pollution from landfills has led to stricter criteria for waste disposal (3). This has caused serious environmental problems for different cities in Iran (6). Generally, the problems raised in traditional waste disposal can be stated as follows (7):

- Most of municipal waste is disposed in lands without prior treatment to reduce waste impact on the surrounding environment.
- Waste disposal is carried out without separation recovering of recyclable materials causes economic loss and raises living cost.
- Open dumping of artificial man-made materials can threatens the biological species, plants and animals.
- Contamination of groundwater and surface by landfill leachate.
- Contamination of geo-formations and soil through inappropriate methods.

The existence of environmental problems has led the geo-environmental researchers look for applied and engineering methods to reduce the effects and consequences of waste disposal. The first and the most important step after identifying the nature of waste (Municipal, chemical, hazardous, nuclear or radioactive) (8) is to select and design the new landfill sites (9). Various parameters should be considered for the selection of a suitable site for landfill. These parameters include geo-factors (geological, hydrological, hydrogeological, topographical, geomorphological, tectonical, seismotectonical conditions); engineering factors (engineering geological, geotechnical, soil and rock properties); environmental factors (urban geology, pollutions, geo-material quality, protected sites, basins and aquatic ecosystems, forests and rangelands, natural resources, water supply, treatment plants); and Social factors (urban management, land use, facilities, cultural and religious aspects, psychological, economical, special conditions) (8).

Selecting suitable landfill sites is a

complex process and needs to be fully engineered. Its ultimate goal is to recommend a reasonable location with the least environmental impact. Generally, municipal solid waste landfills are evaluated by some methods such as:

- Drastic Method (10)
- Oleckno Method (11)
- Monavari Method (12)
- US Environmental Protection Agency, USEPA Method (4)
- Technical Committee on Geotechnical Landfill Engineering, TCGLE Advices (5)

As known, the purpose of landfill site selection is to identify a location to minimise the inverse effects of the environment and human health (13). Multiple-criteria decision making method (MCDM) or multiple-criteria decision analysis (MCDA) is one of the recommended practices and common method used for different site selection studies (14). MCDM/MCDA is a sub-discipline of operations research that explicitly considers multiple criteria in decision-making environments. MCDM was developed in 1979 to optimally measure several variable parameters under discussion. Mainly, in decision-making theory and MCDM the problems are classified in continuous and discrete groups (15). The engineering geological and geotechnical analysis is categorised in discrete problems or 'discrete MCDM'. In the analysis of site selection, like landfills, dams, power-plants, disposal, refineries, hazardous disposal, tailing dams, etc. the combination of MCDM with analytic hierarchy process (AHP) and GIS plays a significant role.

AHP is a structured technique for organising and analysing complex decisions (16). Saaty (17) introduced for the first time the AHP systematic decision method and Siddiqui *et al.* (18) was the first person who used GIS and AHP combination for landfill site selection (13). The GIS and AHP combination is a powerful approach for the selection of landfill site, because using GIS provides information for classification and layering and AHP logical choice and multi-criteria decision (19).

In the city of Maragheh, municipal waste landfill site is selected using the MCDM and AHP based on the definition of dependent and independent parameters. These parameters are sorted by importance, sensitivity, and site limitations. The aim of these works is to find the upmost site with appropriate conditions.

Case study: The city of Maragheh is located in the south of East-Azerbaijan province, northwest of Iran, and is the second largest city after Tabriz in this province. This city is located in east of Urmia Lake and Bonab city, south of Sahand Mountain and Tabriz, west of Hashtrood city and north of Malakan city (20). Maragheh is geographically situated between $37^{o}23'$N to $37^{o}23'$N latitudes and $46^{o}14'$E to $46^{o}15'$E longitudes. Figure 1 shows geographical location of Maragheh in the province and Iran.

According to the results of census by Statistical Centre of Iran in 2012 (21), population of this city was approximately 163,859 persons in 47,982 families living in 25.97 km^2. The average elevation from the sea level is about 1477.7 m. with an average 12.5^{o}C annual temperature. The average annual precipitation is about 322.4 mm and the 81.5 annual frost days. This city is located in a mountainous region where the climate conditions prevail with mild and rainfall summers and cold and snowy winters.

Table 1-Appropriate criteria for Maragheh landfill site selection based on international standards

No.	Criterion	Considered parameters
1	Soil quality and alluvial outcrops	Soil physics (compressibility, excavation capability, durability, etc.)
		Soil Chemistry (soil quality, composition, mineralogy, coverage quality, etc.)
		Clay minerals (clay percentage, absorbability, hydrophilicity, clay mineral type, potential, activity, etc.)
		Permeability (porosity, void ratio, effective porosity, hydraulic conductivity, mobility, transmission, etc.)
2	Climate and weathering status	Climate (site location: arid, humid, semi-arid, etc.)
		Precipitation (rainfall, seasonal and annually fluctuations, nutrition, water quality, etc.)
		Temperature (average temperature, seasonal and annual variations, soil heat capacity, thermal response, etc.)
		Evaporation (evapotranspiration, seasonal and annual variations, maximum evaporation, etc.)
		Erosion (degradation, sedimentation, erosion - sedimentary cycle, soil durability, etc.)
		Winds (intensity, speed, direction, carrying capacity, abrasivity, etc.)
3	Geological setting	Structural status (folds, joints, fractures, ruptures, landscapes, anticline, syncline, etc.)
		Tectonical status (faulting, fault type, fault mechanics, situ-stress, shear zones, Crash zones, etc.)
		Seismical status (seismic activity, ground acceleration, damping, seismic magnification, iquefaction, etc.)
		Lithological status (crystallography, mineralogy, formations and outcrops, structures and textures of rocks and soils, etc.)
4	Hydrological and hydrogeological conditions	Karst status (presence of limestone formations, the karstification ability, karstic formations)
		Hydrological status (watershed, waterways, drains, streams and rivers, caves and cavern deposits, marine sediments and lakes, floodplains, river bed, , etc.)
		Hydrogeological status (water table, distance to water sources, water supply, Drinking water, nutrition, discharge conditions, transmission, hydraulic conductivity, hydrodynamic coefficients, etc.)
		Springs (discharge, mechanism, seasonal and annual variations, etc.)
5	Urban management	Urbanism conditions (distance from town, residential areas, main roads, etc.)
		Land use (initial and final user, land ownership, enclosed, soil type, etc.)
		Facility (possibility of water supply, electricity, sewage, security, controlling difficulties, devices and equipment, etc.)
		Cultural and religious status (distance from religious places, historical, ancient, touristic, cemeteries, etc.)
		Special status (near to sensitive areas, power plants, military bases, camps, prisons, etc.)
6	Environmental setting	Protected environment (protected areas, hunting prohibited, forests, national parks, wildlife, etc.)
		Basins and aquatic ecosystems (lakes, seas, swamps, wetlands, etc.)
		Restored environments (plantation area, parks, green spaces, etc.)
		Habitat (natural and synthetic)
7	Engineering geological and geotechnical properties	Permeability (hydraulic conductivity, transmissivity, storage coefficient)
		Soil density(γ_d), compaction, optimum moisture
		Grain size analysis, hydrometery
		Atterberg limits (LL, PL, PI, LI, CI)
		Soil engineering classification (Unified, AASHTO, ASTM)

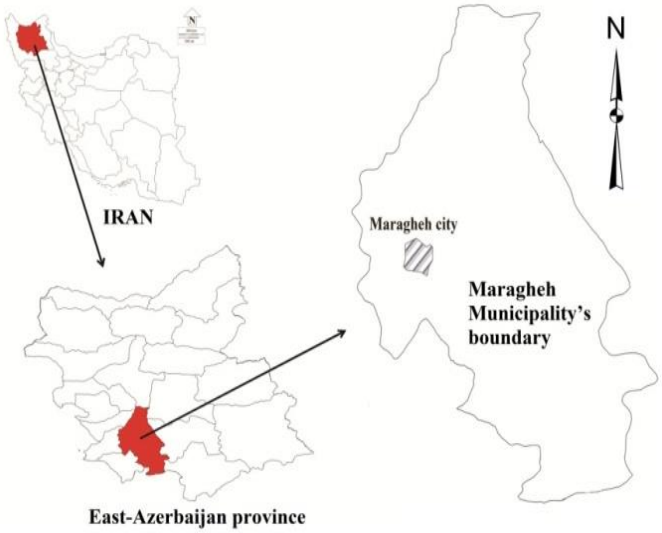

Fig. 1- The geographical location of Maragheh

Material and Method

The environmental protection and public health are considered as the main concerns in landfill site selection. Thus, the most important step in landfill site selection is to evaluate the soil and rock properties (geology), surface and groundwater condition, soil permeability to identify the pollution mechanism and to present controlling method leachate in the landfill. It requires a weighted approach to municipal waste landfill site selection. The weighted approach that is proposed for Maragheh landfill site selection is presented in Fig. 2. Moreover, for this city's landfill site selection weighted factors (please see Table 1) are used.

Using the GIS to prepare various ground maps will help to assess the entire region based on the outlined criteria in the landfill site selection. This ability allows the identification of favourable or unfavourable areas. This approach is applicable by the creation of a database which is practical. For the digital GIS database development, various maps were used as separate information layers and were collected in ArcGIS Desktop 9.3 software (22). In order to select the municipal waste, landfill site for ground mapping US environmental protection agency instructions (4) along with Landsat ETM^{+} data and satellite images (geo-referenced without cloud cover from USGS) were used (23). The AHP is a good recommended decision making method for determination of issues relating to the optimal choices. For this study, the weights criterion calculated by Expert-Choice 11 software is used (24).

Hierarchical model of suitable landfill site consists of forty criteria that were used in the computation processes and were divided into nine main groups. These main groups cover the environmental, geological, engineering geological and geotechnical, soil quality, hydrogeological, hydrological, climatological, social and economical factors. Environmental and engineering geological factors should be considered more sensitively than other factors, because leachate produced in the landfill has hazardous and polluting effects on the environment (7). This issue is shown in Table 2.

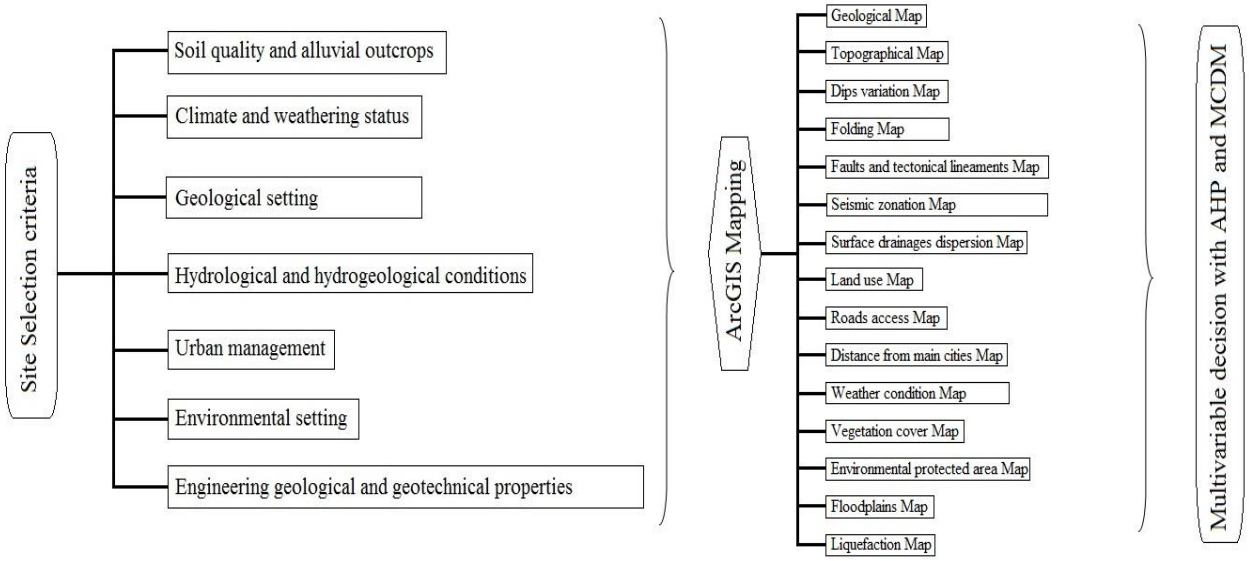

Fig. 2- Landfill site selection steps and process

Table 2- Hierarchical model of landfill site selection of Maragheh

Goal	Objectives	Σ Weight	CR	Description
Landfill site selection	(I) Environment Factors	0.255	0.086	O.K.
	(II) Geological Factors	0.142	0.062	O.K.
	(III) Geotechnical Factors	0.130		O.K.
	(IV) Soil quality Factors	0.115	0.055	O.K.
	(V) Hydrogeological Factors	0.108	0.031	O.K.
	(VI) Hydrological Factors	0.093		O.K.
	(VII) Climatological Factors	0.076	0	O.K.
	(VIII) Social Factors	0.064	0	O.K.
	(IX) Economic Factors	0.017	0	O.K.

Results

The factors described in Table 2 are considered in the landfill process for this study. As can be understood, depending on the conditions of each region, the site selection for landfill location criteria is necessary (13). Each criterion that is considered for Maragheh municipal waste landfill site selection is explained below.

Geological factors: Geological map of the Maragheh metropolitan area with the scale of 1:100,000 are presented in Fig. 3. According to this figure, this city is located on young alluvial formations, lake sediments of evaporate deposits (Neocene formations) from Urmia lake (20) to volcanic and igneous masses of rocky outcrops of Sahand Mountain activity. In terms of geomorphology, Maragheh metropolitan is located on an alluvial fan and on the bank of Sofi-chay River. From the north and northeast parts, it is limited by Sahand Mountain and it has caused the establishment of Maragheh tuff (Pl_t formation) in these sectors. This city is limited to the Bonab and Urmia Lake basin from the west (25). Geomorphological and topographical structures like other geological factors are the most affective parameters for transformations in the earth's surface and it is considered as the most important principle in the creation, changes and volatility of weather, erosion, evaporation, wind, sedimentation, etc. (26). In landfill site selection, the structure of the earth is the first issue to be considered so that plain areas, due to low erosion, topographical uniformity (in terms of ups and downs), low hydraulic gradient have the priority. For this purpose, the elevation and dips maps of the studied area, based on DEM data, have been prepared and are shown in Figs. 4 and 5, respectively. Tectonically, Iran is located in the Alps-Himalaya's belt and is very active. Also, this country is in the compressive situation treated by Arabia plate and Eurasia plate in SW-NE and shortening with oriented NW-SE direction (27). In the Azerbaijan province, tectonic setting is more complex than the whole country (28). This region is formed by a collision of three Arabia, Eurasia and Aral tectonic plates (29). Maragheh city was in the forehead of Arabia plate compression and is tectonically under stress in NNE - SSW, thus geo-structural shortening is NNW-SSE on this region. Thus, tectonical structures established in the area are mostly parallel with this strike. According to the field surveys, geomagnetic surveys, and remote sensing investigations conducted in study area, tectonic structures can be divided into folds and faults groups. Tectonic structures maps of Maragheh are shown in Figs. 6 and 7. In addition, this city, as is located in a seismically active zone, has witnessed many earthquakes (Fig. 8).

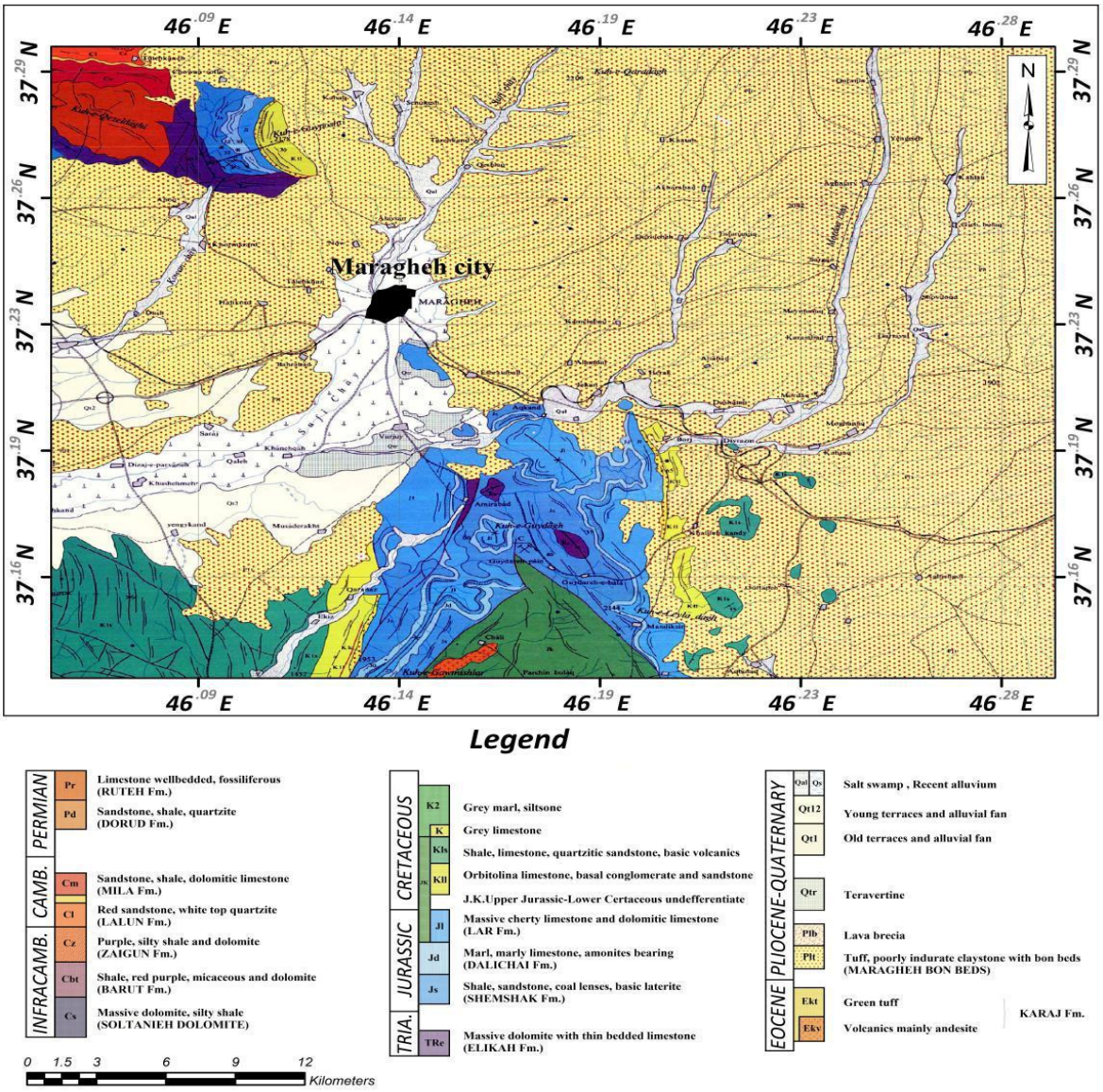

Fig. 3- Geological map of the Maragheh region (30)

Hydrological and hydrogeological factors: The Maragheh region, due to certain geological conditions and being on the Sahand alluvial fan, is considered as drainage path for Maragheh-Bonab plain and Urmia Lake basin. Drainages with erosion-sedimentation cycles in lapse of time have caused changes in the morphology of region. For determining the location of a landfill site, it should be noted that the site should not deal with drainages, rivers, and streams, because waste leachate can contaminate water bodies (8). Therefore, surface drainage mapping for site selection is required. This map has been prepared for Maragheh and is shown in Fig. 9. In conducting hydrogeological studies, the depth of groundwater table and its seasonal fluctuations, hydraulic conductivity, and hydrodynamic factors should be considered. In order to measure and calculate the described parameters, 11 boreholes were drilled in Maragheh plain (31). The results of hydrogeological studies are presented in Table 3.

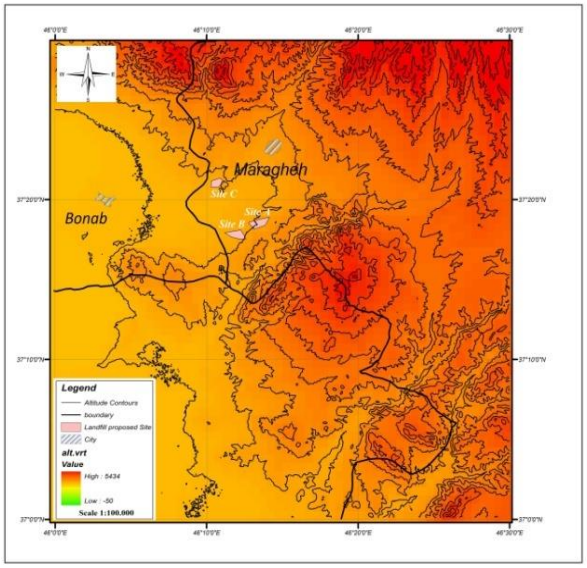

Fig. 4- Topographical map of Maragheh region (altitude rate)

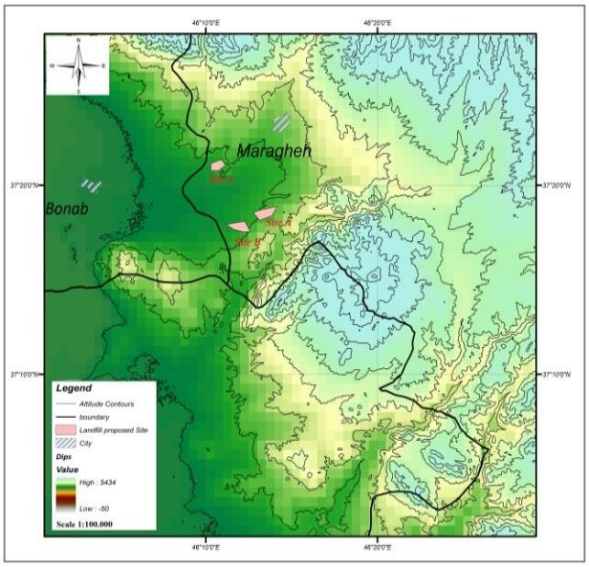

Fig. 5- Dips variation map of Maragheh region

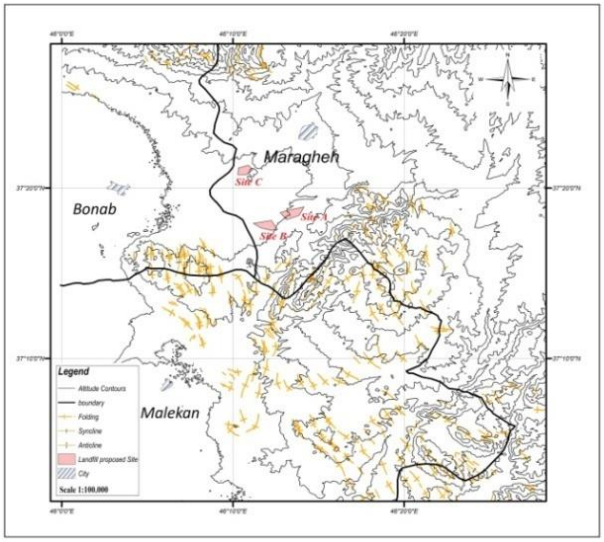

Fig. 6- Folding map of Maragheh region

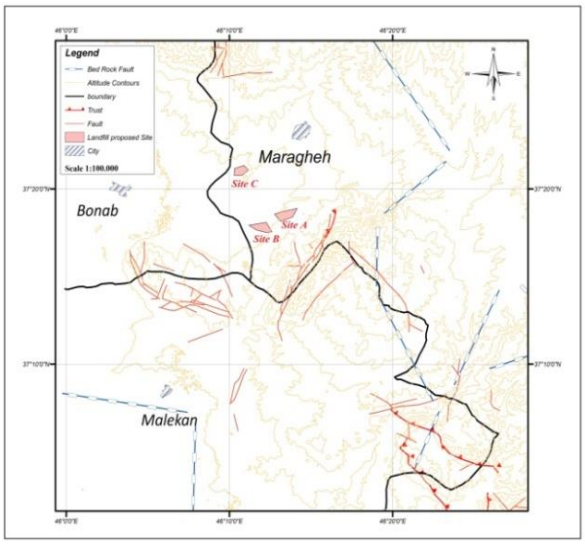

Fig. 7- Faults and tectonical lineaments map of Maragheh region

Urban management factors: Urban system is one of the most important parameters in site selection of municipal structures (32). In the landfills case, urban systems have limitations such as access to roads, railway, distance from residential areas, industrial areas, town, main roads, water bodies, dietary sources, distance from particular zones, military bases, power plants, distance from special structures like dams, tunnels, highways, airport, infrastructure projects, special land use, cultural, historical and religious zones, etc. (33). Landfill constructions near rural and urban residential areas and towns can cause negative impacts on the population due to odour, dust, and noise (34). According to urban planning regulations, the establishment of landfill constructions near particular zones, military bases, power plants, aquatic ecosystems, water supplies and dietary sources is not allowed (35).

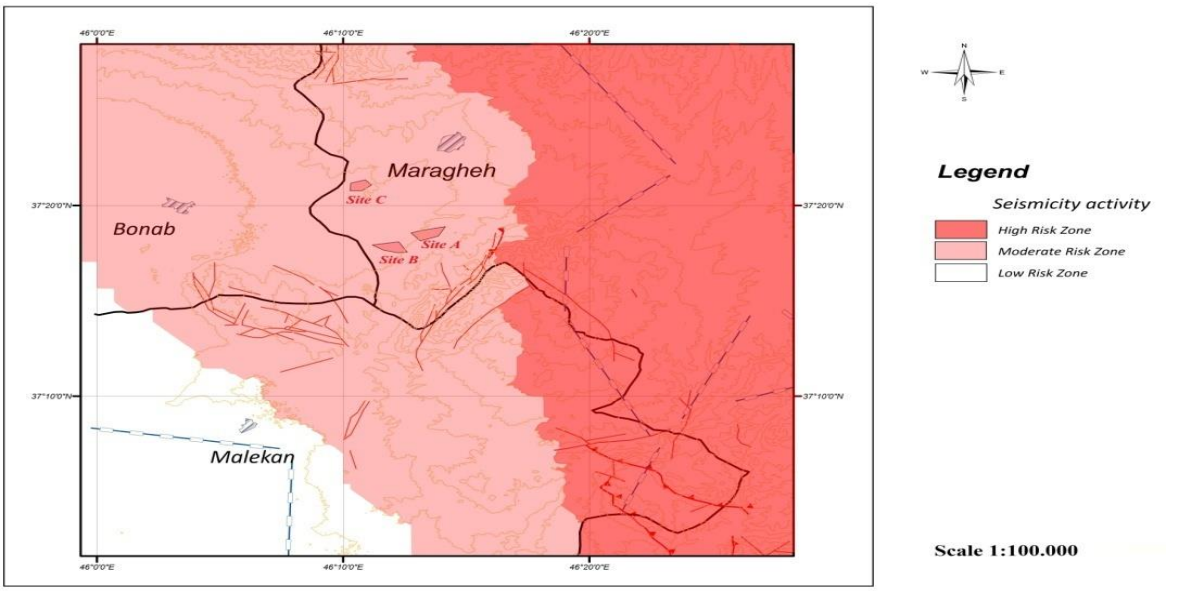

Fig. 8- Seismic zonation map of Maragheh region

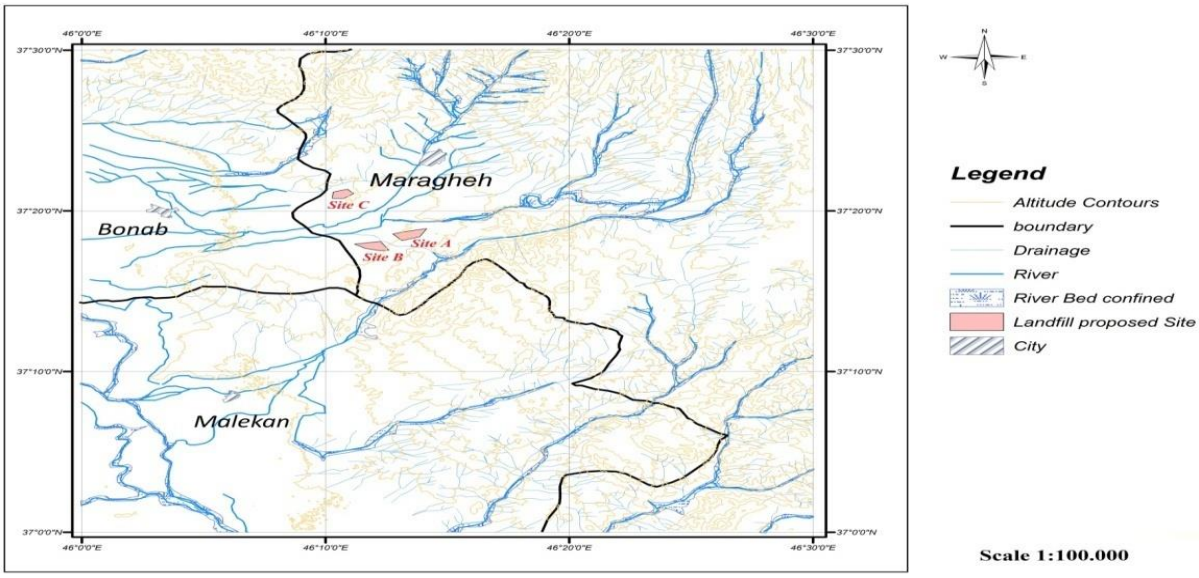

Fig. 9- Surface drainages dispersion map of Maragheh region

Table 3- The results of hydrogeological studies of Maragheh plain (31)

B.H.	Village	Water table depth (m)	Cross length (m)	Hydraulic gradient	Transferability (m^2/day)	Inflow volume (m^3/day)	Outflow volume (m^3/day)
1	Aleyvan	25.6	5263	0.009	525	24867.6	1262.8
2	Nova	12.5	1447	0.008	100	1157.6	1010.4
3	Gale	11.5	2105	0.007	100	1473.5	1183.5
4	Sirij	9.3	1842	0.005	100	921	1893.6
5	Narjabad	11.9	1315	0.01	400	5260	15030.72
6	Khangah	20	5000	0.011	500	27500	1620.64
7	Zineg	12	4473	0.016	400	28627.2	3157.6
8	Dizej	14	2236	0.015	500	16770	6156.8
9	Chlaghay	11	3421	0.01	500	17105	24866.1
10	Ravosht - bozorg	11.7	1578	0.009	350	2534.9	4970.7
11	Ravosht - kochak	13.3	4736	0.005	350	25509	8288
Total Flow (m^3/day)						151725.8	69440.86
Total Flow (MCM/year)						45.14	25.34

In Maragheh landfill site selection, each sub-criterion of urban management factors is weighted separately by AHP. The maps of the results of these weighted criteria were obtained via ArcGIS software (22). Maps of Land use, access to roads and distance from main cities for studied area are shown in Figs. 10 to 12. In addition, Tables 4 and 5 present urban management and municipal waste studies and land use level data in the city of Maragheh.

Environmental factors: Landfill is considered as an environmental structure due to high potentials for contamination (7). The major parameters considered in environmental engineering of landfill site selection are presented in Figs. 13 to 17 and expressed as follows (4):

Weather conditions like climate, erosion, rainfall, temperatures, evaporation, and wind
Vegetation
Distance from environmental protected area
Distance from basins and aquatic ecosystems
Distance from regions with damage potential
Distance from floodplains
Distance from regions with flooding potential
Distance from landslide
Liquefaction

Engineering geological and geotechnical factors: The main issue facing the construction projects is site investigation and establishment of a link between engineering and design (36). In each project, the geological engineering and geotechnical studies are required. In order to have a successful design, a vision of the selected site's present condition must be gained. Although, there may be some sites assessed to be appropriate in terms of environmental conditions, they should be abandoned due to their engineering geology and geotechnical features. In landfill site selection, in order to determine the suitable place for waste sanitary landfill, the geological engineering and geotechnical factors are considered as practically basic infrastructure and operation of landfill construction.

Table 4- The results of urban management and municipal waste studies in Maragheh city

No.	Item	Outcome	Considerations
1	Effective radius	25 km	
2	Term interest in the landscape	40 year	
3	Current population	163,859 p	(21)
4	Expected population growth	2%	Statistical analysis
5	Waste production capita (person per day)	750 gram	(21)
6	Waste production capita (city per day)	140 ton	(21)
7	Waste produced (person per year)	273.75 km	Statistical analysis
8	Waste produced (city per year)	51100 ton	Statistical analysis
9	Waste compounds	Most household	Field surveys and field observations
10	Type and concentration of waste	Organic and moist matter	Field surveys and field observations
11	Leachate produce ability	Yes	Field surveys and field observations
12	Terms of leachate	Bio-organic, saline	Leachate chemical tests
13	Environmental effects	High pollution potential	Leachate chemical tests
14	Waste transportation	Vehicle	
15	Landfill final use	Unsuitable for construction	Large-scale land subsidence

Table 5- Levels and information of land use in hectares (21)

Item	Maragheh municipality	Area of Maragheh County (%)	Area of EA province (%)	Total involved area
Level A				
Forest and woodlands	00000.0	00000.0	00000.0	00000.0
Dense pastures	32573.5	14.9	3.7	892123
Semi-dense pastures	73586.5	33.7	6.7	1099675.4
Agricultural lands	27524.5	3.2	8.3	574353.8
Dry farming	49705.7	22.7	6.6	755310.6
Irrigated farming	2806.2	1.3	10.3	27350
Gardens	4218	1.9	14.9	28372.5
Residential areas	1337.9	0.6	8.7	15396.1
Watershed	330.2	0.2	18.9	1747.4
Industrial areas and facilities	7676.3	3.5	1.7	442316.6
Barren and unused areas	218.7	0.1	17.6	1242.6
Lagoon	67.8	0	0.1	8264.9
Land without data	295.1	0.1	2.7	10853
Total	218565.9	100	100	4492448.5
Level B				
Forest and woodlands	00000.0	00000.0	3.9	175511.4
Pasture Lands	124385.6	56.9	57.1	2566152.2
Agricultural lands	84254.3	38.5	26.6	1195488.3
Barren and unused areas	7744.1	3.5	11.7	52057.5
Other	2182	1	0.7	29239.1
Total	218565.9	100	100	4492448.5

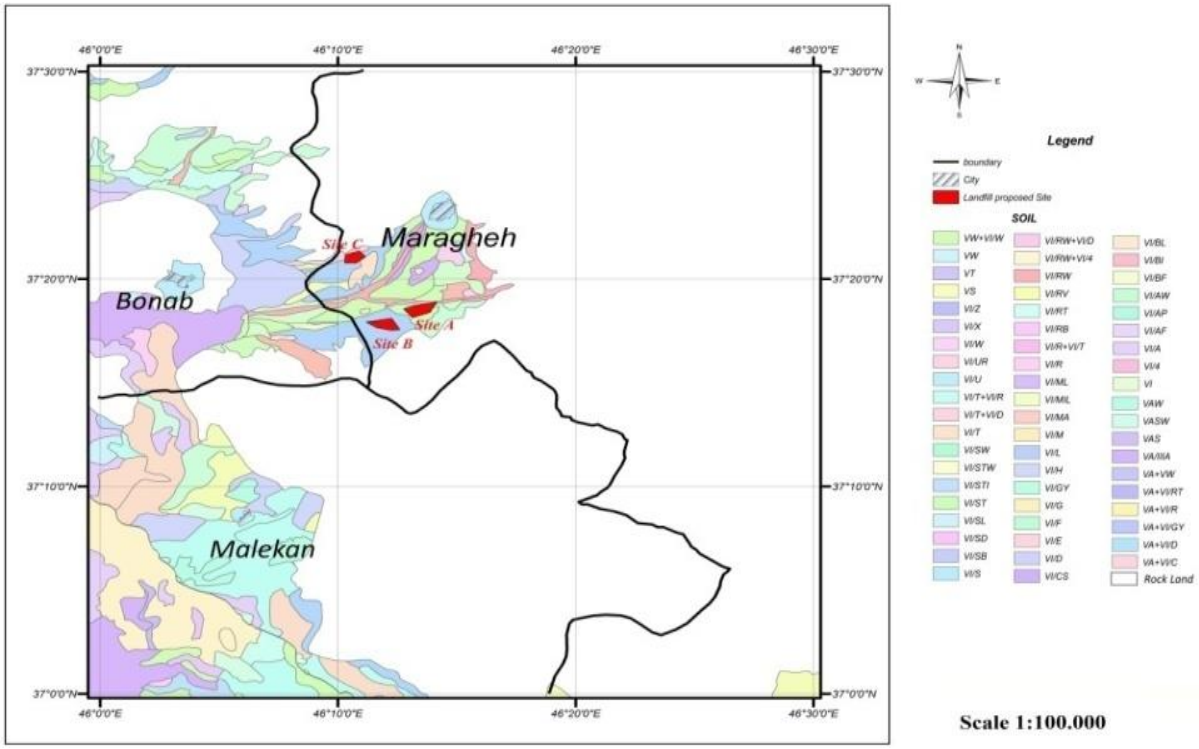

Fig. 10- Land use map of Maragheh region

Lack of implementation and consideration of these factors have always been accompanied by leachate transfer (infiltration) and extensive environmental contamination (8). In order to estimate the engineering geological and geotechnical parameters, laboratory experiments are needed (21). In the city of Maragheh, landfill site selection was carried out based on remote sensing studies. Three sites have been pinpointed and proposed. During the surveys carried out on these sites, samples were taken and transferred to laboratory for grain size analysis (37), hydrometery (38) and Atterberg limits (39). The results of these studies are shown in Figs. 18 to 22.

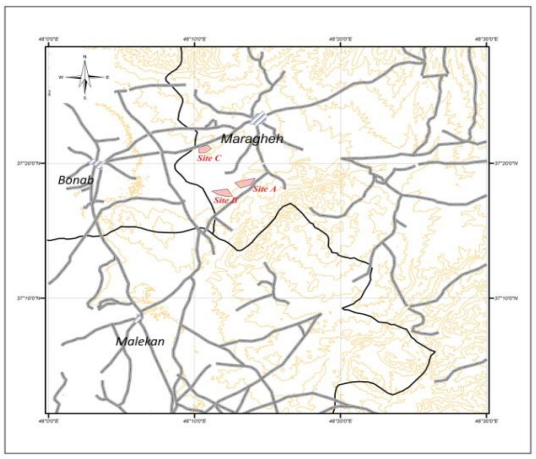

Fig. 11- Roads access map of Maragheh region

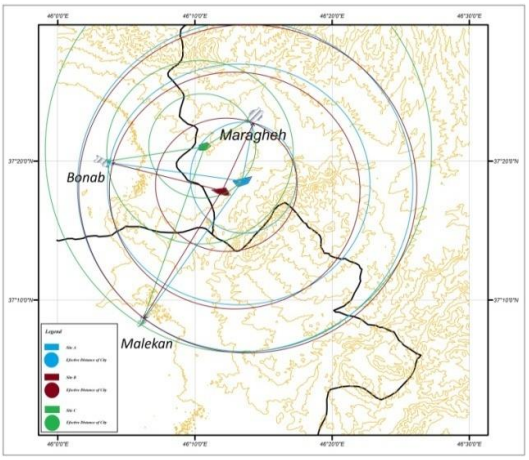

Fig. 12- Distance from main cities map of Maragheh region

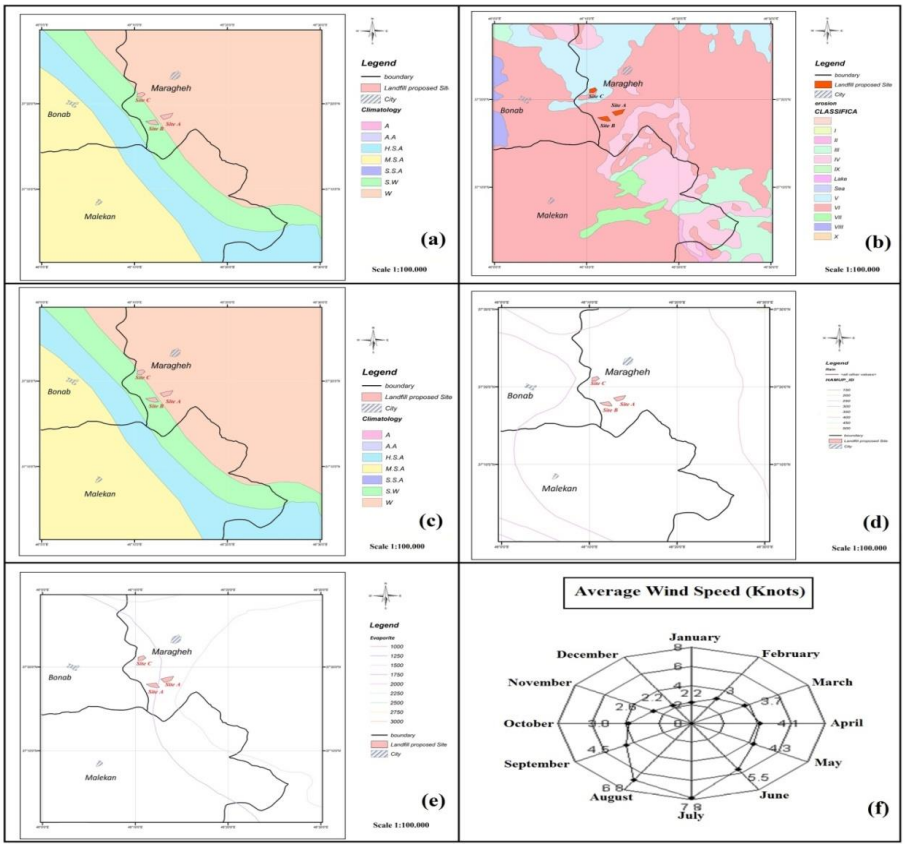

Fig. 13- Weather condition maps of Maragheh region, (a) climate, (b) erosion, (c) rainfall, (d) temperatures, (e) evaporation, (f) wind

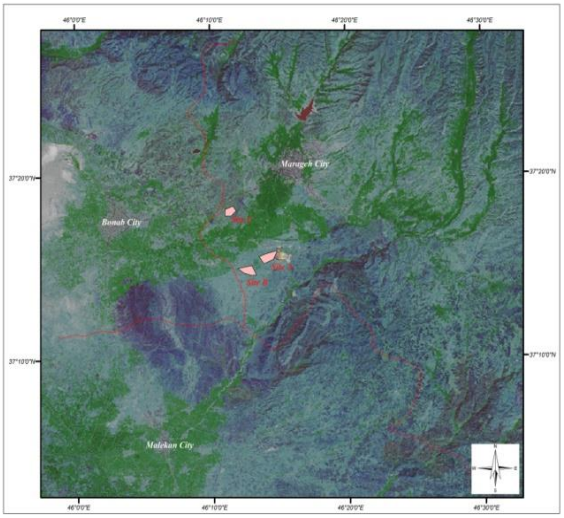

Fig. 14- Vegetation cover map of Maragheh region

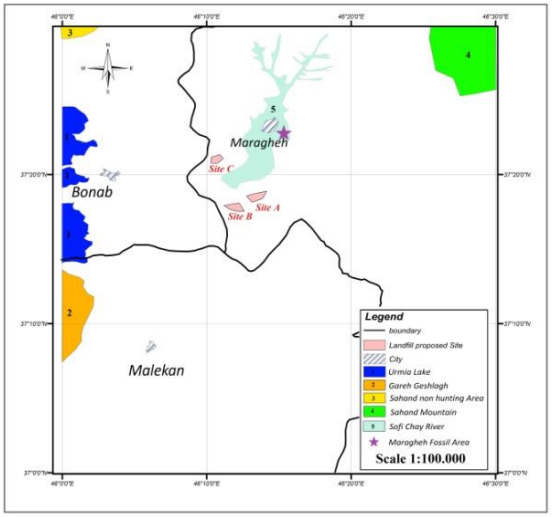

Fig. 15- Environmental protected area map of Maragheh region

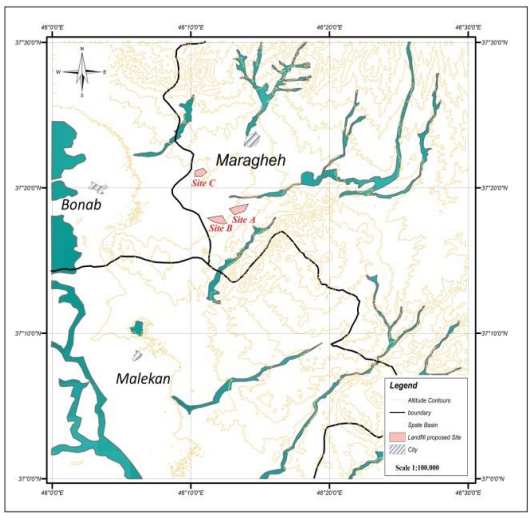

Fig. 16- Floodplains map of Maragheh region

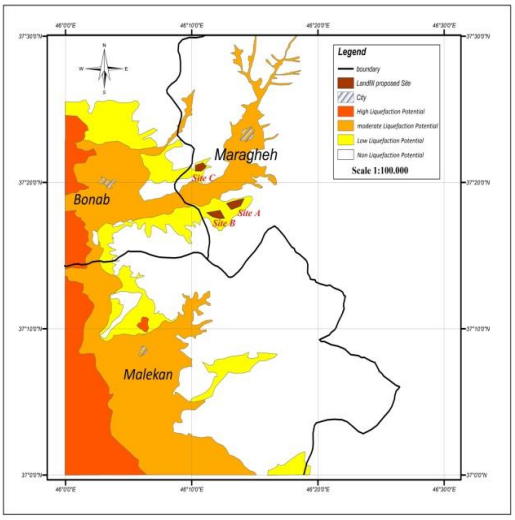

Fig. 17- Liquefaction map of Maragheh region

Fig. 18- View of the grain size analysis test

Fig. 19- View of the Atterberg Limits test (Casagrande method)

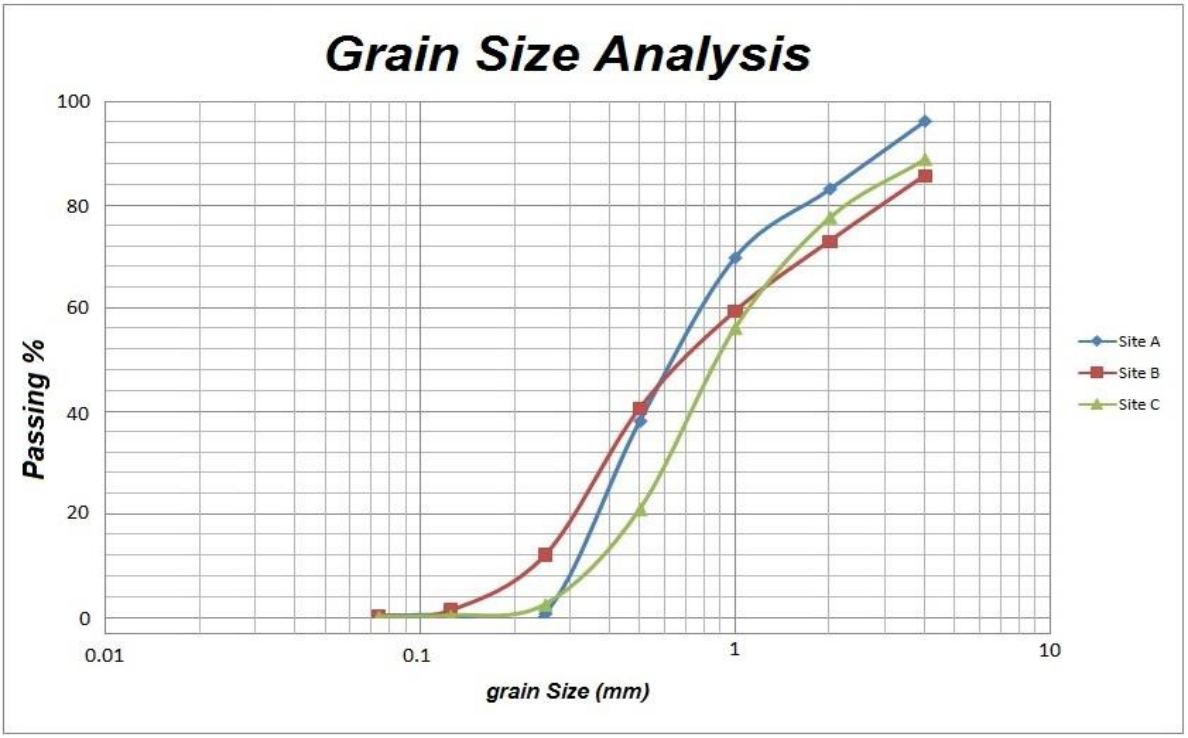

Fig. 20- The results of grain size analysis of samples

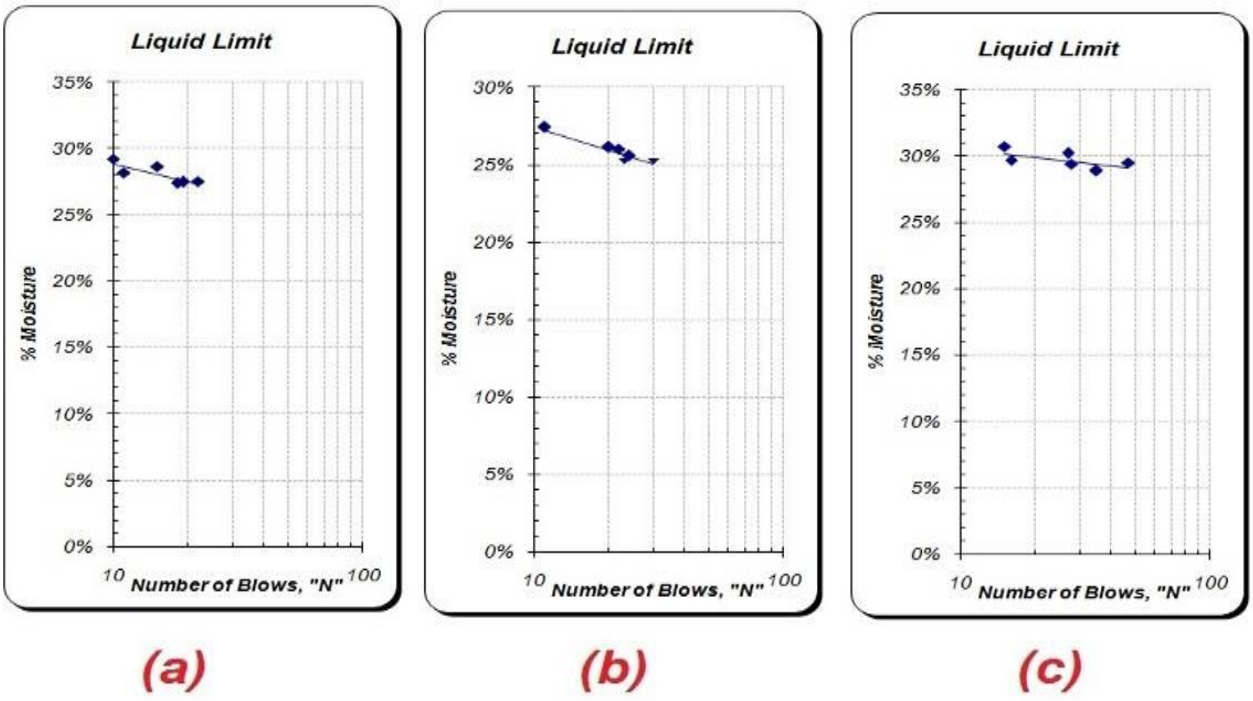

Fig. 21- The results of Atterberg Limits of samples, (a) Site A, (b) Site B, (c) Site C

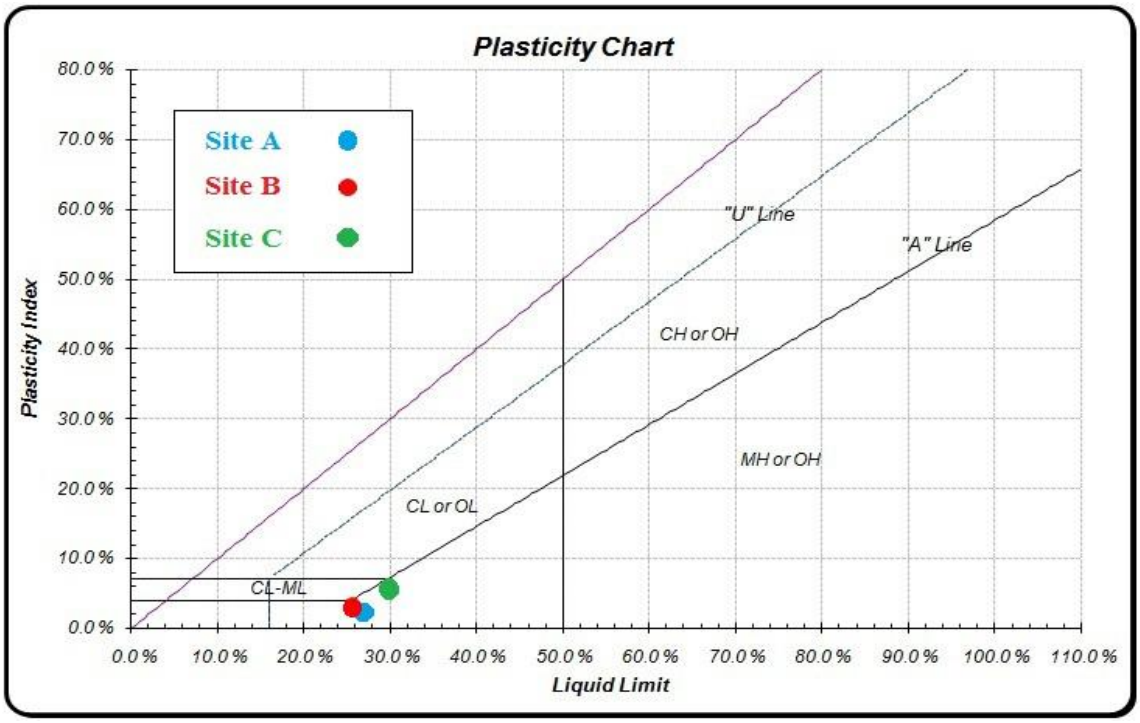

Fig. 22- Distribution of samples in plasticity Chart

AHP and MCDM decisions: The AHP process was applied in Maragheh landfill site selection by using the MCDM technique and sub-criteria were defined based on USEPA (4) and TCGLE (5) regulations criteria. In this study, all parameters were calculated for three proposed sites and there were applied in a pair-wise comparison matrix and normalised principal eigenvector for landfill site suitability factors. The results of multiple-criteria decision making of Maragheh landfill are shown in Figs. 23 and 24.

Discussion and Conclusion

Lack of waste management studies has caused serious damages to the environmental and public health, which in many cases makes the restoration of initial state and reclamations practically impossible. Therefore, appropriate management and monitoring in urban waste management is a crucial matter that must be considered. The first step in waste management is the site selection of landfill. Selection of a suitable site based on geological, hydrological, hydrogeological, urban and environmental management and other factors such as social, cultural, psychological, economical are among the most recommended issues in the developing countries. However, in Iran, these parameters (especially the first factors) are paid less attention and leachate problem and water resources pollution always exist. In this study, GIS and AHP are used in combination with layers and multifunctional variables for municipal waste landfill siting in Maragheh city. For this purpose, all factors (USEPA and TCGLE regulations) were considered. Thus, the three suitable areas (named sites ‘A’, ‘B’ and ‘C’) are proposed for municipal waste disposal and sampling was taken along with geotechnical laboratory

tests such as grain size analysis, hydrometry and Atterberg limits. Results indicated that 'Site A' is categorised in MH, 'Site B' in MH with CL-ML, and 'Site C' is MH with CL classes in USCS classification system. According to the Atterberg test results, the proportions of these sites are as follows:

- Site A: LL = 27.9 %, PL = 26.6 %, ω = 27.5 % and PI = 1.3 %.
- Site B: LL = 24.6%, PL = 22.6 %, ω = 22.5% and PI = 2.0%.
- Site C: LL = 28.9%, PL = 24.2 %, ω = 24.2% and PI = 4.6%.

After deciding with AHP and MCDM, 'Site A' was recommended as the best location for sanitary landfill.

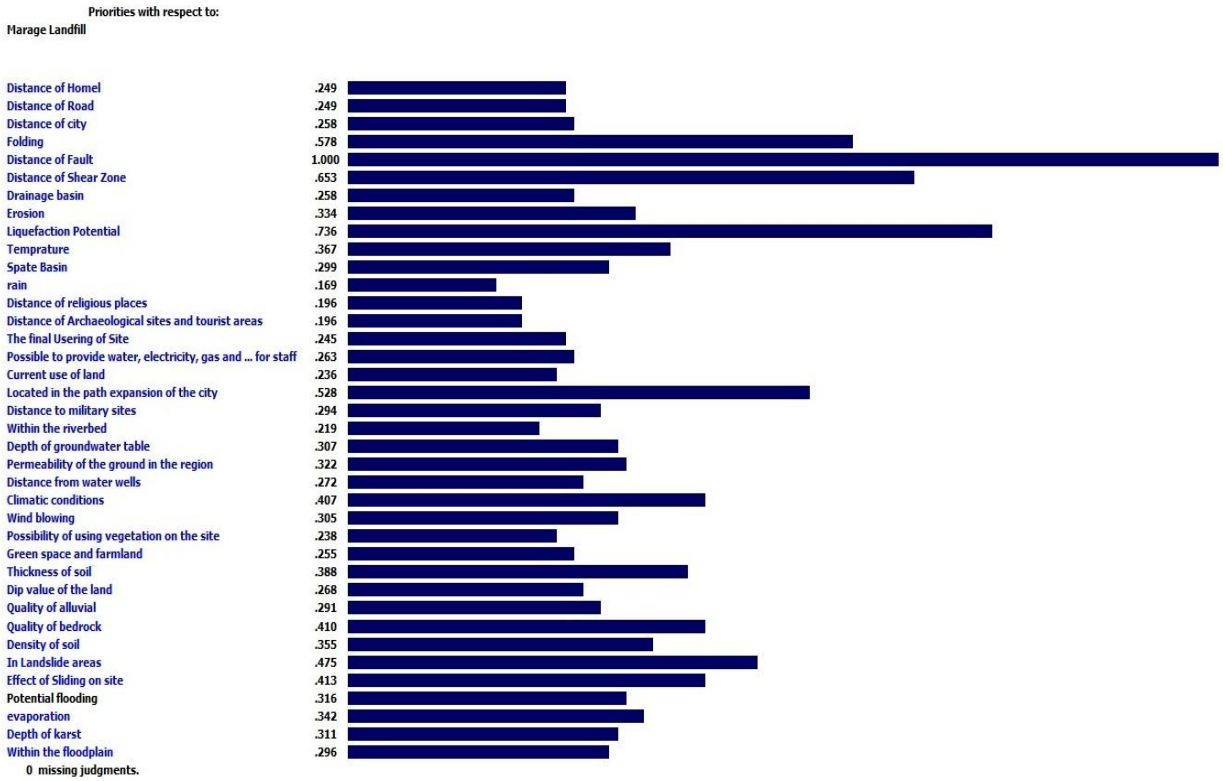

Fig. 23- Results of multiple-criteria decision making of Maragheh landfill

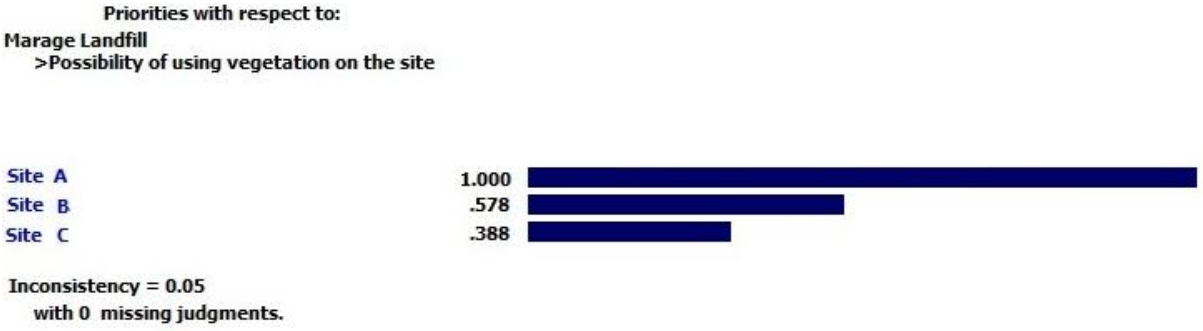

Fig. 24- Results of Maragheh landfill site selection

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