Comparison of two suitability methods to assess a landfill site using Geographic Information System Analysis

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Abstract

Open dumping is the common procedure for final disposal of Municipal Solid Waste in Iran. Several environmental pollutions and land degradation have caused in Iran because of poor planning, insufficient financial resources, lack of rules, guidelines and regulations in MSW management system. In Iran standards and regulations of environmental issues are not perfectly attended, evaluation an open dumping can show existing restrictions and troubles in these areas. So recognition of the MSW landfill state is required to prevent environmental problems and the negative environmental impacts. The objective of this work is study the suitability of Tonekabon existing municipal landfill site in the west area of Mazandaran province, located in north of Iran, and the south coast of the Caspian Sea using Geographic Information System methods. In order to carry out this evaluation, two guidelines are used, Minnesota Pollution Control Agency (MPCA) and Regional screening guidelines. Eventually the authenticity of the deposit site and also the entire city was examined. The results indicated the incoherence in appropriateness of the existing landfill site, with two mentioned methods and field view and also the shortage of suitable areas in Tonekabon city based on Regional screening method compared to MPCA method.

1 Introduction

In the developing countries, due to population increase and urbanization, it is necessary to develop an efficient waste management system. Despite of the developing in waste management in the world, the disposal of solid wastes in landfills still remains the most commonly used method in developing countries. (Sumathi et al., 2008). Sanitary landfill is one of the initial methods of municipal solid waste disposal. It is the most commonly used method for urban solid waste disposal (Mahini and Gholamalifard, 2006). Of course sanitary land-filling is one of the best ways to reducing environmental health problems, and gathering the gas and leachate and in addition, it can decrease the volume of waste quantity (Wang et al., 2009), nevertheless lack of effective environmental laws and enough land for landfill site sitting in developing countries is a main issue which causes many problems. Unfortunately, in most Iranian cities, the simplest method of waste disposal is still confined to pile-up and open dumping. An open dump site is a great environmental hazard which causes natural resources degradation and environmental pollution. Previous works found that leachates from landfills had contaminated the underground water (Mor et al., 2006; Dimitrio et al., 2008; Nema et al., 2009), and soil (Raman and Narayanan, 2008; Shaylor et al., 2009; Hernandez et al., 1997). Another main problem in open dumping and also in this mentioned site is open air burning because of gases emitted from waste degradation process. In some literatures the effect of fire on soil have been studied (Guenon et al., 2013; Leon et al., 2014). The other serious threat to soil in landfill site is salinity, improper land use such as deforestation causes soil salinity. Salinity effects on soil physical and chemical structure, and causes soil degradation and promotes underground water salinization level (Iwai et al., 2013). One of the major cause of land degradation is insufficient and improper land use management, the effects of land use changes on degradation had been examined (Mohavesh et al., 2015). Our research is an example for improper land use which causes forest degradation. There are many research investigations, emphasize the negative impacts of improper land use management system (Biro et al., 2013; De Suza et al., 2013; Pallaviciny et al., 2014).One of these unsuitable systems in developing countries is MSW management system and improper landfill site sitting. To protect the environment and natural resources in the developing countries, a proper solid waste management is a necessity (Rao et al., 2007). In most developing countries, the environmental standards are not completely considered, so the environmental evaluation of landfills is an example of these limitations and problems. Despite the increasing advances in modern methods of locating waste landfills in the world, 49 percent of the total solid waste

disposal methods in Iran is piled up which is unsafe method. (Abdoli, 2005a). The MSW management systems in Iran are not in good condition. These systems have not been adequately progressed in Iran and so the open dumping of solid waste is a prevalent manner. Despite numerous efforts around the world, in order to reuse the municipal solid waste, unfortunately in Iran, wastes are dumped without any consumption. In this time reuse of waste and treated wastewater has increased in the world (Murogan et al., 2013; Al-Karaki et al., 2011). In Iran the municipalities are responsible for MSW management systems and there are not administrative legislations for landfill site siting. Due to Poor planning, insufficient financial resources, defective collection system, insufficient data and experience, unsuitable disposal convenience, and insufficient rules ,guide lines and regulations and totally a lack of knowledge of new municipal solid-waste management options in municipalities, and increasing needs to remove wastes from cities , final disposal way which municipalities select is uncontrolled dumping (Abdoli, 2005b).The Most common way of waste disposal in humid regions as the south coast of the Caspian sea has been open dumping too. (Monavari and Shariat, 2000). The quality and quantity of municipal solid waste crated in the southern coast of the Caspian sea in Iran has changed in during the previous years, but unfortunately the methods of collection, transportation, and disposal have remained the same. So there are many serious environmental problems. For example, some of the rivers and forests and coastal regions in Iran are contaminated and destroyed and have been converted into dumping sites (Diaz, 1997).Therefore, it is both essential and useful to understand the quality of current municipal landfill sites included in this study area too. Some evaluation of municipal landfill sites have been done in Iran and the other parts of the world by different methods, for example Monavari and partners evaluated all the landfill sites in Tehran province in Iran by Oleckno method, (Monavari et al., 2007), Salimi and partners evaluated the suitability of the new sanitary landfill site location in Isfahan with Oleckno method too (Salimi et al.,2013), Assessment of groundwater vulnerability to landfill leachate induced arsenic contamination in Maine had been done with Drastic method (Wang, 2007), USEPA method (Christensen et al., 1992); In another research in Iran two municipal solid waste landfills, Rasht in Gilan province in the north of Iran and Andisheh, in Karaj Province which are, respectively, located on humid and arid areas, were evaluated by Monavari 95–2 method (Ghanbari et al., 2011), and the Karaj municipal landfill site had been evaluated by local and Regional Screening method (Aliowsati et al., 2013), Davami and partners evaluated the municipal solid waste landfill site in Ahvaz city by local screening incorporating GIS (Davami et al., 2014). The first step to

improve MSW management system is evaluation of the current landfill sites state in the country. The objective of this work is to evaluate the Tonekabon landfill site suitability using two methods: Minnesota pollution control agency and regional screening method.

2 MATERIALS AND METHODS

2.1 Area of study

Tonekabon region (1631.8 km^2) is located in the west of Mazandaran province, on the Northern edge of Iran between Ramsar and Abas Abad city (Fig. 1).The MSW landfill of Tonekabon is located at Dohezar road, 30 km from south of this city in the Pordesar forest. This site has an area of over 5 acres, located at 36◦42′ N, 50◦49′ E at 520 m above the sea level. Located between the Alborz mountain range and Caspian Sea, the studied area has temperate and humid climate. The average annual precipitation from the nearest meteorological station (Khoram abad station) is equal to 994 mm, and monthly relative humidity is 82%. The input solid wastes which are collected from 3 municipal districts to this site are 70 to 100 tons per day: central district, Nashta, and Khoram Abad districts with 149010 inhabitants (Tonekabon municipality, 2014). Application of the methodology is based on the collection of data related to the physical environment, state and characteristics of deposit site. Data collection involved visiting the current deposit area as well as studying the existing information. In this study, input map layers according to mentioned guidelines including; surface water (rivers and lakes), flood basin, geology (fault, bedrock, Seismicity), ground water, underground water resources (springs and wells), land use (agricultural land, forest land, residential area), distance to airport, distance to residential areas, road distance to waste production centres. In this site wastes are dumped in the forest without applying any environmental and engineering standard. More precipitation of the area provides more humidity, more leaches. The lack of proper waste management systems and humid climate increased environmental problems in this site.

2.2 Investigate the evaluation criteria

Sanitary municipal solid waste landfill site sitting, such as the other engineering project needs basic information and accurate planning (Chang et al., 2008). Methods of evaluating landfill site measure many spatial criteria which, supplying different and proper spatial data, and matching between the suitable parameters and regulations is mandatory. There are many methods to landfill site sitting in the world which can found in past researches and articles, (Alexakis and Apostolos, 2014; Rezazade et al., 2014; Moeinaddini et al., 2010; Sumathi et

al., 2007) while in this research two methods, Minnesota Pollution Control Agency method and Regional screening guideline are used to suitability evaluation of the current Tonekabon landfill site. Each system, evaluates waste site according to the criteria described below:

a. MPCA method:

MPCA method, the prevalent method in landfill siting, was presented by the Minnesota Pollution Control Agency in 1983 (Badve, 2001). In this method of landfill siting, 6 determinative factors and 7 conditional factors are allocated. Complete achievement of 6 determinative factors is committed in landfill siting where as other conditional factors should be achieved by engineering considerations. Determinative and conditional factors utilized in MPCA method are illustrated in Table 1.

b. Regional screening method:

In regional screening method, three important parameters such as natural conditions, land use and economic factors are considered. (Ball, 2004) each of which include:

Natural Conditions

1. The MSW landfill sites should not be sited near the surface water (minimum distance of 61 m should be observed).

2. Regions with high underground water levels are not compatible for MSW sites, if the hydraulic trap method is used.

3. The MSW landfill site should not be sited in the ravines.

4. The areas with shortage supply of heavy clay and fine grained soil for using coating layers are not suitable for municipal solid waste landfill siting. This soil type should have a permeability coefficient of minimum $10^{-9} m/s$ The layers of clay-silt type soil under the landfill should be with permeability of $10^{-9} m/s$ at least the depth of 15m and more.

5. The distance from faults must be at least 61 meters.

6. The regions with slide risk potential and sensitive clays are not suitable for landfill sites.

7. The regions with high sensitive soils such as limestone and fragile soils are not suitable for landfill sites.

- Land Use

1. At least distance of 150 m from, commercial, educational and residential centers and at least 80 m from industrial applications.

2. At least 3 km distance from the airport

3. At least 300 meters distance from water wells

4. The agricultural land use can be suitable for solid waste landfill sites.

- Economic Factors

1. A proper distance from the main road should be considered. (Less than one kilometre is ideal).

2.3 Preparation and investigation of thematic maps and overlaying these maps in Geographic Information Systems (GIS)

Evaluation of a suitable landfill site is a complex procedure which involves evaluating aspects, such as regulations, environmental, socio-cultural and engineering factors. Using Geographic Information Systems (GIS) for evaluation and choosing a proper location for the landfill sites is an economical and practical method which had been used in past researches (Ghanbari et al, 2011; Sumathi et al., 2008; Mahini and Gholamalifard, 2006). Over the last few years, GIS has emerged as a suitable tool for land use analysis (Malczewski, 2004). Using GIS is helpful to distinguish between more suitable and unsuitable or restricted by regulations or constrained locations. However, the combination of findings from GIS software

and field view is very useful. In this study our work is, considering the characteristics of the Tonekabon landfill site based on reviewing the library information, past literatures and so application the digital maps in Arc GIS version 10.2. Most maps and data were obtained from Mazandaran Management and Planning Office of Governor. And its scale is 1:100,000.The surface and ground water maps were obtained from the Geographic Information Centre of Mazandaran Regional Water Organization with the scale of 1:250,000. The landfill site map layer is prepared by locating the GPS coordinates of Tonekabon landfill site in field view and entering it as latitude and longitude in the GIS software database, and then converting it into the point data. In this research, at first the geographical and environmental condition of Tonekabon landfill site is identified then, Minnesota Pollution Control Agency and the Regional screening methods are applied to evaluation of mentioned Landfill site. So in this study 12 criteria maps according to evaluation criteria in MPCA method and Regional screening guidelines were used. Fig 2 showed the Tonekabon landfill site location and condition.

2.3.1. Data and evaluation criteria

After collection and preparation of the thematic maps according to evaluation criteria in MPCA method and Regional screening guidelines the characteristics of studied area are mentioned in below:

Surface water (Hydrology) map: These are important environmental factors due to potential risk of contamination. There is no lake and pool in this area. Because of the specific climate conditions, there are multiple rivers in this area, and the nearest river to this site is located far from 1.8 km. The distance less than 61 metres according to Regional screening and at least 92 metres based on MPCA method are unsuitable and more than these distances are suitable.

Infiltration Map: An infiltration map displays the various soil types existing in the studied area. The infiltration rate is a key parameter to evaluate the probability risk of underground water pollution, and thus is important factor for landfill site sitting in the study area. This map is used to estimate the ground water level and soil type. The infiltration of this site is high and the soil type is silt clay loam. So the high level of underground water is not suitable.

Residential areas map: This map displays the existing cities and villages. There are 4 towns in Tonekabon city, Khoram abad, Shiroud, Tonekabon, Nashtaroud, the nearest one of them, Khoram Abad, is located at the distance of 10 km to this site. There are 875 villages in this studied area too. So the distance of less than 150 m from residential areas is not suitable for landfill site base on Regional screening legislation.

Road network map: The road network map delineates all the major and minor roads of the studied area. The location of the landfill is at the distance of about 3 km from Dohezar main road.

Land use map: It illustrates the land used by human and the natural environment in the area. This map shows good and medium ranges, gardens, agricultural lands, forest and four towns in Tonekabon city .The dominant type of land being used in this area is forest .This landfill site is located in Pordesar forest.

Ground water source (Hydrogeology) map: This map displays the wells and springs in this area. The nearest well is located at the distance of more than 6 km; and the nearest spring is located far from about 3 km.

Geology map: This map shows that dark grey medium bedded to massive limestone (Ruteh limestone) is geological unit in the landfill site.

Protected area sites map: The map displays the protected areas, under the management of the Department of the Environment of Iran (DOE). Beleskoh protected area, is located at distance of less than 2.5km to landfill site.

Flood basin map: This map shows that the studied landfill is not at risk of area with 100 retention period flood.

Faults map: This map displays the existing faults of this area. The areas without faults or the ones which have a safe distance from the faults are suitable for landfill sitting. In this study area we have two kinds of major and minor faults. The nearest fault is located far from 2.5km.

Airport map: There is not any airport in this city, the Ramsar airport is located at the distance of about 13 km far from Tonekabon town centre.

Municipal solid waste landfill site map: This map displays the location of Tonekabon landfill site in studied area.

Fig.3, show the flowchart of the methodology followed in the study. We have two kinds of maps in this research: factor maps such as geology, land use, … and Constraint maps such as distance to residential area, distance to faults, distance to river, protected area, … . Since each of the 2 methods have some do's and don'ts to evaluate landfill sites, we standardized the constraint and factor map layers based on Boolean logic. So all the mentioned area in the MPCA method and Regional screening guideline and their regulations are forbidden to landfill site sitting (constraints) and also the distances which must be considered (buffers) in the map layers have been evaluated 0 and the other areas have been evaluated 1. Thus with the reclassified module in Arc GIS software, the restricted area's value was zero (unsuitable area) and the other area's (suitable area) value was one, as a form of coefficient. The GIS-based constraint mapping technique was applied to the study area. Different criteria are used to obtain GIS data sets of the buffer zone for rivers, water supply sources, fault lines, cities and flood basins. Maps represent the acceptable distance which should be considered in site sitting for different criteria using the buffer option in ArcGIS. They were produced on the basis of existing standards which are indicated above. The areas within the buffer zones are not suitable for landfill sitting and solid waste disposal. Buffer maps are generated in which the 'areas of constraints' are displayed. Such areas which are encompassed from residential areas, rivers, water supply sources, roads and fault lines. For example, in order to prepare the buffer for rivers in MPCA guideline, at the first the rivers in our studied area were investigated then around each of them a buffer distance of 92 metres was performed. In the same way, buffer zones for the other criteria such as roads, water reservoir sources and faults, were created at a distance which is mentioned in 2 methods. A GIS-based overlay analysis of generated Boolean factor maps and Boolean constraint maps was done in order to identify the landfill site suitability. After reviewing all specified criteria in each of the guidelines, the authenticity of deposit site and the study area was identified.

3 Result

Available information related to geology, hydrogeology, hydrology, soil, land use, collected and produced based on current studied area in a digital format. So these maps at various scales and containing various types and amounts of information were used in preparation of the geographic database. After that thematic maps and GIS data maps were prepared base on mentioned parameters for evaluation of landfill site, the thematic maps, overlaid upon one another. GIS based analysis was applied according to proposed algorithm which mentioned in methodology. Also field studies were implemented in terms of providing more information for a suitability evaluation. After reviewing current site with maps and field views; it was found out that Tonekabon landfill site is suitable based on MPCA determinative guideline (see Tab. 4), but it is unsuitable according to Regional screening method (see Tab.5). Totally the suitability of Tonekabon city base on the Regional screening criteria is about 949.3758 km2 equivalent to 58.2% of the entire studied area and according to MPCA about 1555.4507 km2 equivalent to 95.32% of the entire studied area (Fig.6 and Fig .7). Although Tonekabon landfill site is accepted according to MPCA method, but in field view, lack of machinery and necessary equipment, destructed walls around the site, insufficient guards and lack of office stand, also lack of gas and leach control and open air burning are some of the disadvantages in this landfill site. It is already clear that the main problem in Tonekabon landfill site is due to the non-compliance with landfill site selection standards, engineering frameworks, and design as well as lack of appropriate waste management and sanitary landfill. The problems include open-air waste burning, open-pit dumping, and uncontrolled waste disposal in landfill, which can result in negative impacts on human health and on the environment. Unfortunately hardly any of the applicable criteria are applied to Tonekabon landfill site.

4 DISCUSSION

Humid areas are vulnerable and sensitive towards environmental impacts of landfills, due to their special physical and biological conditions. These special conditions include high precipitation, several water currents, high water level, productivity of farms, existence of forest and wetland, agriculture, drinking water consumptions, etc. (Monavari and Shariat. 2000). As it has already been mentioned, basically, municipal solid waste landfills are evaluated by methods such as Oleckno method, Drastic method, USEPA method, Monavari 95–2 method and Local and Regional screening. Each system evaluates waste sites for one or more hazard migration route(s), namely groundwater, surface water, soil and public health. In

MPCA method, surface water resources; such as, river, pool, lake, wetland; and geological conditions are determinative criteria to evaluate municipal landfill site, but in regional screening method, the landfill will be evaluated in 3 sections (Natural and land use) and with more criteria to be considered. So in this method evaluation is more accurate than MPCA method. Identifying incompatible impacts of different parameters in landfill of Tonekabon and considering different standards will help to control different types of existing landfill problems. Paying more attention to waste management's issues will change the weak points to power points. It is important, that the defined criteria in MPCA method and Regional screening guideline are for Sanitary landfill site evaluation and selection, but the evidences in Tonekabon landfill site suggests open dumping not sanitary landfill site. In municipal solid waste landfill site sitting, there are many criteria which must be considered such as wind direction, distance from sensitive ecosystem, slope, ….. To achieve more accurate results and to develop a practical method, we need to study the most comprehensive and detailed studies on the specificity of the expert teams. The comparing of this study and also the other studies has been conducted before, has confirmed that each method has the more evaluation criteria the accuracy of the assessment will be greater. Comparing the regional screening and MPCA method showed this result too. In regional screening method more criteria have been considered, as a result the suitable areas have been decreased in studied area. Since each of the 2 methods have some do's and don'ts to evaluate landfill sites, we standardized the map layers based on Boolean logic. The feature of this logic is speed and the easiness in performance, at least the suitable and unsuitable places will be separated. This method is appropriate and useful in developing countries such as Iran. This logic has some defects, the result of Boolean logic has two locations, or appropriate or inappropriate and therefore not able to prioritize between locations, while to achieve the desired final result in site sitting is better to use the other multi-criteria decision making methods and to weight the criteria according to the relative importance based on ecological, economic and social features in each region. The evaluation of the current unsanitary landfill sites and the implications of land degradation, can open a new way to start restoration of these regions and convert them to self-sustaining and productive ecosystems in developing countries. So a better management approach can be planned to decrease land degradation. There are many researches which can be used to recovery the degraded lands in this site and convert this degraded forest to a productive ecosystem in the future such as: (Iwai et al.,2013; Courtney and Harrington, 2012; Esawy and El-kader, 2014; Gasco et al.,2014).

5 Conclusions

The main objectives of this paper are:

- There is incoherence in appropriateness of the existing landfill site, with two mentioned methods.
- According to Regional screening method the Tonekabon landfill site is not acceptable.
- According to MPCA method, Tonekabon landfill site is acceptable only because of the lack of enough evaluation criteria.
- The suitability of Tonekabon city based on the Regional screening criteria is about 949.3758 km2 equivalent to 58.2% of the entire studied area.
- The suitability of Tonekabon city based on the MPCA method criteria is about 1555.4507 km2 equivalent to 95.32% of the entire studied area.
- The study shows the shortage of suitable areas in Tonekabon city based on Regional screening method compared with MPCA method.
- The field view shows the unsuitability in Tonekabon landfill site. The evidences in Tonekabon landfill site suggests open dumping not sanitary landfill site.

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Table 1.Six determinative and seven conditional factors of MPCA method (Badve, 2001)

Number	Determinative Criteria	Conditional Criteria
1	Minimum305 meters distance from any lake or pool	Minimum 305 meters distance from road, parks and residential area
2	Minimum92meters distance from any river or channel	No threat to any water resources pollution
3	Distance from area with 100 retention period flood	Avoiding from area with high erosion and drainage

4	Avoiding from wetlands	No threat to drinking water storage
5	Do not cumulate birds in sensitive area around airport	No threat to groundwater resources contamination
6	Distance from area with limestone caves	Constructed with enough precaution consideration
7	-	Feasibility of monitoring and sampling of ground water

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٢ Table 2. The suitability of Tonekabon landfill site based on MPCA method criteria

Determinative Criteria	**Buffer and constraint**	**suitability**
Distance from any lake or pool	Minimum305 meters	Suitable
Distance from any river or channel	Minimum92meters	Suitable
Distance from area with 100 retention period flood	Not be sited in this area	Suitable
wetlands	Avoiding	Suitable
Distance from airport	Do not cumulate birds in sensitive area around airport	Suitable
Distance from area with limestone caves	Not be sited in area with limestone caves	Suitable

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٤ Table 3.The suitability of tonekabon landfill site with regional screening criteria

Criteria	Buffer and constraint	Landfill site Suitability
Distance from surface water	minimum distance of 61 m	Suitable
Distance from underground water resources	At least 300 m	Suitable
Land use	Distance from industrial application at least 80 metre	Suitable
Distance from population centres	At least 150 metre	Suitable
Distance from faults	minimum distance of 61 m	Suitable
Distance to landslide	The regions with slide risk potential are not suitable	Suitable
Geology	Lime stone bed rock is not suitable	Unsuitable

Distance to airport	At least 3 kilometre	Suitable
Soil depth	At least 15 metre	Suitable
Soil type	Sensitive clay is not suitable	Suitable
Under ground water level	The regions with high underground water level are not suitable	Suitable

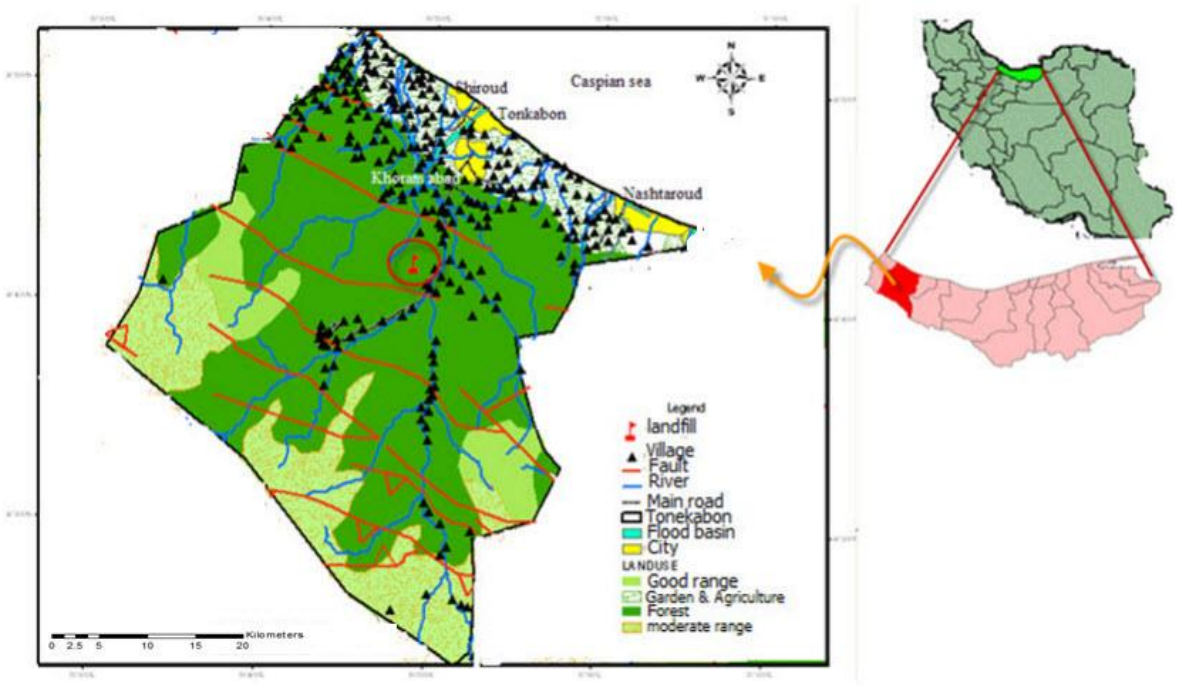


Fig1: location of Tonekabon in Mazandaran province, Iran

Fig2: Location and conditions of Tonekabon landfill site

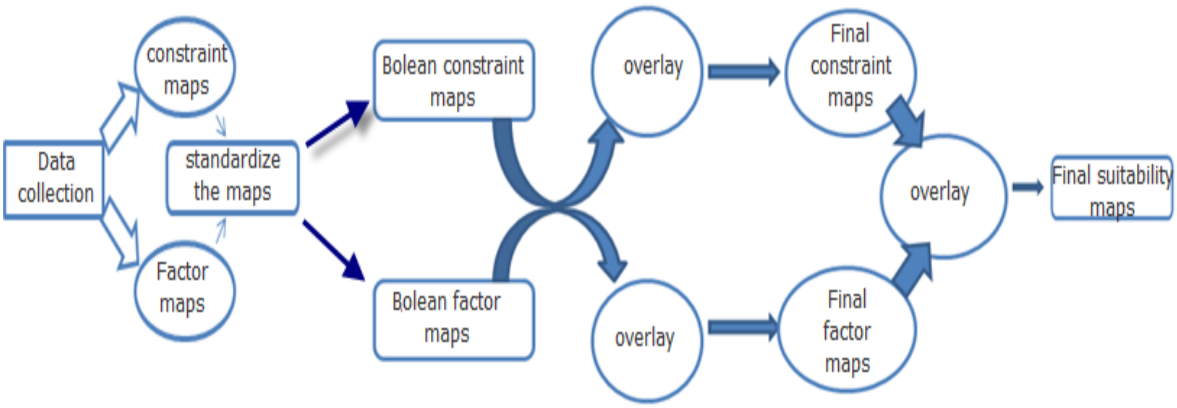
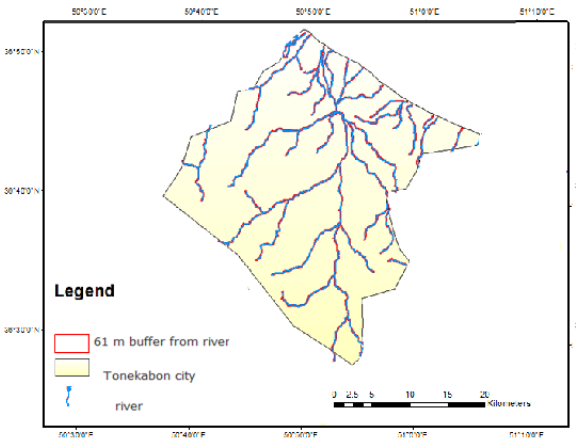
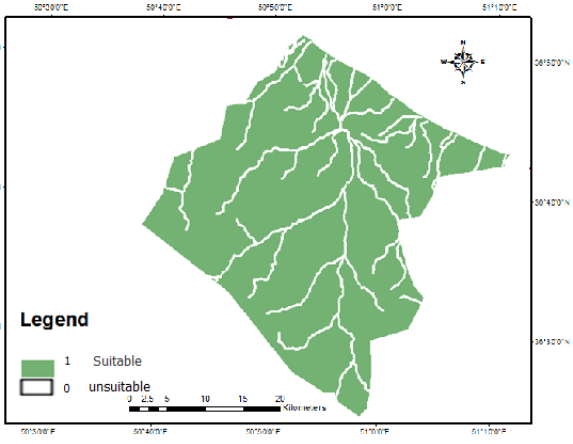


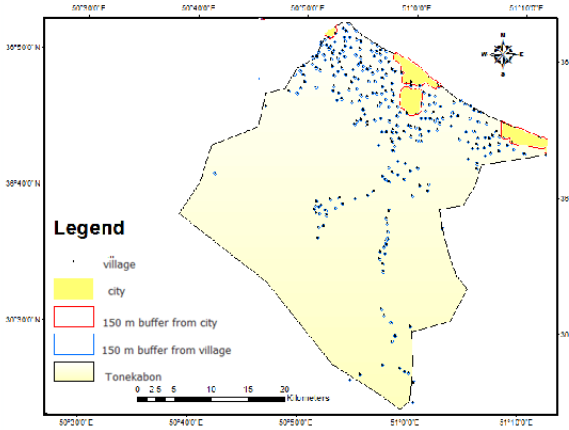
Fig 3: Flowchart of the methodology followed in the study



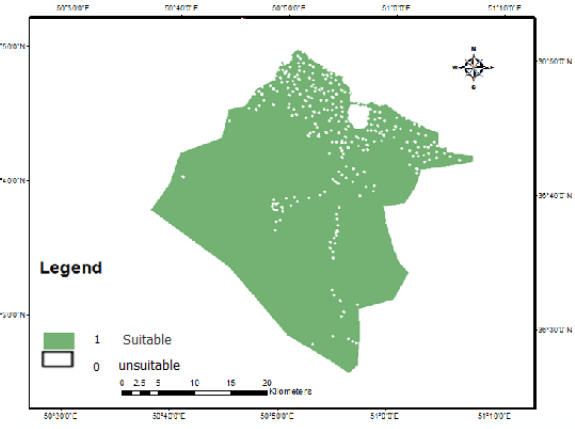
(A) surface water map



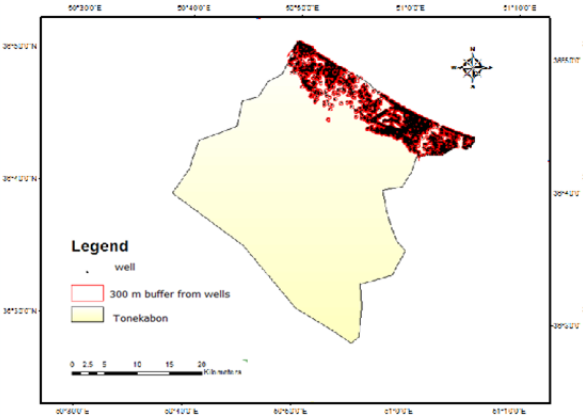
(B) standardized surface water map based on boolean logic



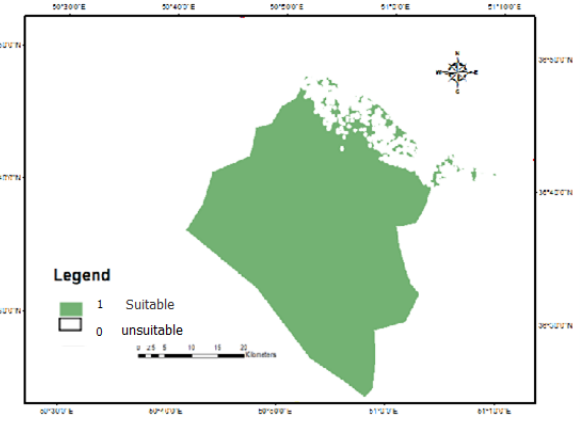
(C) Residential area map



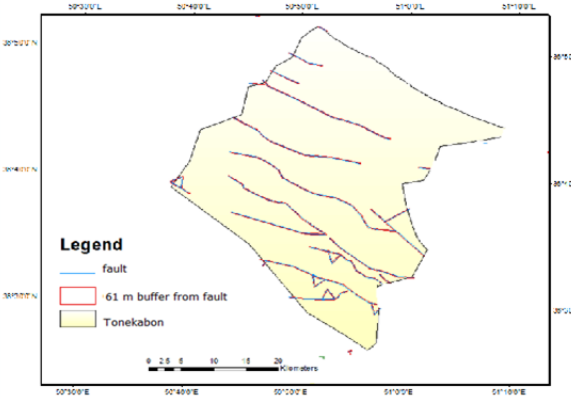
(D)Standardized residential areas map based on Boolean logic



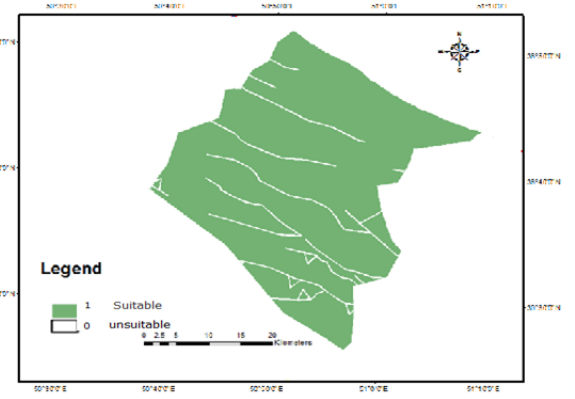
(E)Underground water sources map



(F)Standardized wells map based on Boolean logic



(G) fault map



(H) Standardized fault map based on Boolean logic

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Fig4:The constraint map layers in Regional screening method and standardized maps based on Boolean logic

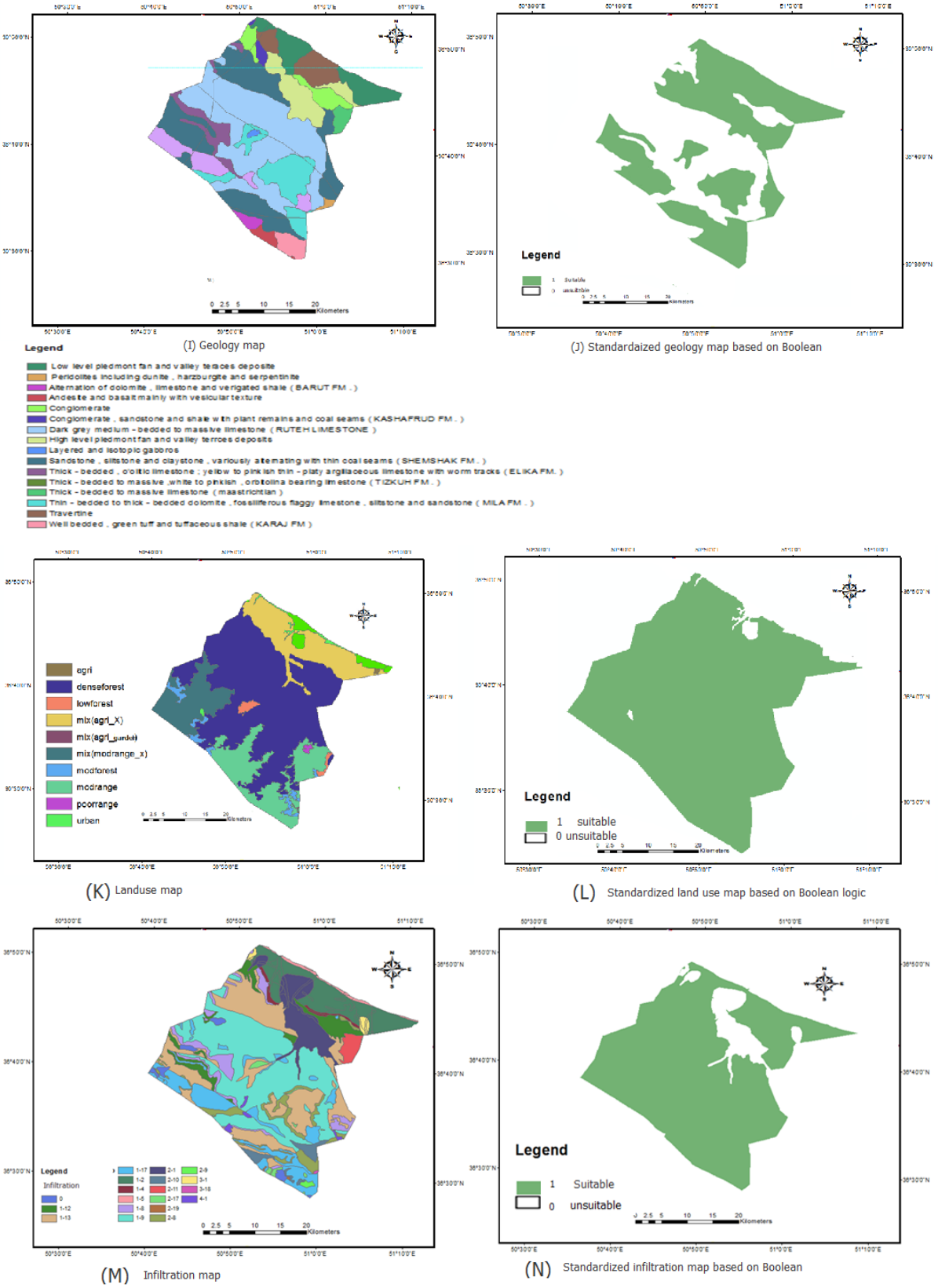

Fig5:The factor map layers in Regional screening method and standardized maps based on Boolean logic

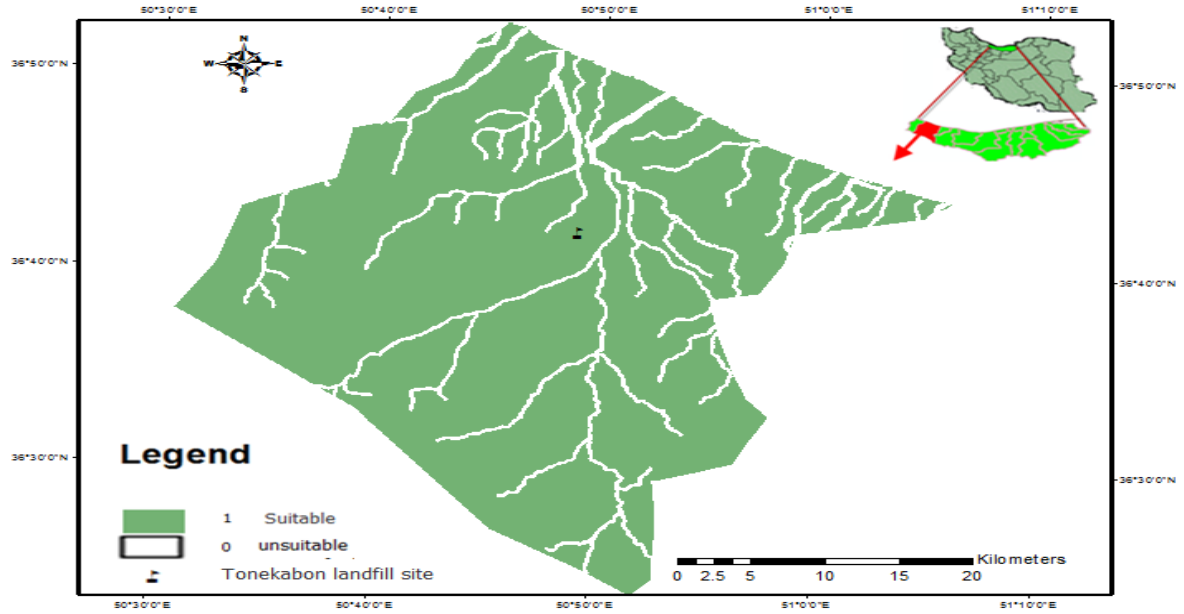

Fig6:The suitability of the studied area based on MPCA determinative criteria

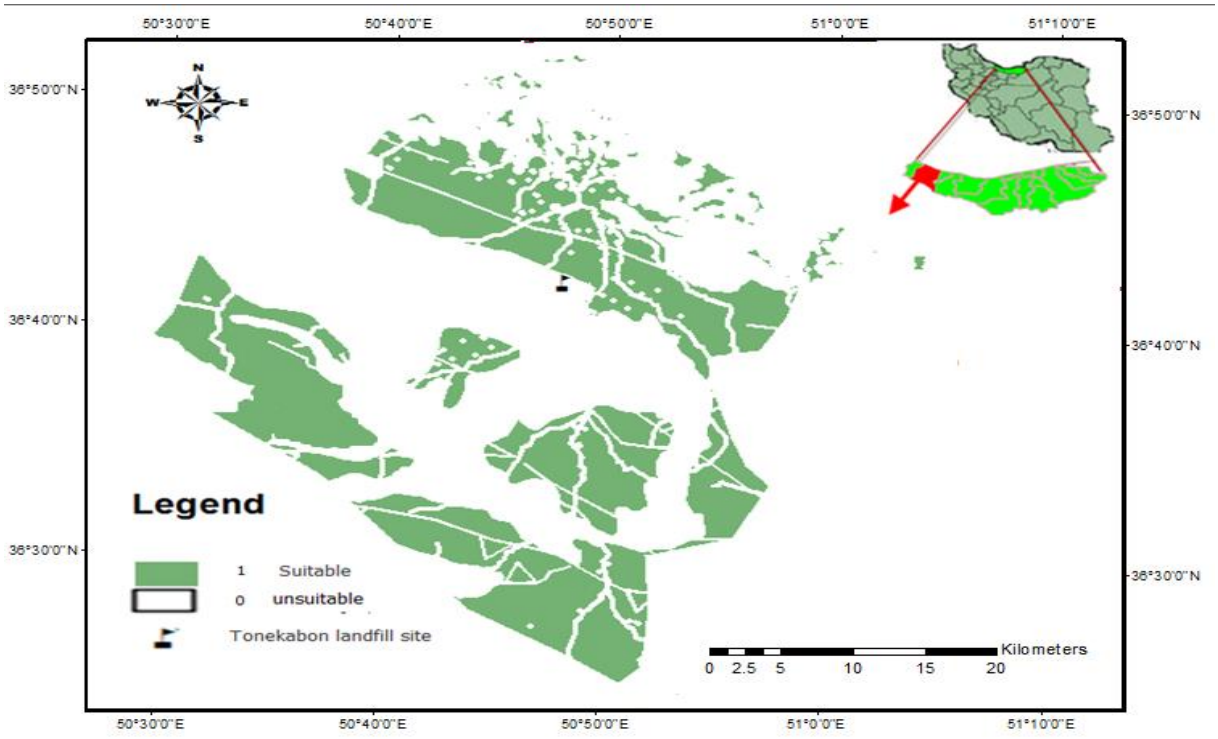

Fig7: The suitability of the studied area based on Regional screening method