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Landfill site suitability assessment by means of geographic information system analysis

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Abstract. Open dumping is the common procedure for final disposal of municipal solid waste (MSW) in Iran. Several environmental pollution and soil degradation problems were found as a consequence of poor planning of landfills. So recognition of the MSW landfill state is required to prevent environmental problems. The objective of this research was to study the suitability of existing municipal landfill sites using geographic information system methods. Tonekabon city in the west area of Mazandaran province, northern Iran, along the southern coast of the Caspian Sea, was chosen as a case study. In order to carry out this evaluation, two guidelines were used: Minnesota Pollution Control Agency (MPCA) and regional screening guidelines. The results indicate that the landfills were not located in suitable sites and also that there are few suitable locations to install the landfills.

1 Introduction

The soil system is an important part of the carbon, water and sediment cycles and there is a need to research different aspects of the soil and land degradation that affect the fate of the Earth system (Keesstra et al., 2012a; Mandal and Sharda, 2013; Zhao et al., 2013; Ganjegunte et al., 2014; Mukhopadhyay and Maite, 2014; Brevik et al., 2015). The loss of vegetation, degradation of soil and pollution of water, soil and air are seen as signs of land degradation and reduced soil quality, and solutions to these problems need to be found (Giménez Morera et al., 2010; Novara et al., 2011, 2013; Keesstra et al., 2012b; Batjes et al., 2014; Olang et al., 2014; Srinevasarao et al., 2014). Land and soil degradation processes can be seen in landfills. In developing countries it is necessary to develop efficient waste management systems due to increased waste production as a consequence of population growth. Despite developments that have improved waste management systems, the disposal of solid waste in landfills is still the most commonly used method in developing countries (Leao et al., 2004; Mahini and Gholamalifard, 2006; Sumathi et al., 2007; Donevska et al., 2013). Sanitary landfilling is one of the best ways to decrease the volume of waste products (Wang et al., 2009); nevertheless the lack of effective environmental laws and enough suitable land for landfill sites in most developing countries is a major issue that causes many problems (Hagerty et al., 1997). Unfortunately, in most Iranian cities, the primary method of waste disposal is still confined to pile-up and open dumping. An open dumpsite is an environmental hazard which causes natural resource (soil, water, air) degradation and environmental pollution. Previous works found that leachates from landfills contaminated groundwater (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). One of the main problems with open dumping is open air burning due to gases emitted from waste degradation processes; some researchers have investigated the effects of fire on soil (Guenon et al., 2013; Leon et al., 2014). The other serious threat to soil in landfill sites is salinity, which causes soil degradation and promotes groundwater salinization (Iwai et al., 2013). All of these impacts from landfills represent threats to human health (Brevik and Burgess, 2013); landfilled e-waste represents a particular hazard (Brevik and Sauer, 2015).

One of the major causes of land degradation is improper land use, which has already been examined (Mohavesh et al., 2015). There are many research investigations that have emphasized the negative impacts of improper land use and management (Biro et al., 2013; De Souza et al., 2013; Pallavicini et al., 2014). One of these unsuitable land management systems in developing countries is municipal solid waste management when the landfill sites are not chosen appropriately. To protect the environment and natural resources in developing countries, a system for proper solid waste site selection should be developed (Rao et al., 2007). In Iran, the environmental evaluation of landfills must be improved and this paper will contribute with the assessment of two methods. Despite the increasing advances in modern methods of locating landfills, 49 % of the total solid waste disposal in Iran is achieved by piling up the waste products (Abdoli, 2005a). These systems have not been adequately improved in Iran and so the open dumping of solid waste is seen as the only solution by most people. Although numerous efforts to reuse municipal solid waste have been undertaken around the world (Morugan et al., 2013; Al-Karaki et al., 2011), unfortunately in Iran waste is dumped without any treatment. In Iran individual municipalities are responsible for municipal solid waste (MSW) management systems and there is no federal oversight for landfill siting. Due to poor planning, insufficient financial resources, inefficient collection systems, lack of data and experience, unsuitable disposal facilities, insufficient laws, guidelines and regulations, lack of knowledge of new municipal solid-waste management options in municipalities, and increasing needs to remove waste from cities, the disposal method that most municipalities select is uncontrolled dumping (Abdoli, 2005b). The most common way of waste disposal in humid regions such as the southern coast of the Caspian Sea has also been open dumping (Monavari and Shariat, 2000). The quality and quantity of municipal solid waste created along the southern coast of the Caspian Sea in Iran has changed during recent years, but unfortunately the methods of collection, transportation, and disposal have remained the same, leading to many serious environmental problems. For example, some of the rivers, forests, and coastal regions in Iran have been contaminated and destroyed and have been converted into dumping sites (Abdoli, 2005b). Therefore, it is both essential and useful to understand the suitability of current municipal landfill sites for waste disposal.

Some evaluations of municipal landfill sites have been done in Iran and the other parts of the world using different methods. For example, Monavari et al. (2007) evaluated all the landfill sites in Tehran province in Iran using the Oleckno method, and also Salimi et al. (2013) evaluated the suitability of the new sanitary landfill site location in Isfahan with the Oleckno method. Assessment of a Maine landfill site had been done with the DRASTIC method (Wang, 2007) and USEPA method (Christensen et al., 1992). In other research projects 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 in humid and arid areas – were evaluated by the Monavari 95–2 method (Ghanbari et al., 2011), and the Karaj municipal landfill site has been evaluated by local and the regional screening methods (Aliowsati et al., 2013). Davami et al. (2014) evaluated the municipal solid waste landfill site in Ahvaz city by local screening incorporating geographic information systems (GISs). The first step to improve MSW management is evaluation of the state and suitability of current landfill sites in the country. The objective of this work was to evaluate the suitability of the Tonekabon landfill site using two methods: Minnesota Pollution Control Agency and regional screening method.

2 Materials and methods

2.1 Area of study

The Tonekabon region (1631.8 km^2) is located in the western part 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 south of the city in the Pordesar forest. This site has an area of over 2 ha, located at 36°42′ N, 50°49′ E at 520 m a.s.l. Located between the Alborz mountain range and Caspian Sea, the study area has a temperate 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 solid waste inputs are collected from three municipal districts (Central, Nashta, and Khoram Abad districts with 149 010 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 library information. In this study, map layers were input according to mentioned guidelines and included surface water (rivers and lakes), flood plains, geology (faults, bedrock, seismicity), groundwater, underground water resources (springs and wells), land use (agricultural land, forest land, residential area), distance to airport, distance to residential areas, and road distance to waste production centers. At this research site, waste is dumped in the forest without applying any environmental and engineering standards. The lack of proper waste management systems and the humid climate increase environmental problems at this site.

2.2 Investigation of the evaluation criteria

Sanitary municipal solid waste landfill site selection requires basic information and accurate planning (Chang et al., 2008). Methods of evaluating landfill site locations must follow es-

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

Number	Determinative criteria	Conditional criteria
1	Minimum 305 m distance from any lake or pool	Minimum 305 m distance from road, parks and residential area
2	Minimum 92 m distance from any river or channel	No threat to any water resources pollution
3	Distance from area with 100 retention period flood	Avoidance of area with high erosion and drainage
4	Avoidance of 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 groundwater

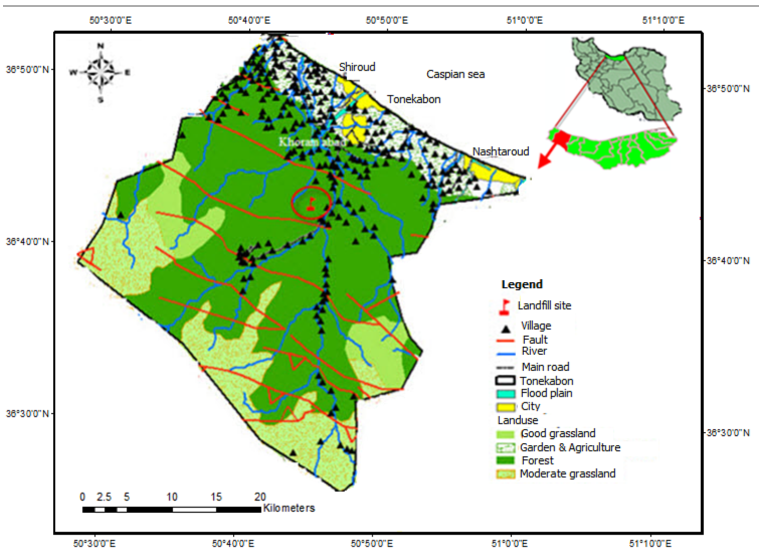

Figure 1. Location of Tonekabon in Mazandaran province, Iran.

tablished regulations. There are many methods used throughout the world to determine appropriate landfill sites that can found in the literature (Alexakis and Apostolos, 2014; Rezazade et al., 2014; Moeinaddini et al., 2010; Sumathi et al., 2007). Two research methods – Minnesota Pollution Control Agency method and regional screening guideline – were used for suitability evaluation of the current Tonekabon landfill site. Each system evaluates waste sites according to a set of established criteria. The Minnesota Pollution Control Agency (MPCA) method, the prevalent method in landfill site selection, was developed by the Minnesota Pollution Control Agency in 1983 (Badve, 2001). The MPCA method includes six primary determinative factors and seven secondary conditional factors. The six primary determinative factors are mandatory and must be observed in landfill site selection; non-compliance with any of these six factors eliminates the site. The other seven factors are conditional; this means that if one of the seven factors fails to meet selection criteria but the problem can be resolved using engineering operations, there is no obstacle to site selection. Determinative and conditional factors utilized in the MPCA method are illustrated in Table 1. The regional screening method uses three important parameters such as natural conditions, land use, and economic factors to determine site suitability (Ball, 2004). Examples of some of the factors used are illustrated in Table 2.

2.3 Preparation and investigation of thematic maps and overlaying these maps in GISs

Evaluation of a suitable landfill site is a complex process, which involves evaluating multiple aspects, including regulations, environmental, socio-cultural and engineering factors.

Table 2. Descriptions of the criteria used in the regional screening method.

Kind of criteria	Criteria description
Natural conditions	1. The MSW landfill sites should not be situated 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 situated 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 a minimum of 10^{-9} m s^{-1}. The layers of clay-silt type soil under the landfill should have a permeability of 10^{-9} m s^{-1} at least the depth of 15 m and more. 5. The distance from faults must be at least 61 m. 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 m 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 1 km is ideal).

Figure 2. Location of and conditions at the Tonekabon landfill site.

Using GISs for evaluation and selection of a proper location for landfill sites is an economical and practical method that has been used in past research (Ghanbari et al, 2011; Sumathi et al., 2007; 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 sites or sites that are restricted by regulations or constrained locations. The combination of findings from GIS software and field review is very useful. In this study our work considered the characteristics of the Tonekabon landfill site based on review of library information, past literature and application of digital maps in ArcGIS version 10.2. Most maps and data were obtained from the Mazandaran Management and Planning Office of the Governor at a scale of 1 : 100 000. The surface and groundwater maps were obtained from the Geographic Information Centre of the Mazandaran Regional Water Organization with a scale of 1 : 250 000. The landfill site map layer was prepared by locating the GPS coordinates of the Tonekabon landfill site in field view and entering them as latitude and longitude in the GIS software database, and then converting them into a point data. In this study, the geographical and environmental conditions of the Tonekabon landfill site were first identified. Then the Minnesota Pollution Control Agency and the regional screening methods were applied to evaluate the suitability of the landfill site. In this study 12 criteria maps according to the evaluation criteria in the MPCA method and the regional screening guidelines were used. Figure 2 shows the Tonekabon landfill site location and general conditions.

2.3.1 Data and evaluation criteria

After collection and preparation of the thematic maps according to evaluation criteria in the MPCA method and the regional screening guidelines, the characteristics of the study

Table 3. The suitability of the Tonekabon landfill site based on MPCA method criteria.

Determinative criteria	Buffer and constraint	Suitability
Distance from any lake or pool	Minimum 305 m	Suitable
Distance from any river or channel	Minimum 92 m	Suitable
Distance from area with 100 retention period flood	Not be situated in this area	Suitable
Wetlands	Avoidance	Suitable
Distance from airport	Do not cumulate birds in sensitive area around airport	Suitable
Distance from area with limestone caves	Not be situated in area with limestone caves	Suitable

Table 4. The suitability of the Tonekabon landfill site based on the 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
Distance to industrial application	At least 80 m	Suitable
Distance to population centers	At least 150 m	Suitable
Distance to faults	Minimum distance of 61 m	Suitable
Distance to landslide	The regions with slide risk potential are not suitable	Suitable
Geology	Limestone bedrock is not suitable	Unsuitable
Distance to airport	At least 3 km	Suitable
Soil depth	At least 15 m	Unsuitable
Soil type	Sensitive clay is not suitable	Suitable
Under groundwater level	The regions with high underground water level are not suitable	Suitable

area were represented by (i) a surface water (hydrology) map which represents important environmental factors due to potential risk of contamination. There are no lakes or pools in the area, but there are multiple rivers in the area, and the nearest river to the MSW site is about 1.8 km away. Distances of less than 61 m according to regional screening and at least 92 m based on the MPCA method are unsuitable while greater distances are suitable. (ii) An infiltration map displays the various soil types in the study area. The infiltration rate is a key parameter to evaluate the risk of groundwater pollution, and thus it is an important factor for landfill site selection in the study area. This map was used to estimate the groundwater level and soil types. The infiltration at this site is high and the soil texture is silt clay loam. So the high level of groundwater is not suitable. (iii) The residential area map displays the existing cities and villages. There are four towns in Tonekabon city: Khoram Abad, Shiroud, Tonekabon, and Nashtaroud. The nearest of them, Khoram Abad, is located 10 km from the study site. There are 875 villages in the study area and the closest village is 450 m from the MSW site. So the distance of less than 150 m from residential areas is not suitable for a landfill site based on regional screening legislation. (iv) The road network map delineates all the major and minor roads of the study area. The location of the landfill is at a distance of about 3 km from Dohezar main road. (v) The land use map shows good and medium grasslands, gardens, agricultural lands, forest and the four towns in Tonekabon city. The dominant type of land use in this area is forest. This landfill site is located in the Pordesar forest. (vi) The groundwater source (hydrogeology) map displays the wells and springs in this area. The nearest well is located at a distance of more than 6 km from the study site; the nearest spring is located about 3 km away. (vii) The geology map shows that dark-grey, medium bedded to massive limestone (Ruteh limestone) is the main geological unit in the landfill site. (viii) The protected area site map displays areas that are protected, under the management of the Department of the Environment of Iran (DOE). Beleskoh protected area is located less than 2.5 km from the landfill site. (ix) The flood plain map shows that the study landfill is not at risk of flooding during a 100-year retention period flood. (x) The fault map displays the existing faults of this area. The areas without faults or the ones that are a safe distance from the faults are suitable as landfill sites. In this study area we have two kinds of faults: major and minor. The nearest fault is located 2.5 km away. (xi) The airport map shows that there are no airports in this city. The nearest is Ramsar airport and it is located about 13 km from the Tonekabon town center. (xii) The municipal solid waste landfill site map displays the location of the Tonekabon landfill site in the study area. Figure 3 shows 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, etc. and constraint maps such as distance to residential area, distance to faults, distance to rivers, protected areas, etc. Since each of the two methods has some dos and don’ts to evaluate landfill sites,

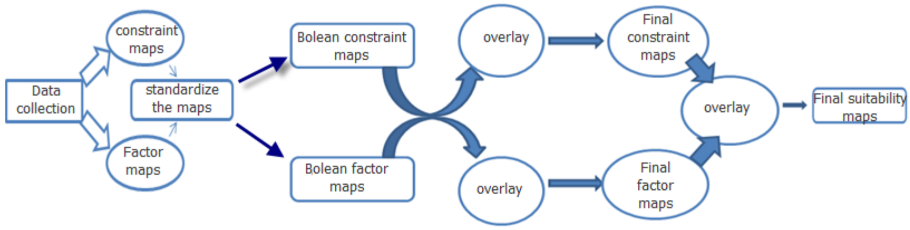

Figure 3. Flowchart of the methodology followed in the study.

we standardized the constraint and factor map layers based on Boolean logic. So all the areas that are forbidden for landfill development in the MPCA method and regional screening guidelines and their regulations (constraints) and also all areas that fall inside the distances within which landfill development is forbidden (buffers) in the map layers have been assigned a value of 0 and all other areas have been assigned a value of 1. Thus with the reclassified module in ArcGIS software, the restricted area's value was 0 (unsuitable area) and the other area's (suitable area) value was 1. 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 plains. Maps represent the acceptable distance, which should be considered in site selection 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 development and solid waste disposal. Buffer maps were generated in which the "areas of constraints" were displayed. Such areas are surrounded by residential areas, rivers, water supply sources, roads and fault lines. For example, in order to prepare the buffer for rivers under the MPCA guidelines, the rivers in our study area were identified and then a buffer distance of 92 m was established around them. In the same way, buffer zones for the other criteria such as roads, water reservoir sources and faults were created at the distances established for each of them in the two 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 from each of the guidelines, the suitability of deposit site and the study area was identified (see Figs. 4 and 5).

3 Results and discussion

After analyzing the study area with maps and field checks (see tables and figures) it was found that the Tonekabon landfill site is suitable based on the MPCA determinative guidelines (see Table 3), but it is unsuitable according to the regional screening method (see Table 4). Our study shows a conflict between the two methods. About 1555.4507 km^2, equivalent to 95.32 % of the entire study area, was rated as suitable for landfill development by the MPCA. About 949.3758 km^2 of the Tonekabon city, equivalent to 58.2 % of the entire study area, was rated as suitable for landfill development based on the regional screening criteria (Figs. 6 and 7). Although the Tonekabon landfill site is acceptable according to the MPCA method, due to lack of machinery and necessary equipment, poorly maintained walls around the site, insufficient guards and lack of a guard house, a lack of gas and leaching controls and open air burning are some of problems at this landfill site. It is clear that the main problem at the Tonekabon landfill is 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 landfills, which can result in negative impacts on human health and on the environment (Brevik and Burgess, 2013; Brevik and Sauer, 2015). Unfortunately hardly any of the applicable criteria are applied to the Tonekabon landfill site.

Landfills contribute to land degradation as they remove vegetation and damage the soil (loss of structure, loss of soil biodiversity, introduction of contaminants including heavy metals and organic chemicals, etc.), and this will change the water cycle and the soil sustainability (Keesstra, 2007; Keesstra et al., 2009), and this requires special policies that are in existence in many developed countries, to recover the soil properties. Soil conservation is an important and fundamental issue of this century (Mekonnen et al., 2014). Humid areas are vulnerable and sensitive towards environmental impacts of landfills, due to their special physical and biological conditions (Monavari and Shariat, 2000). As it has already been mentioned, municipal solid waste landfills are evaluated by methods such as the 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 the MPCA method, surface water resources – such as rivers, pools, lakes, and wetlands – and geological conditions are determinative criteria to evaluate municipal landfill sites, but in the regional screening method, landfill sites are evaluated in three categories (natural, economic and land use) with additional criteria that may be considered. Identifying the impacts of different parameters around the landfill at Tonekabon and considering the implementation of different standards will help

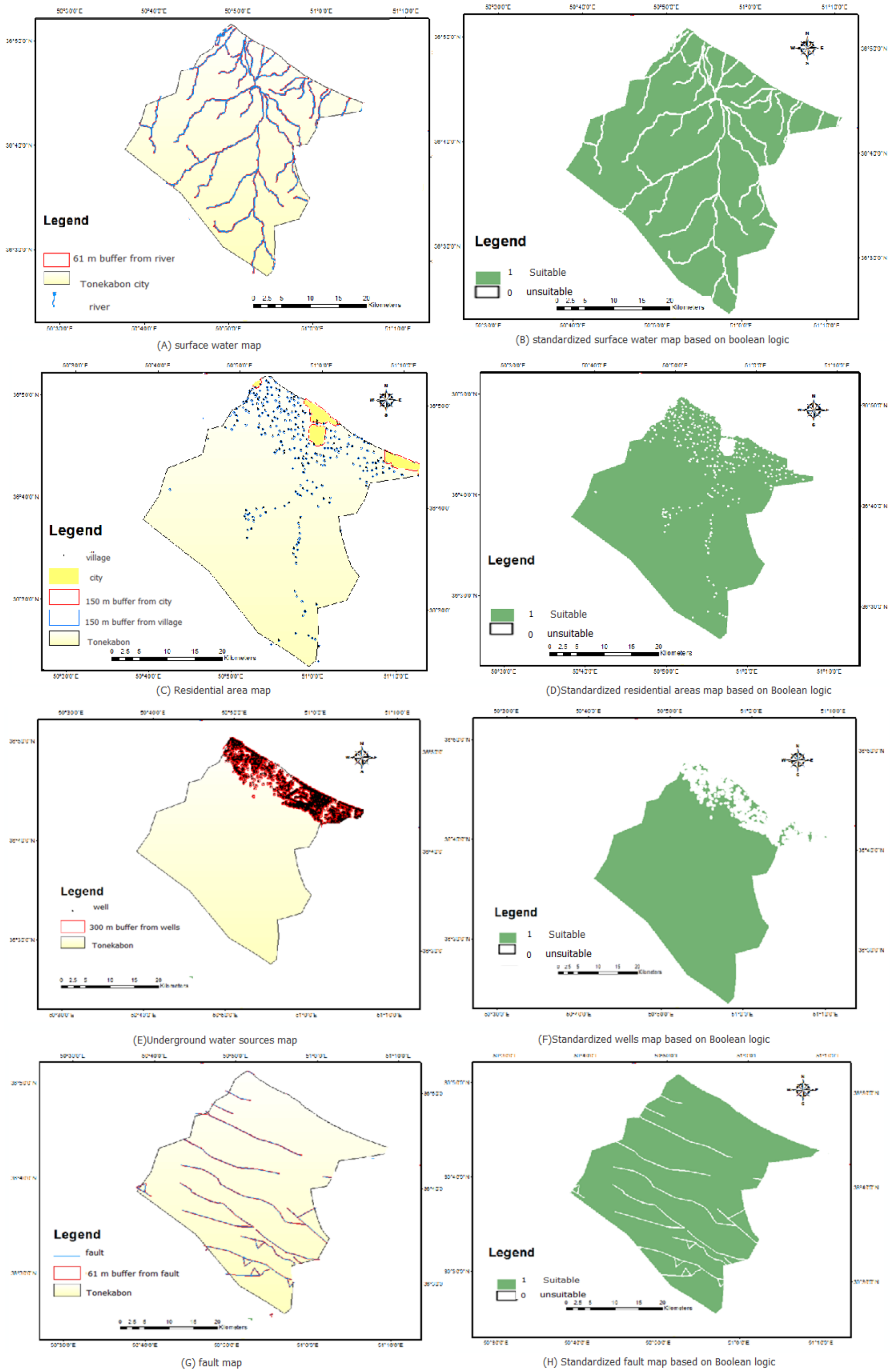

Figure 4. The constraint map layers used in the regional screening method and standardized maps based on Boolean logic.

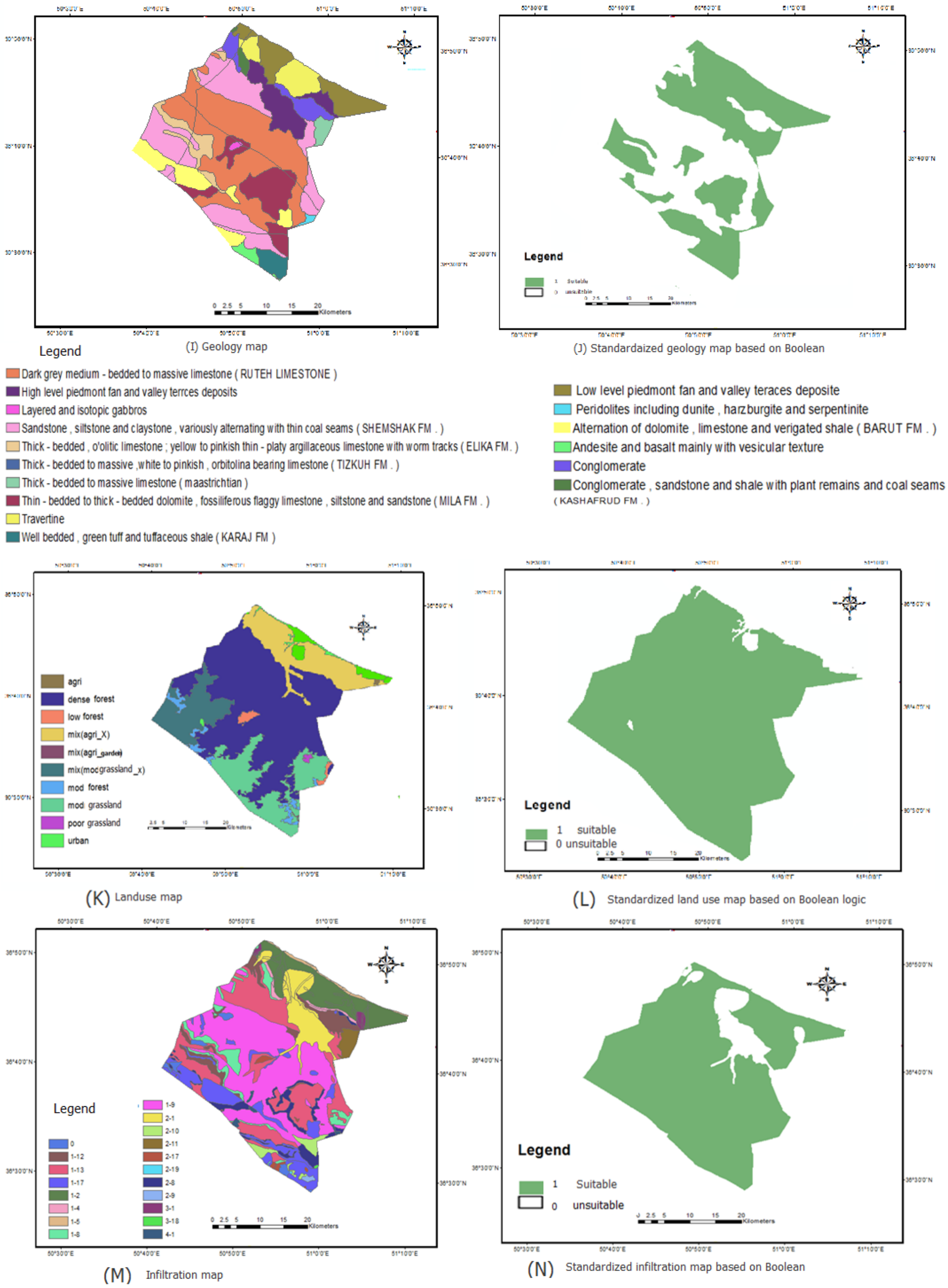

Figure 5. The factor map layers used in the regional screening method and standardized maps based on Boolean logic.

to control existing landfill problems. Paying more attention to current unsanitary landfill sites will change weak points in the current landfill management system to strong points. It is important to note that the criteria utilized in the MPCA method and regional screening guidelines are for sanitary landfill site evaluation and selection, but the evidence at the Tonekabon landfill site suggests open dumping, not sanitary landfill management. In municipal solid waste landfill site selection, there are many criteria which must be considered such as prevailing wind direction, distance from sensi-

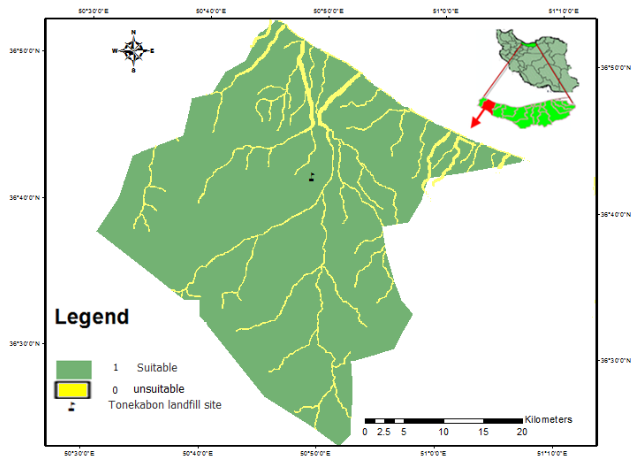

Figure 6. The suitability of the studied area based on MPCA determinative criteria.

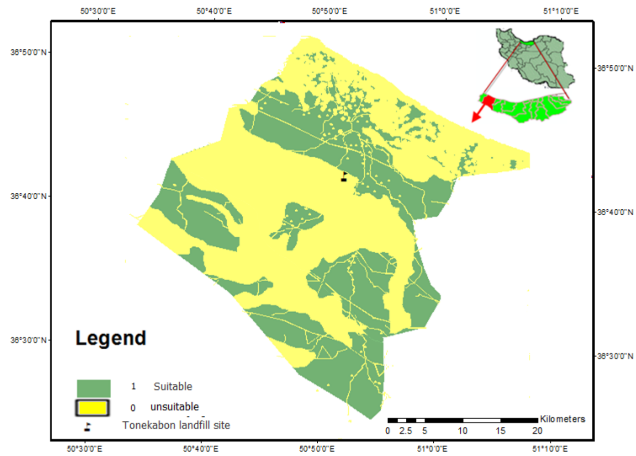

Figure 7. The suitability of the studied area based on regional screening method.

tive ecosystems, slope of the land, soil texture and infiltration. Comparisons between the regional screening and the MPCA method showed that the regional screening method has more evaluation criteria to assess. As a result, fewer suitable areas were identified in the study area. Since each of the two methods has some dos and don'ts to evaluate landfill sites, we standardized the map layers based on Boolean logic. The primary feature of this logic is speed and easiness in performance, but at least the suitable and unsuitable locations will be differentiated. Also this logic is appropriate and useful, but it has some defects. The result of Boolean logic gives only two options – appropriate or inappropriate – and it is therefore not able to prioritize between locations. To achieve the desired final result in site selection it would be better to use other multi-criteria decision-making methods and to weight the criteria according to their relative importance based on ecological, economic and social features in each region. The evaluation of the current unsanitary landfill sites and their implications for 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, including better management approaches for sanitary landfills to decrease land degradation. Restoration of sanitary and non-sanitary landfills is necessary to minimize adverse impacts on the environment (Do et al., 2013). To provide scientific data for future restoration management, Chen et al. (2015) compared the ecological performances between natural sites and revegetated landfill sites and showed that, during the study period, there was a gradual change in the plant communities at restored sites and an increase in biodiversity. Research has also shown that exotic plant species may be more suitable for use as pioneer species in the restoration of sanitary landfills (Wong et al., 2015b) and also pioneer native species were much better than other native species (Wong et al., 2015a). Many research projects have been conducted that can be used to recover the degraded lands at this site and convert this degraded forest to a productive ecosystem in the future (Iwai et al., 2013; Courtney and Harrington, 2012; Mahmoud and El-kader, 2014; Paz-Ferreiro et al., 2014; Mekonnen et al., 2014). This requires a multidisciplinary view of the soil system (Brevik et al., 2015) and also applied methodologies to restore soil quality (van Leeuwen et al., 2015; Zornoza et al., 2015).

4 Conclusions

Open dumping is an important cause of land and soil degradation in Iran. According to the regional screening method the Tonekabon landfill site is not acceptable, while according to the MPCA method the Tonekabon landfill site is acceptable. About 949.3758 km^2, equivalent to 58.2 % of the entire study area of Tonekabon city, was determined to be suitable for sanitary landfill development based on the regional screening criteria, while about 1555.4507 km^2, equivalent to 95.32 % of the entire study area, was determined to be suitable using the MPCA method. The study showed fewer suitable areas for landfill development in Tonekabon city based on the regional screening method as compared to the MPCA method. Field research confirmed that inappropriate management techniques were being used at the Tonekabon landfill site and the urgent need for a restoration program.

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