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Site Selection of a Hazardous Waste Landfill Using GIS Technique and Priority Processing, a Power Plant Waste in Qazvin Province Case Example

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Abstract
In recent years the increases in the popularity of applying environmental criteria in national planning and management has provided a wide range of scientific approaches to determine the best location of hazardous wastes to be land filled. In the present study, concern to the hydro-geological and social-economical considerations as well as national environmental legislations, an efficient method to determine suitable sites for land filling of hazardous wastes is presented. Site screening study based on GIS database in two scales, and priority processing are utilized. This approach demonstrates how the criteria such as geology, topography, land use, climate, surface and ground water chrematistics, accessibility, applicability and other related factors can be used into the over layer technique to determine some appropriate sites in a vast region. For priority processing between candidate sites also a new approach based on DRASTIC and MPCA methods and zonal feature of the study area is given. The introduced method was used to find a disposal site for hazardous wastes of Shahid Rajaee power plant in Qazvin province, located in west central part of Iran. Results showed that site named 1 in Abyeck zone next to Shahid Rajaee power plant has highest score between 17 primarily selected sites.

Keywords: landfill, priority processing, hazardous waste, site selection, power plant.

انتخاب مکان مناسب دفن پسماندهای خطرناک با استفاده از تکنیک GIS و اولویت بندی سایت‌ها، مثال موردی: پسماند یک نیروگاه در استان قزوین

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چکیده
در سالیان اخیر، توجه بیشتر به معیارهای زیست‌محیطی در برنامه‌ریزی‌های کلان مملکتی، ایجاد یک نگرش علمی جهت دفع زیست محیطی زائدات خطرناک از طریق انتخاب محل‌های مناسب دفن این مواد را به دنبال داشته است. در این مطالعه با در نظر گرفتن ملاحظات زمین شناسی، فنی و اقتصادی- اجتماعی در کنار مقررات زیست محیطی ایران روشی کارآمد جهت مکانیابی مناسب محل دفن زائدات خطرناک ارائه شده است. در این مطالعه با استفاده از پایگاه اطلاعاتی GIS و اولویت‌دهی سایت‌های منتخب شده، نسبت به غربال‌گری مکان‌های مناسب دفن زائدات در سطح یک منطقه وسیع اقدام شده است. روش مورد استفاده در این مقاله، نشان می‌دهد که چگونه معیارهای تاثیرگذار نظیر زمین‌شناسی، توپوگرافی، کاربری اراضی، اقلیم منطقه‌ای، آب‌های سطحی و زیرزمینی، قابلیت دسترسی منطقه و سایر فاکتورها می‌تواند جهت لایه‌بندی کلی ناحیه وسیع مورد مطالعه مورد استفاده قرار گیرد. جهت الویت‌دهی مکان‌های کاندید شده در این مطالعه از روشی ترکیبی بر پایه روش‌های DRASTIC، MPCA و ویژگی‌های منطقه مورد مطالعه استفاده شده است. روش ارائه شده در این مقاله جهت مکانیابی محلهای مناسب دفن زائدات خطرناک نیروگاه شهید رجایی قزوین مورد استفاده قرار گرفته است. نتایج مطالعه نشان دهنده آن است که سایت شماره ۱ در منطقه آبیک در مجاورت نیروگاه شهید رجایی بیشترین امتیاز را در میان ۱۷ سایت انتخاب شده در سطح منطقه دارا می‌باشد.

کلید واژه‌ها: مدفن، اولویت بندی، پسماندهای خطرناک، انتخاب سایت، نیروگاه.

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Introduction

For many years, land filling has been used as the most common way for the disposal of generated hazardous solid wastes (Komilis *et al*., 1999). Land filling of residuals is the final and vital step of an effective hazardous waste management plan in an area (Visvanathan, 1996). Despite the intensive efforts in other methods of disposal such as incineration, immobilization, off-shore and underground storage, landfills remain as an integral part of countries' solid waste management plans.

Hazardous waste which is simply defined as a waste with properties making it dangerous or harmful to human health and environment are generated in large amounts in municipal and industrial communities. In developing countries most of these wastes, are presently being disposed in uncontrolled dump sites or municipal waste landfills while the secure landfills are the ones that are used in developed countries. In last years adverse environmental impacts, public health and socio-economic issues associated with landfills have led to the issuance of stricter regulations and increases in public opposition to the siting such facilities in the word (Ham, 1993). Because of that, siting of landfills has become one of the most difficult tasks faced by communities (Tchobanoglous *et al*., 1993).

Siting the best available location for the landfills requires an extensive evaluation process to find a site which minimizes all involved economic, environmental, health, and social costs (Siddiqui *et al*., 1996). The question then arises is that how the decision maker can reach a compromise among these conflicting parameters to select the best landfill location in the region? The site selection procedure actually should make maximum use of available information and management tools to ensure that the outcome of the process is acceptable by governmental environmental protection agency and stakeholders (Noble, 1992; McBean *et al*., 1995).

Several techniques for landfill siting have been found in the literature (Balis *et al*., 1998; Dorhofer and Siebert, 1998; Yagoub and Buyong, 1998; Herzog, 1999; Lukasheh *et al*., 2001; Kontos *et al*., 2003). These techniques used geographic information systems (GIS) to perform an initial screening of the study region in order to find suitable areas. These techniques are binary since the final result is a discrimination of the study region in suitable/unsuitable areas (Yesilnacar and Buyong, 2005). Other techniques combine GIS and multiple criteria analysis (MCA) (Lin and Kao, 1998; Allen *et al*., 2002; Kontos and Halvadakis, 2002) or multi-criteria decision analysis (MCDA) method for land fill siting (Hipel, 1982; Hokkanen *et al*., 1994; Hokkanen and Salminen, 1997). Using the combination of priority processing and GIS technique for evaluation of sites and selection of best site are reported in a few papers too (Badve, 2001; McBean *et al*., 1995). All these methods are aimed to evaluate the suitability of the entire study region based on a suitability index.

The hazardous solid waste (HSW) management system in Iran seems not to be a well organized integrated system. The present study is a preliminary study to determine candidate areas and site selection process of hazardous wastes of Shahid Rajaee power plant located in Qazvin province, central west of Iran. The paper describes a HSW landfill siting methodology with combined utilization of GIS and priority processing to locate the best landfill site in the big plane of Qazvin province. Utilization of GIS method as a sophisticated spatial statistics method, giving some efforts for the analysis of results to highlight some better sits in the wide region has been performed. Priority processing through comparing to ideal condition also provides an efficient way to identify the best site between the primary selected candidate sites.

Materials and Methods

Study Area and the Waste

In this paper land fill siting for Shahid Rajaee power plant's hazardous waste within the province of Qazvin is investigated. The plant is located at western central part of Iran 100 km off Tehran (Fig. 1). The province is bounded by Alborz, Rameneh, and Kharghan mountains while agricultural and industrial applications are the main land uses within the area. Shahid Rajaee thermal power plant which is located at 25 km east of Qazvin (center of the province) has power generation capacity of 1000 MW consisting four 250 MW natural gas and fuel oil burning units. It should be pointed out that there also are some other combined cycle power generating units within the site of the plant which makes the power generation capacity of the complex more than 1000 MW. However, hazardous wastes to be land filled arise from the complex but originating from the processes of thermal steam units. The amount of issued wastes are about 15-20 tones/year with high concentrations of hazardous leachable pollutants such as heavy metals.

This waste bulk is mainly mixed of two type of wastes; fuel oil burning furnace bottom ash residuals and dewatered sludge of chemical waste water treatment which arises from chemically washing out of heat transfer surfaces like boiler tubes and air heaters. The waste contains high contents of heavy metals like Cd, Pb, As, Hg, V, Sn, Se, Cr, Ni and Zn (Saeedi and Amini, 2007). Typical contents of some metals in the waste are presented in Table 1. Disposal of this waste in municipal landfills, as is prevalent in some countries, is forbidden in Iran. Thus siting secure landfill for disposal of hazardous solid waste of Shahid Rajaee power plant has been considered.

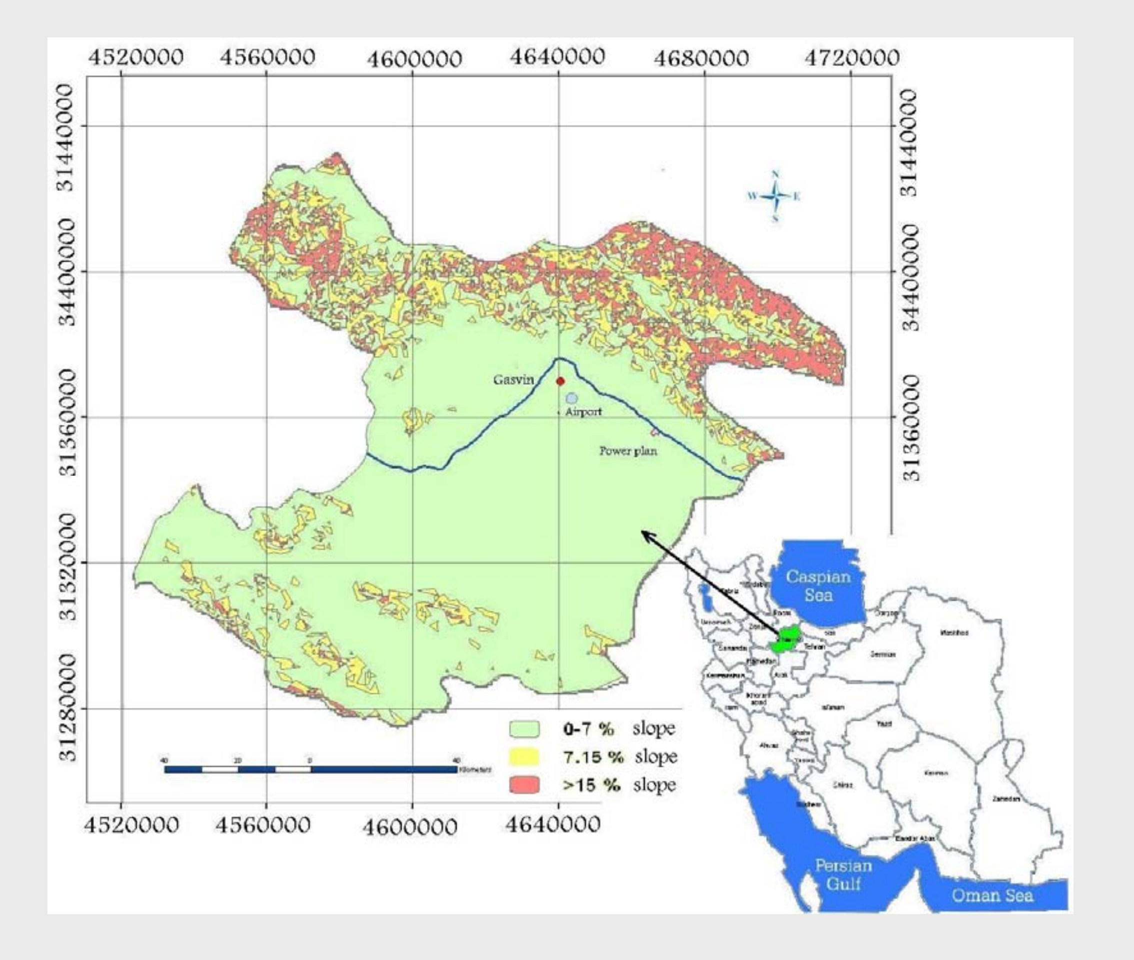

Figure1. Location of Qazvin province and its land slop characteristics

Table1- Mean concentration of heavy metals in wastes of Shahid Rajaee thermal power plant (ppm) (Saeedi and Amini, 2007)

Waste type	Copper (Cu)	Cadmium (Cd)	Chromium (Cr)	Nickel (Ni)	Zinc (Zn)	Iron (Fe)	Lead (Pb)	Vanadium (V)
Residual bottom ash of furnaces	111.6	0.8	532.4	6775.4	310.2	18.67	151	29644
dewatered sludge of chemical washing waste water treatment	360	0.8	454.4	9127.4	646	15.95	192.4	31244
Dewatered residuals of water treatment plant	2.26	0.7	10	13.1	22.4	0.21	2.1	-

GIS maps and Evaluation Criteria

Technological development in computer science has introduced geographic information system (GIS) as an innovative tool in landfill siting process. GIS combines spatial data (maps, aerial photographs, satellite images) with the other quantitative, qualitative and descriptive information databases. For assessing a site as a possible location for solid waste land filling, several environmental and political factors and legislations should be considered (Savage *et al.,* 1998). These factors may be presented in many ways; however, the most useful way is the one that may be easily understood by the community (Tchobanoglous *et al.*, 1993). The GIS-aided methodology presented here utilizes GIS to create the digital geo database as a spatial clustering process and easily understood way for landfill siting in Qazvin plane, Iran. The methodology utilizes GIS to evaluate the entire region, based on certain evaluation criteria for the analysis of landfill site suitability. These criteria are grouped into four main categories, including physical, environmental, social-economical and technical information. The criteria were selected according to Iran legislations and standards on the tope of study area's local characteristics. The principal sub criteria that used for spatial analysis are topography, soil and geology characteristics, climate, vegetation maps, surface and ground water characteristics, specific environmental areas, residential areas, accessibility, distance to residential areas, applicability and waste transport facility (Table 2).

Table2- The Criteria and sub criteria used in development of GIS database

Physical Criteria	Topography
	Soil and geology characteristics
	Climate
Environmental Criteria	Vegetation maps
	surface and ground water characteristics
	specific environmental zone
	Residential zones
social- economical Criteria	Accessibility
	distance to residential areas
	distance to water resources
Technical Criteria	Applicability
	Waste transport

In this study, on the basis of mentioned criteria and sub criteria, over layer technique is used for preparing the final site selection maps. This technique is an approach that includes various features of the study region (Geology, Topography, Soil, Climate, Etc.) that makes joint comparison possible through GIS softwares.

For developing of the digital GIS database, large varieties of maps in two scale were used as separated information layers. The methodology consists of the following steps:

(a) Development of a digital GIS database, includes all information layers in 1:250,000-scale maps

(b) Development of a digital GIS database, includes detail information layer of some zones in 1:25,000-scale maps

Information layers were divided on two determinative and effective layers which concern to environmental legislation must satisfy respectively. Political segmentation map, map of mines and industrial zones, maps of residential areas and archeological sites, specific environmental areas map, vegetation map, road and rail road map, land slope map, soil characteristics map, groundwater and surface water maps, depth of groundwater, isothermal and isohyets maps, land use maps, channel and wetland location maps, major infrastructure systems maps, seismic activity map, highway and airport location maps in appropriate scales were the maps that used for development of a GIS database in the province.

Using these maps site selection process in that area proceeds through a phased approach, as describe below. At first base on available 1:250,000 scale maps, regional screening techniques was performed to reduce the large study area, to manageable number of discrete search areas which satisfied all national environmental legislations. For incorporation of maps and information layers Arc View Ver. 3.2a software was used. Some utilized maps in 1:250,000 scales are shown in Fig 2, 3,4 and 5.

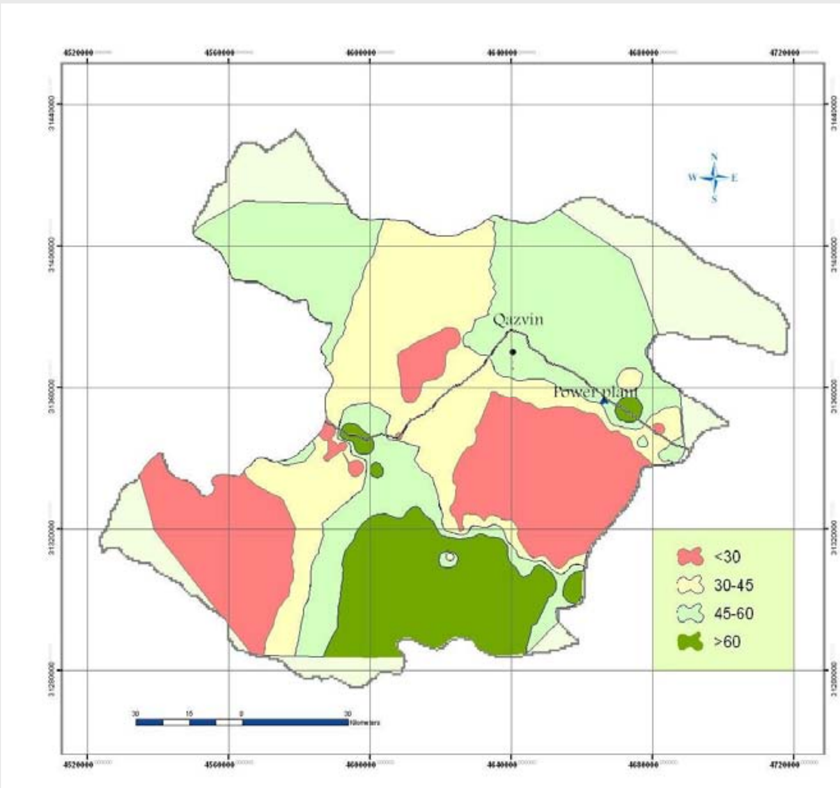

Figure2. Ground water Depth in the Qazvin Province

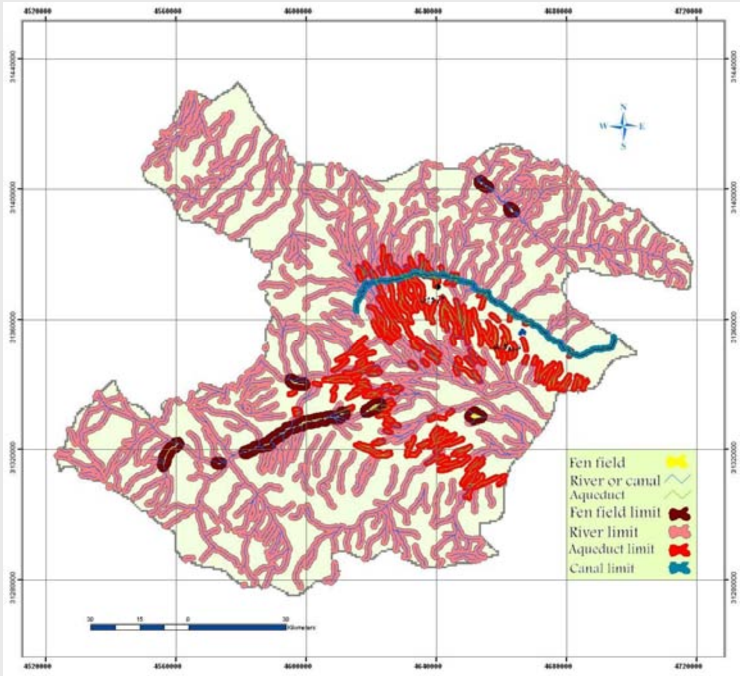

Figure 3. Map of Rivers, canals, aquifers and their limits

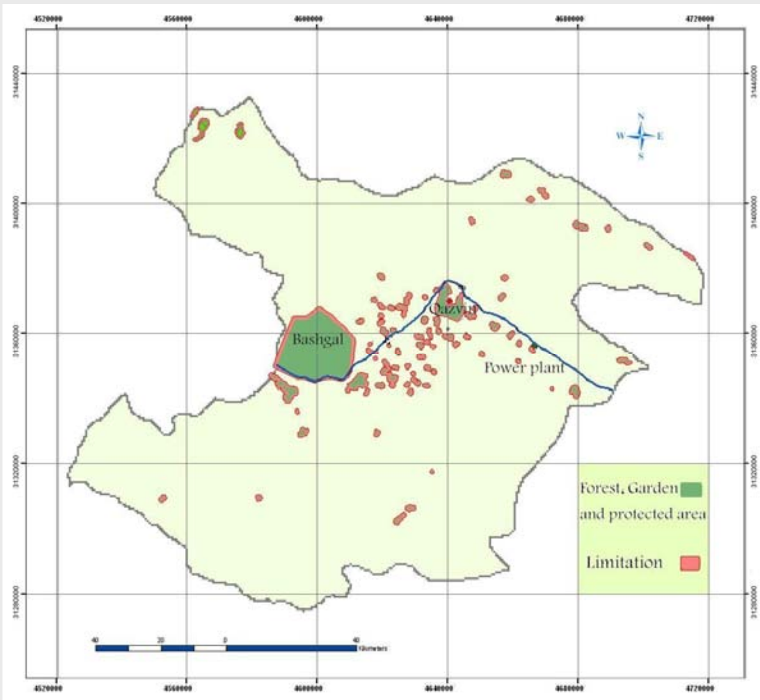

Figure 4. Map of forests, gardens, protected areas and their limits

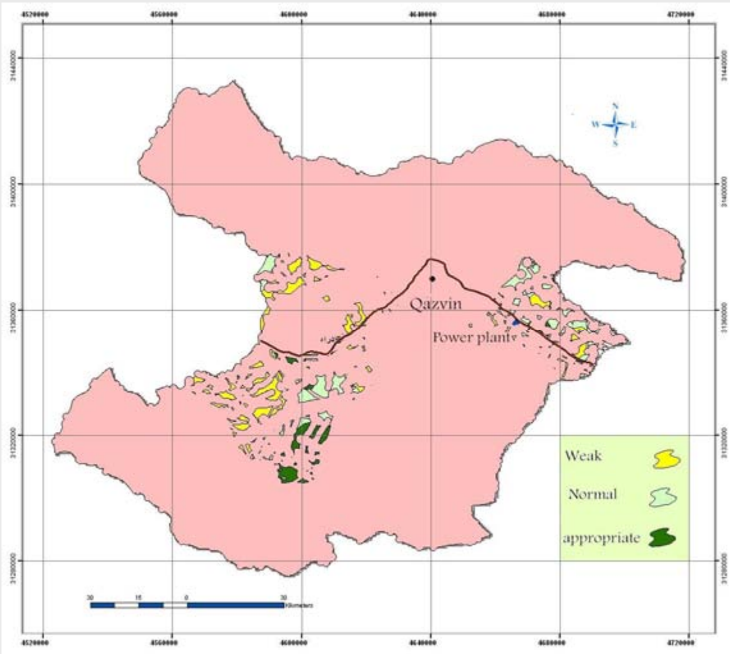

Figure 5. priority of proper zones under all legislations

By the screening therefore the large study area was reduced to some more suitable areas as search areas in the next phase. In the end of first phase, three different parts of the Qazvin province in Abyeck, Takestan and Khoramdasht zones were candidate for more detailed evaluation (Fig. 6). In continuation, in the second phase using available 1:25,000 scale maps candidate areas were evaluated in more detailed. Finally based on minimum needed volume for landfills, 17 sites were identified for hazardous solid waste land filling in the Qazvin province (fig. 7).

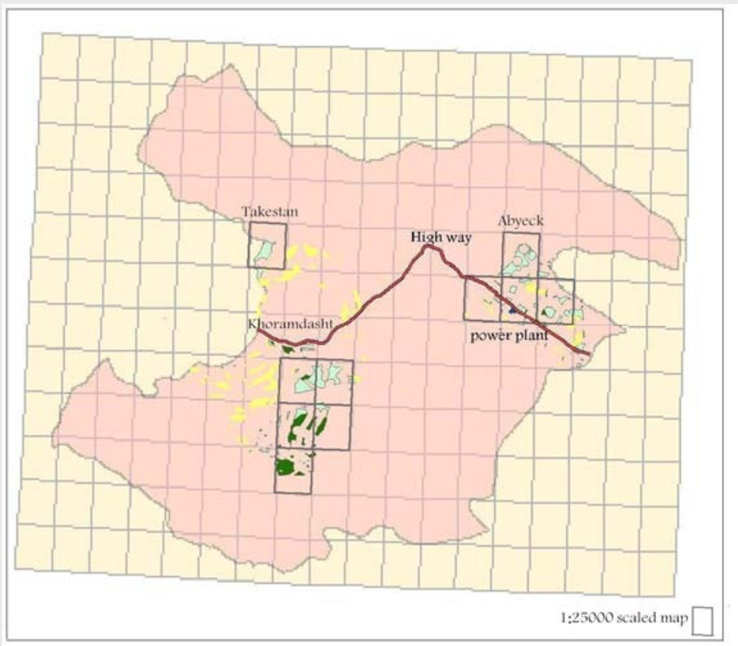

Figure 6. Candidate areas in primary phase and ten sheet maps in 1:25,000 scale that should be considered in more detailed evaluation

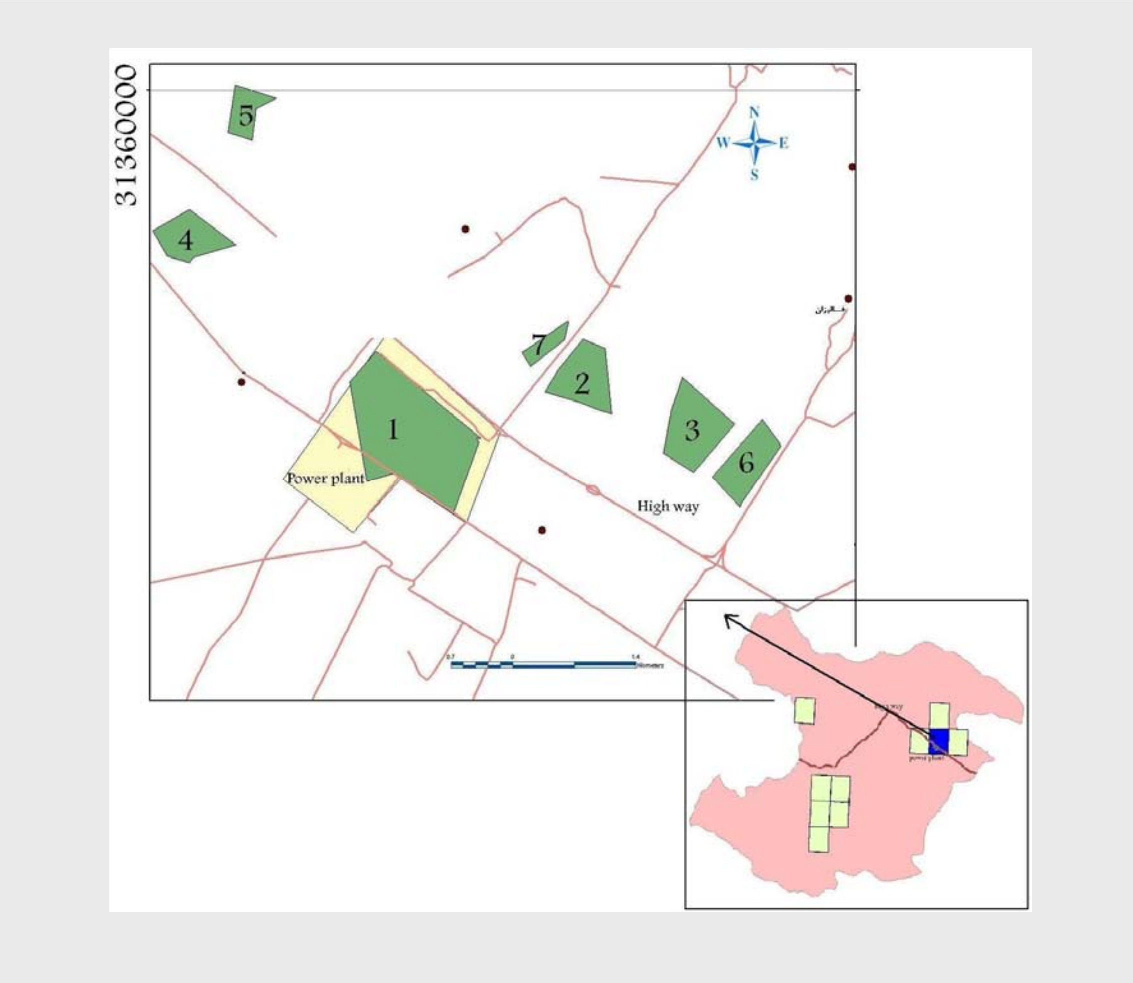

Figure 7. Seven candidate landfills in Abyeck area

Priority Processing

Environmental problems especially ground water contamination is the most significant inverse impact of landfills which change them to one of the most important sources of contamination in shallow aquifers. Leakage generated by percolation of water through the waste, either from outside the landfill or from semi-liquid waste deposited in the landfill is the main source of associated contamination. Proper siting and suitable design of landfills directly alleviates ground water contamination while improper site selection, in areas of ground water recharge, may contributed to ground water contamination to toxic materials. Groundwater is a major source of water for domestic, industrial and agricultural uses in the Qazvin province (study area). Prevention of contamination is hence critical in effective land fill siting in the area. In the current paper concerning to DRASTIC method an attempt has been made to assess the vulnerability of groundwater to contamination in each candidate site. Also, according to MPCA method in addition to Iranian legislations and standards some further technical, social and economical aspects were considered in priority processing of the candidate landfills.

DRASTIC method, the more prevalent method in quantifying the vulnerability of groundwater (El-Naqa, 2004), was presented by USEPA (US Environmental Protection Agency) And NWWA (National Water Well Association) in 1985. El-Naqa *et al.* (2006) used

DRASTIC method for Aquifer vulnerability assessment in northeast Jordan. This model has been widely used in many countries due to the fact that the required inputs are generally available and easy to obtain (El-Naqa, 2004). According to Aller *et al.* (1985) "in DRASTIC method vulnerability is determined by assigning a numeric hierarchical outline to the parameters represented by the acronym DRASTIC— Depth to water table; net Recharge; Aquifer media; type of Soil; Topography; Impact of the vadose zone, and hydraulic Conductivity". Parameters and their assigned weights in DRASTIC method are shown in table 3. DRASTIC index number, which reflects the pollution potential for the aquifer is based on these seven parameters (Aller *et al.*, 1987). In DRASTIC method each factor was normalized to a scale from 1 to 10. These values are multiplied by a respective weight, which numerically represents the importance and influence that each factor has in the handling of the groundwater.

MPCA method, the prevalent method in land fill siting, was presented by Minnesota Pollution Control Agency (MPCA) 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 land fill siting whereas other conditional factors should be achieved by engineering considerations. Determinative and conditional factors utilized in MPCA method are illustrated in Table 4.

Table 3- Parameters and their Assigned weights in DRASTIC method (Aller *et al.*, 1985)

Number	Parameters	weight
1	Depth to water table	5
2	Net recharge	4
3	Aquifer media	3
4	Type of soil	2
5	Topography	1
6	Impact of the vadose zone	5
7	Hydraulic conductivity	3

Table4- Six determinative and seven conditional factors of MPCA method (Badve, 2001)

Number	Determinative Criteria	Conditional Criteria
1	Minimum 305 meters distance from any lake or pool	Minimum 305 meters distance from road, parks and residential area
2	Minimum 92 meters distance from any river or channel	No threat to any water resources pollution
3	Distance from area with 100 year 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 ground water resources contamination
6	Distance from area with limestone ground and caves	Constructed with enough precaution consideration
7	-	Feasibility of monitoring and sampling of ground water

In this study a new method which is developed concerning to DRASTIC and MPCM methods and based on local hydro-geological and social-economical characteristics was utilized for quantifying the potential vulnerability of groundwater. The criteria of this method are classified in two main criteria and 12 sub criteria. The main criteria, social-economical and environmental-technical criteria have 4 and 8 sub criteria respectively. Sub criteria and their assigned weights are present in Table 5.

Ranges and scores of two sub criteria in each main criterion are presented as an example in Table 6. Concern to weight and score of each criterion and on the basis of sites' local information, final scores of the sites were calculated. The calculated scores provided a basis for prioritization amongst 17 primarily candidate sites. In Table 7, as an example, detailed calculations of priority process are shown for sites 1, 9 and 14 as the best sites in each three mentioned zones. Table 8, also represents the priority of all candidate sites apart the study area.

Table5- Social-Economical and Environmental-Technical criteria and their assigned weights in the new method

Social-Economical criteria		
Number	Title	Weight
1	Distance from waste generation source	5
2	Easily owning	4
3	Distance from residential area	4
4	Easily access	3
Environmental - technical criteria		
Number	Title	Weight
1	Depth of ground water level	5
2	Ground water monitoring feasibility	3
3	Rain fall and run off	3
4	Soil type	4
5	Seismic activity	4
6	Distance from mines and industrial areas	3
7	Distance from sensitive environmental areas	3
8	Land Slope	3

Table 6- Ranges and scores for two sub criteria in the developed method

Distance from waste generation source	
Distance(km)	Score
<2	10
2-5	8
5-15	6
15-30	4
30-60	2
>60	0
Slope	
Rang (%)	Score
0-3%	10
3-7%	7
7-10%	3
>10%	0

Table7- Calculations used for determination of utilitarian in site 1, 9 and 14 in Abyeck, Khoramdasht and Takestan zones, respectively

Social-Economical criteria									
Title	Site 1			Site 9			Site 14		
	weight	score	utilitarian	weight	score	utilitarian	weight	score	utilitarian
Distance from waste generation source	5	10	50	5	0	0	5	0	0
Easily owning	4	10	40	4	5	20	4	5	20
Distance from residential areas	4	5	20	4	2.5	10	4	2.5	10
Easily access	1	10	30	1	6	18	1	6	18
Environmental -Technical criteria									
Depth of ground water level	5	10	50	5	10	50	5	7	35
Ground water monitoring feasibility	3	10	30	3	5	15	3	0	0
Rain fall and run off	3	3	9	3	6	18	3	6	18
Soil type	4	10	40	4	10	40	4	5	20
Seismic activity	4	7	21	4	10	30	4	10	30
Distance from mines and industrial areas	3	10	30	3	0	0	3	5	15
Distance from sensitive environmental areas	3	7	21	3	7	21	3	3	9
Land Slop	3	10	30	3	10	30	3	7	21
Total Score			371	Total Score		252	Total Score		196

Table 8- Score of each site amongst candidates sites

Site	Abyeck zone							Khoramdasht zone						Takestan zone			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Score	371	324	308	288	288	294	304	186	252	242	196	205	252	196	195	174	186

The results of priority processing between primarily candidate sites showed that site 1 is the more appropriate site for land filling of hazardous solid wastes of Shahid Rajaee power plant within Qazvin province.

Summary and Conclusions

Finding/selection of suitable sites for hazardous waste landfills is one of the major awaiting problems in developing countries where the industrial development is adversely affecting the environment. The main environmental issue which should be considered in disposal of hazardous solid waste is the location of its land filling. In this paper, a multidisciplinary approach based on GIS screening maps and priority analyses for hazardous waste landfill siting problem in an important province of Iran is presented. In first step of the study, the principal affecting factors were identified and used for development of GIS database in 1:250,000 scale. Three zones in this stage were selected for more detailed evaluation by 1:25,000 scale maps. In the second step, on the basis of DRASTIC and MPCM method and local features and legislations of the study area, a new method was developed and used for priority processing and ranking the candidate sites of the first stage. Eventually site 1 as highest scored site amongst 17 primarily selected sites is selected for land filling of the hazardous waste of Shahid Rajaee power plant. The proposed method may be used for site selection processes in other conditions and locations where the intensity of introduced parameters shows discrepancies.

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