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Application of Delphi method for Criteria prioritization in hazardous waste landfill site selection in Iran

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***Abstract*— The disposal is the final step of any hazardous waste management plan. Convenient Landfill Site Selection depends on various criteria. This study sought expert consensus in a 2-round Delphi survey to rate the importance of environmental criteria for hazardous waste landfill site selection in Salafchegan-Iran. A group of 17 experts rated the importance of 14 criteria. Consensus was reached on all 14 criteria (Standard Deviation for all criteria was less than 2.00 and the Mode of answers was considered as consensus).**

Keywords—Delphi method; site selection criteria; hazardous waste landfill

I. INTRODUCTION

The disposal of hazardous wastes is the final and vital step of an effective hazardous waste management plan (1). Inappropriate disposal of solid waste results in pollution of water, air, and soil and poses a serious threat for the human health and the environment (2). Convenient Landfill Site Selection depends on various criteria(3). Environmental factors are very important because the landfill may affect the surrounding biophysical environment and the ecology of the area (4),(5). Economic factors must be considered in the sitting of landfills as well (6).

On the other hand, it cannot be said that all criteria play the same role in landfill site selection. Hence, prioritization of landfill site selection criteria is a key step in landfill site selection process in any specific region.

Delphi, firstly developed by Dalkey and Helmer (1963), is understood as a tool for reaching expert consensus through scientific discourse and helping to solve complex situations in which, scientific knowledge elements are relatively certain, the relations between variables are very complex (7). A Delphi traditionally involves an anonymous survey using questionnaires with controlled feedback to allow interaction within a panel of experts(8). The choice of a specific design and the methodological of a Delphi process dependent on the research question defined by the analyst and vary significantly among studies(9),(10) .

Delphi consensus techniques have been used in different natural resources and environmental management researches(11). Some cases include: tourism (12),(13),(14), natural hazards(15-17), prioritization of negative factors affecting on mangrove forests (18), Criteria Selection in Site Survey of oil jetties (19), determination of effective environmental criteria in site suitability assessment of large extractive industrial units (20) and urban sustainability indicators(10) .

However, few researches have used the method for prioritization of hazardous waste landfill site selection.

The aim of the Delphi technique in the present study was to identify and aggregate the opinions of the experts regarding the importance of the hazardous waste landfill site selection criteria in Salafchegan-Iran.

In Salafchegan industrial park which is located in salafchegan watershed(fig.1), there are four active motor oil purification plants and 6679 tons of hazardous waste per year are produced, which is 80 percent of Qum province hazardous wastes (21). So properly criteria prioritization for appropriate landfill site selection in the region is a vital step in the protection of the environment.

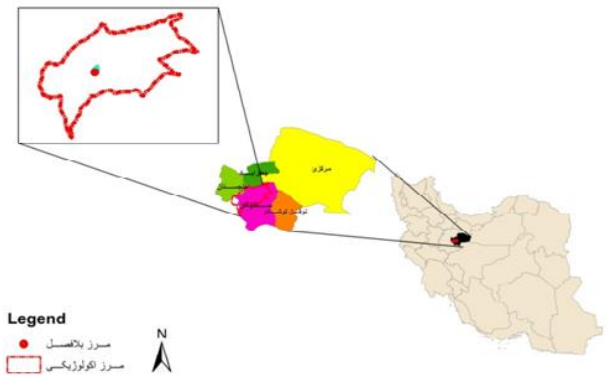

Fig.1. *The location of the study area in Iran*

II. METHOD

A. Identification of Criteria

Identifying and choosing appropriate criteria is the first step of this study. So, we tried to extract the main criteria by precise literature review. Previous studies indicate that aquifers, surface waters, lithology, land use, slope, aspect, human settlements, climatology, protected regions, hot spots, karst, springs, ghanats and wells, cultural heritage and infrastructures are some of the most important criteria (2, 22-29) . So we selected the criteria of this study (Table1) based on the literature review combined with the results on the necessary factors identified at the study area (salafchegan watershed).

B. Description of selected criteria

All of the selected criteria can be classified in five groups: geologic and geomorphologic criteria, hydrologic and hydrogeology criteria, biologic criteria, social and economic criteria and climatology criteria. Every selected criterion has a category of environmental factors which have different effects on finding an appropriate hazardous waste landfill site. As described before, some of these criteria are selected because of the study area necessities. These criteria are described as below:

1) geologic and geomorphologic criteria:

a) Lithology: Low permeability rocks such as shale, marl, claystone and schist are suitable for landfill practices, while rocks like limestones, sandstones, dolomite and alluviums and terraces have low suitability to waste management practices(3) as they tend to be relatively permeable(30).

b) Soil: *The permeability of the subsoil of a landfill site has an important role to play in the development of landfill as it acts like a barrier to leachate(31).*

c) Fault: The objective of this criterion is to minimize the potential that ground movements associated with active faults will damage the landfill containment system and compromise its performance(31).

d) Land use and land cover: The objective of this criterion is to minimize the potential for the landfill to be located in areas that are incompatible with surrounding land use. The less the economic importance of the site the more suitability of the site for landfill development. Also, because of unavailability of the rocky terrain in the land cover map of the study area and the necessity of using the data, we used an integration of land use and land cover criteria. This criterion can also be classified as an economic factor.

e) Height: The objective of this criterion is to minimize the potential for the landfill to be located in areas with high altitude.

f) Slop: Natural slope of a site is important from the drainage consideration. But, land with higher slopes may pose difficulty in the construction and may need leveling up(31).

2) hydrologic and hydrogeologic criteria:

a) Springs, wells, ghanats: Proximity of a landfill to groundwater wells, springs and ghanats is an important environmental consideration in the landfill site selection so that aquifers may be protected from the runoff and leaching of the landfill (22).

b) Depth to groundwater: To protect subsurface drinking water, landfills should not be situated over high quality groundwater resources*(23).*

c) River: The landfill site should not be placed within surface water or water resources protection areas to protect surface water from contamination by leachate(6). The objective of this criterion is to minimize the potential that surface water runoff from a landfill will impact a river or stream with contaminated runoff, sediment load, and/or waste(31).

3) biologic criteria:

a) Protected area: The objective of this criterion is to minimize the threat posed by a landfill to

- cause destruction or adverse modification to critical habitat of an endangered or threatened species,
- jeopardize the continued existence of endangered or threatened species or contribute to the taking of endangered or threatened species (31).

4) social and economic criteria:

a) Industrial park: The site should be located reasonably close to the centre of hazardous waste generation or to the transfer station. BCRC Industrial areas are not principally excluded as location of a landfill. Dependent of the kind of industry, an industrial area or close to it is suitable for a landfill

b) Infrastructure: If the location of the new landfill come across with existing infrastructural provisions such as cables, roads or existing plans for drainage, it is very difficult to make the location suitable for the use as a landfill (6),(2).

c) Highway, railroad, main road: The objective of this criterion is to minimize the visual impacts associated with a landfill from adjacent highways, railroads and main roads (31). Landfill location must be close to roads network to aid transportation and reduce relative costs(30) .

d) Village roads: The objective of this criterion is to minimize the visual impacts associated with a landfill from adjacent village roads.

e) Villages: The objective of this criterion is to minimize the potential for the landfill to be located near or within populated areas(31). In relation to a hazardous landfill siting there are always various social factors which include all of the real and perceived societal implications of the proposed landfill site(32). The landfill is considered to have a significant impact on those living within close proximity to the site, due to excessive noise, traffic, odor, litter, and scavengers. The impact is considered to be moderate on those living at somewhat greater distances from the site. According to current guidelines for industrial development projects in Iran a landfill cannot be located within residential area.kurdestan Landfills may not be constructed on sites within a distance of less than 2000 m to villages (22).

5) climatology Criteria:

a) Precipitation: The objective of this criterion is to minimize the potential for the landfill to be located in areas with high annual precipitation rate.

b) Evaporation: The objective of this criterion is to minimize the potential for the landfill to be located in areas with lower annual evaporation rate.

There are three kinds of factors in terms of exclusion from the study area and the Delphi process in this study:

- The first group is the completely excluding factors. Based on the reviews of the literatures (2),(6),(26),(27),(31),(33). Three different criteria including faults and the buffer zone, protected areas and the buffer zone and villages and the buffer zone are selected as the excluding criteria . These factors are not entered in the Delphi process. According to (2), The exclusion areas are those which are unsuitable for landfill sitting due to their potential risks to environment, human health, or imposing excessive cost.

- The second group factors are excluded from the study area, but the related buffer zone is not excluded. So the proximity to these features is prioritized in the Delphi process. These factors include: proximity to springs/wells/ghanats, river, Industrial park, Infrastructure, Highway/rail road/main road, secondary roads, Villages and depth to groundwater.

- The third group is the remaining factors. These include: lithology, soil, height, slop, precipitation and evaporation. In the present study, these factors and the second group factors were prioritized by experts in a Delphi process.

C. Application of Delphi method for selecting criteria of hazardous waste site selection

The Delphi study presented here was devised in a structured format in order to prioritize a list of pre-defined environmental criteria drawn from the literatures. The 14 identified criteria were given to 17 experts, through Delphi questionnaires for determining the importance of each criterion for hazardous waste landfill site selection by asking “What is the importance value of every criterion with respect to our interest?” the stages have been presented below:

1) Selection of experts: Experts’ panel selection is an important component in the Delphi method, as the validity of the results relies on their judgement(34). Donohoe stated that, the decisions regarding panel size, characteristics, and composition should ensure that the expertise represented on the panel is congruent with the research issues in question. Four ‘expertize’ requirements should be taken into account: knowledge and experience of the field of study; ability and willingness to participate; adequate time to participate; and effective communication skills (10). In this context, thirty highly informed experts were selected among academicians in the field of waste management and environmental management with enough domination on both environmental and technical aspects of our purpose in Salafchegan.

The purposively sampled experts have at least five years work experiences in landfill site selection and design. Purposive sampling was used in order to ensure that the experts meet pre-defined definitions of expertise in the fields. The sample size for the study is considered appropriate and fulfilled a Delphi survey criterion. Literature recognized a minimum appropriate size of seven or eight experts(10).

2) Preparation of the questionnaire and sending to experts: Invitation letter was sent to nominated participants by email. The participants were asked to assigne a weight between 1 – 10(1,2,,…,10) for each criterion, Where 1 represents the highest and 10 represents the least importance of the criterion.

The questionnaire provided the participants to add free text comments. Two-email reminder was sent in each round. At the second round, the experts were presented with feedback results for each criterion rated (or weighted) in first round. At this stage, the experts were also allowed to change their comments according to the results. Interactions among the participants remained anonymous and obtained information was released without participants' identification.

3) Questionnaire analysis: Analyzing methods applied in Delphi procedure are determined based on purpose, rounds structure, presented questions type and number of participants. Main statistics used in

Delphi studies include central tendency measures (mean, median and mode) and dispersion measures (standard deviation and inter-quartile range)(18).

In this study, after the first round, the Mode and Standard Deviation of expert's opinion was calculated. If the Standard Deviation was less than 2.00, the Mode of expert's opinion was considered as consensus.

4) Standardization of each criterion weight: Because the scores of the criteria were given on different scales, they must be standardized to a common dimensionless unit (6). For this process, the following formula is selected and applied. The table showes Mode, Standard Deviation and normalized weights for all criteria.

$$W = (n - rj + 1)/(\sum(n - rj + 1) \quad (1)$$

Where W is the normalized weight, n is the total number of used criteria and, rj is the raw weight.

III. RESULTS AND DISCUSSION :

The table below describes the results of the first and the second rounds. Thirty participants were invited to the Delphi process, seventeen experts gave their consent to participate. All of those numbers provided weightening at the first round and completed weightening in the second round. Descriptive information about the experts shows that the majority of the experts had at least 5 to 10 years working experience in waste and environmental management. All experts had PhD degree and Most of them had 5 or more years of experience as full-time professionals in the fields.

In terms of criteria suitability, the results of the Delphi analysis revealed that all values of data Std. Deviation was less than "2"(table1). In the second round, non of experts changed opinion, Consequently, the answers can be considered as acceptable consensus for criteria weights regarding the main goal of the study.

Literature review shows that regardless of climatological setting, most researchers and organizations allocate highest weights to hydrological and hydrogeological parameters (2),(23),(30),(35) ,(36) ,(37).

The table shows the results of the criteria prioritization by Delphi method and normalized weights for Salafchegan hazardous waste site selection. The results of this study indicated hydrologic and hydrogeologic criteria are the most important criteria for hazardous waste landfill site selection in Salafchegan. In this regard, most of experts gave the highest weight to "Distance from river" (Std. Deviation= 1.76) and "groundwater depth" (Std. Deviation= 0.61). In both cases, normalized weights were calculated "0.093". "springs, ghanats and wells" is the second important factor. Std. Deviation and normalized weight was calculated "1.27" and "0.086" respectively. This shows vulnerability of these water resources and the importance of pollution prevention in the region. The least weight is considered for "secondary road" (Mode = 8, Std. Deviation = 1.75, normalized weight = 0.046) and "infrastructure" (Mode = 7, Std. Deviation = 1.92, normalized weight = 0.053) respectively.

IV. CONCLUSION:

Convenient Landfill Site Selection depends on various criteria. These criteria have not equal importance in landfill site selection. Hence, prioritization of criteria is a key step in landfill site selection process in any specific region. Through a two-round Delphi survey procedure, a set of pre-defined environmental criteria drawn from the literatures was prioritized for hazardous waste landfill site selection in Salafchrgan-Iran. The most important criteria identified by the expert panel was the depth to ground water and proximity to river (Mode=1). This shows the vulnerability of these water resources and the importance of pollution prevention in the region. The other 12 criteria in order of the importance attributed, were springs/wells/ghanats (Mode=2) , industrial park and precipitation (Mode=3), lithology and soil and highway/railroad/mainroad(Mode=4) , slop(Mode=5) , height and landuse/landcover and evaporation (Mode=6) , infrastructure(Mode=7), secondary road(Mode=8).

TABLE I. Rating Result of the Importance for the Delphi First and Second Rounds

Criterion	Both 1st and 2nd Delphi rounds		Normalized Weight
	Mode	*Std. Deviation*	
River	1	1.76	0.093
Ground water	1	0.61	0.093
Springs,wells, ghanats	2	1.27	0.086
Lithology	4	1.85	0.073
Soil	4	1.15	0.073
Slop	5	1.65	0.066
Height	6	1.98	0.060
Industrial park	3	1.74	0.080

Criterion	Both 1st and 2nd Delphi rounds		Normalized Weight
	Mode	*Std. Deviation*	
Landuse and landcover	6	1.94	0.060
Infrustructure	7	1.92	0.053
Highway, railroad, main road	4	1.50	0.073
Secondary road	8	1.75	0.046
Precipitation	3	1.94	0.080
Evaporation	6	1.96	0.060

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