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Uncertainty Modelling of Waste Disposal Site Selection (Case Study: Marivan City)

Kayvan Bagheri Sayed Shekari, Najmeh Neysani Samany*, Morteza Omidipoor[1] and Sirous Hashemi Darehbadami

Department of Remote Sensing and GIS, Faculty of Geography, University of Tehran, Iran
✉ nneysani@ut.ac.ir

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Abstract: Waste disposal site selection is complex and multifaceted decision making process. In this regard to find appropriate sites, there are different local, national and international standards. These standards emphasize on certain criteria and related on different environmental, economic, social and political considerations. Lack of a comprehensive, integrated and efficient waste disposal site selection approach for determination of the proper sites stems from different experts comments. Since every expert in such problems doesn't have adequate knowledge of all aspects about the subject; their opinions are facing with uncertainty. This study aims to modeling uncertainty of waste disposal site selection based on Dempster-Shafer Theory (DST). The main contribution of this study is the reduction of uncertainty in the standard combination according to experts using DST. In this research three main standards including 'Environment Protection Agency of Iran (EPAI)', 'Management and Planning Organization of Iran (MPOI)' and 'Minnesota Pollution Control Agency (MPCA)' standards are considered and then site selection performed for each standard independently. In order to combining these standards, opinions of 40 experts are attained through DST as an integration approach that is able to manage the uncertainty. These comments are examined by DST and gained results are depicted as waste disposal location. Finally, the achieved results are compared with the results of simple weighting method (average of the opinion experts). Results showed that standard weight in questioning, that does not follow the normal, gives a lot of uncertainty in analysis that DST significantly reduces its impact.

Key words: Waste disposal, uncertainty, MPCA, EPAI, MPOI, DST.

Introduction

Waste disposal site selection is a complex and multifaceted decision making process. Finding an appropriate site selection requires an organized and systematic approach. Generally, regarding environmental dimensions, social/cultural considerations, political boundaries, legal requirements, aesthetic, technical and economic issues are essential on specification of proper waste disposal site evaluation criteria (Fabbricino, 2011; Tayyebi, et al., 2010; Han et al., 2016; Waste Management Agency and the University of Science and Technology Iran, 2011; Udeorji et al., 2005; Udeorji and Oke, 2007).

If groundwater levels are near the earth surface, it will be polluted. Also there is high possibility of surface waters contamination because of surface water and runoff accumulation in these places (Chakraborti et al., 2016; Jhamnani and Singh, 2009). Social factors are including distance from population areas (residential, commercial) and historical sites. Waste disposal location must not be closed to population centres. Issues such as waste disposal area, access to the road network and distance from waste production centres are considered

*Corresponding Author

economically important. From engineering point of view, selected location should not be located in active tectonic regions, because there is contamination potential risk in fault and earthquakes zones (Alhumoud and Al-Mumin, 2006; Pongracz, 2006; Shmelev and John Powell, 2006). Politically, waste should be disposed inside the political boundaries of the waste producer region (Kontos et al., 2003). There are several criteria and factors for selecting an appropriate waste disposal location and cited articles have failed to comprehensively address this issue. In this study, three important national and international standards—MPCA, EPAI and MPOI—are used to resolve this divergence.

According to the tips, rules, considerations and limitations mentioned about effective criteria (Suomi et al., 2017), we can say that in opinion of various experts waste disposal site selection decision making process is not homogeneous and relevant subject. So site selection is done according to each expert opinion and as a result there will be an uncertainty in their opinions. This matter was not surveyed in previous articles, and in this study we will deal with it. In decision-making process, different criteria do not have equal importance, so weight and relative value of each criterion should be determined. Several methods are provided for determining the weight of criteria including Ranking methods, Paired Comparison and Boolean Logic models. Uncertainty always exists in comparisons, because different field experts don't have enough knowledge about all aspects of the issues in a multi-criteria subject (Amiri, 2007). In this study, DST is used for weighting of expert's opinion because this method regards polls uncertainty (Mohebbi, 2015). Ashghan (2006) based on extended DST, introduced a new decision-making process in which all kinds of uncertainty lead to more accurately risk assessment and making decisions in a better manner (Ashqan, 2007).

Amiri (2008) evaluated the seismic risk and vulnerability in Tehran. He utilized from DST and integrated different experts' opinions. The various criteria were weighted and finally the level of seismic risk was obtained. Jahankhah (2009) used DST to assess seismic vulnerability and uncertainty modelling using GIS in Tehran. The used MCDM method includes all vulnerability effective criteria (Jhankhvah et al., 2008). Moradi et al. (2010) used DST theory, weighted factors affecting landslide (Mrady et al., 2010). Tayebi et al. (2010) applied DST and MCDM approach in order to selecting an optimum waste disposal location. They evaluated a few number of criteria and factors (Tayyebi et al., 2010).

The main goal of this study is modelling waste disposal site selection uncertainty using DST. Criteria are selected based on 'Iran Environment Protection Organization', 'Iran Management' and 'Planning Organization and Minnesota Pollution Control Agency' standards. For this reason, 40 experts opinion is gathered for prioritization of standards. Finally, DST is used for integrating weights provided by experts, so uncertainty effects in the weighting process have been considered and the best location for waste disposal has been selected.

Research Methodology

This study conducted waste disposal site selection uncertainty modelling in a few steps: standards were chosen by Literature Review and study area conditions. Site selection is performed for each standard independently, and then experts' opinions are obtained for standards prioritizing and incorporating. These comments are examined by DST and gained results are depicted as waste disposal location. Finally, the achieved results are compared with the results of simple weighting method (average of the opinion experts). Figure 1 illustrates the diagram of the proposed methodology.

Standards in Selection and Evaluation of Waste Disposal Location

In previous researches (Kontos et al., 2003; Amiri,

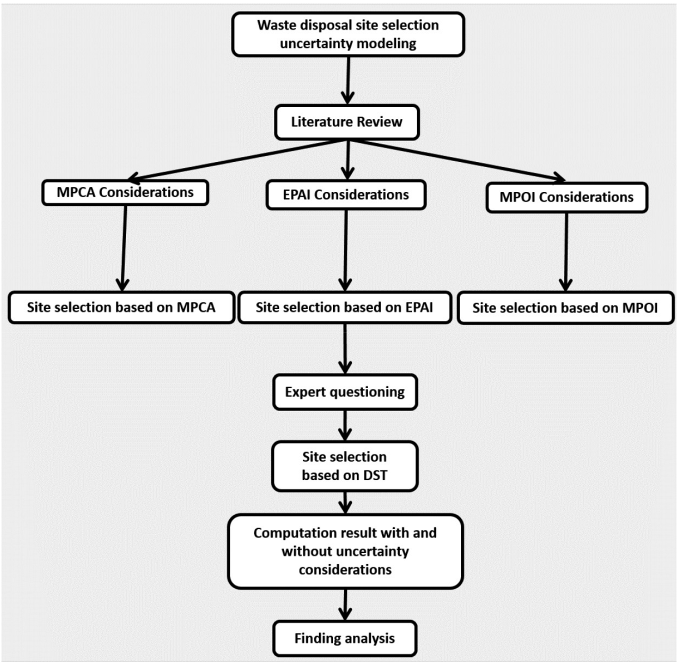

Figure 1: Flowchart of the proposed methodology.

2007; Suomi et al., 2017) and Environmental Protection Agency (APG), there are standards for waste disposal site selection. Each standard considers specific criteria. The following three models are introduced as the three different expert systems.

Minnesota Pollution Control Agency (MPCA) Method
This model is based on six primary deleted factors and seven secondary conditional factors (Sidifar et al., 2013).

The six factors are: 1. at least 305 metres distance from a lake or pool; 2. at least 92 metres distance from river or any local culvert; 3. the site should not be located in discharge stream with 100-year return period; 4. the site should not be located in swam land; 5. the site should not make birds to enter the local airport; and 6. the location should not be in places with limestone cave.

The seven conditional factors are: 1. The site should not be located in less than 305 metres away from the main roads and highways, public parks and residence areas. 2. The site should not be located in erodible and drainage areas. 3. The site should not be a threat for public water contamination. 4. The site should not be a threat for drinking water supplies contamination. 5. The site should not be a threat for groundwater pollution: a) the water resources that are used by wells. b) The water resources with four litres per minute discharge. Other water resources that feeds an aquifer in the region. 6. The site should not be located in areas that water stop does not exist to prevent the passages of groundwater. 7. The site should not be located in areas that cannot sample groundwater resources by conventional methods (Sidifar et al., 2013).

Iran Environmental Protection Agency (EPAI) Method
Iran Environmental Protection Agency (EPAI) has defined standards for proper disposal waste site selection. In Table 1 factors related to EPAI standard mentioned.

Iran Management and Planning Organization (MPOI) Method
Iran Management and Planning Organization (MPOI) has defined standards for proper disposal waste site selection. In Table 1 factors related to MPOI standard are mentioned. These standards are set with emphasis on environmental protection.

Dempster–Shafer Theory

Because decision-making process criteria do not have equal importance, their weight and relative preferences should be assigned in the first step. There are several methods for determining the criteria-weight ratio to each other, such as Paired Comparison Analysis, Ranking method and Boolean Logic Model, but in this research DST is used to reduce the uncertainty. Uncertainty always exists in comparisons, because different experts don't have enough knowledge about all aspects of the issue in a multiple criteria subject (Amiri, 2007). So a multi-criteria decision making approach is required to model the uncertainty in data and process. In this study, DST is used for modelling experts' opinion uncertainty in assigning criteria weight. DST integrates experts' opinion about criteria weight and assesses final weight (Mohebbi, 2015).

DST is based on belief which resulted from evidences (Shafer, 1967). The basic concepts in relation to the evidence can be as follows.

Detection Framework

If θ be a finite set, an element can be a hypothesis, a goal, or status of a system. θ is called detection frame. θ Power set is determined by Ω(θ). For example, suppose $\theta = \{a, b\}$. Power set θ is equal to:

$$\Omega(\theta) = \{\phi, \{a\}, \{b\}, \{a, b\}\} \tag{1}$$

ϕ is empty set that implies perfect system.

Basic Probability Assignment Function, Core Elements and Main Elements Core
Basic probability assignment function, represented by *m*, is defined in equation (2):

$$\begin{aligned} m : \Omega(\theta) \rightarrow [0, 1] \\ \Omega(\phi) = 0 \\ \sum_{A \subset \Omega(\theta)} m(A) = 1 \end{aligned} \tag{2}$$

The value of the bpa for a given set *A* (represented as), expresses the proportion of all relevant and available evidence that supports the claim that a particular element of θ belongs to the set A but to no particular subset of *A*. In the system failure state, *m* (*A*) is considered as belief measure which is obtained by viewing specific defect. Different information or evidence create different degrees of belief about the deficiency. Each *A* subset of θ is called central element, such that $m(A) > 0$ and $C = \bigcup A \; A$ is called a core element of mass function in θ (Amiri, 2007; Ltfy, 2011; Pasha, 2013; Dempster, 1997).

Belief and Plausibility Function
Belief function is defined as equation (3):

$$\text{Bel} : \Omega(\theta) \rightarrow [0, 1] \tag{3}$$

Table 1: Sub-criteria and limitations of the two organizations

Factors	*Iran Environmental Protection Agency*	*Iran Management and Planning Organization*
Distance from airport	At least 8 km	At least 3 km
Flood return period	Site should not be in flood plains with less than 100 years return period.	Site should not be in flood plains with less than 100 years return period.
Wetlands	Wetlands should not be selected as waste disposal site	Wetlands should not be selected as waste disposal site
Distance from public walkway	---	At least 300 metres
Distance from water wells	At least 1,500 metres horizontal distance from water wells	At least 400 metres distance from urban water wells
Earthquake sensitive areas	Site should not be in areas with active faults, underground mines, subsidence and holes resulting from the liquidation.	----
Groundwater	In areas with high groundwater level, the static level should be less than 5 metres.	----
The place area	Site should be large enough to store at least 10 years wastes	----
Topography	Smooth area	----
Weather	The place should reduce the effects of gases and odours to a minimum	----
Wind	The place should not be in upper streams of prevailing region winds	----
Land use	The place should not be in populated area	----
Agriculture	Distance from agricultural farm should be more than 500 metres	----
Distance from surface water	At least 200 metres	At least 100 metres
Distance from residential areas, restaurants, hotels, schools, churches, parks, cemeteries, historical place etc.	At least 10 km	----
Distance from hunting grounds and birds habitat	Should not be in these places	Should not be in these places
Distance from lake, pond, water stop, dam	----	At least 300 metres
Distance from road	At least 3-5 km	At least 300 metres

$$\text{Bel}\ (A) = \sum_{A \subset A} m(B)$$

Plausibility function is defined as follow:

$$\text{Pl} : \Omega(\theta) \rightarrow [0, 1] \qquad (4)$$

$$\text{Pl}\ (A) = 1 - \text{Bel}(\overline{A}) \sum_{A \cap B = \phi} m(B)$$

Bel (A) Function assigns the total probability of A, and is the lower bound belief for a set A. Pl (A) Function assigns the maximum probability of A, and is the upper bound belief for a set A.

Belief Interval [Bel (A), Pl (A)]

This interval reflects the uncertainty belief interval and Pl (A) – Bel (A) interval size describes unknowns of A (Figure 2). As you can see below, different belief interval has different meaning. Plausibility function is linked to the Belief function and based on equation (5) a definition is expressed (Amiri, 2007; Ltfy, 2011; Pasha, 2013; Dempster, 1997):

$$\begin{cases} Pl(A) = 1 - \text{Bel}(\overline{A}) \\ Pl(A) = 1 - \text{Doubt}\ (A) \end{cases} \qquad (5)$$

Evidence Combination Rules

DST rule is easily understandable, if it interprets as main possible number and graphic forms of expression. If m_1 is basic probability contribution for belief functions Bel_1 on $A_{1, \ldots,} A_K$ (Evidence and expert opinion), then probability values expressed by the main possible number includes m_1 (A_1), …, m_1 (A_K) which can be shown as line segments (Figure 3). It should be noted that the figure is a person probability values and is not a part of the detection framework. Similarly, Figure 4 shows main possible numbers for second belief functions Bel_2 with basic probability contribution m_2 and members $B_{1, \ldots,} B_P$. Figure 5 illustrates that how two line segments explain m_1 and m_2, they can integrate with each other and form a square (Amiri, 2007; Ltfy, 2011; Pasha, 2013; Dempster, 1997).

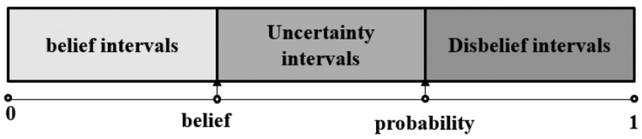

Figure 2: Uncertainty, belief and disbelief intervals.

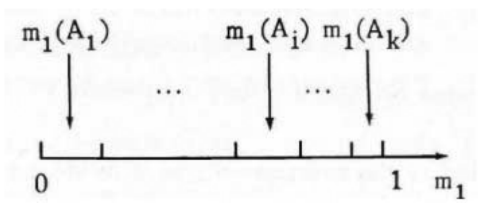

Figure 3: Main possible numbers m_1.

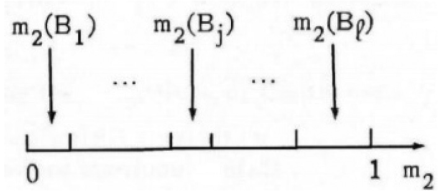

Figure 4: Main possible numbers m_2.

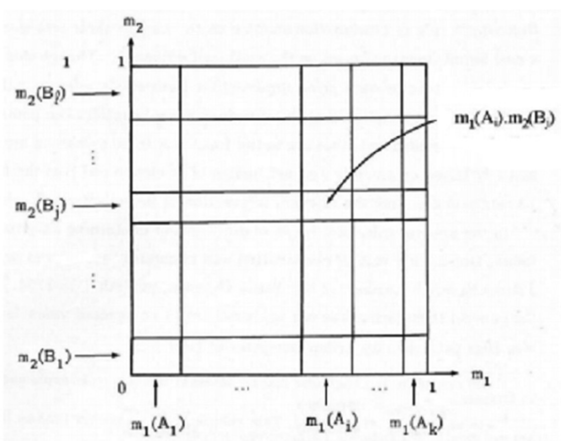

Figure 5: Integration of two factors m_1 and m_2.

The large square shows the total probability. Vertical stripes are Bel_1 members and horizontal stripes indicate Bel_2 members. For example m_1 (A_l) vertical strip (through m_1) is allocated to A and m_2 (B_j) horizontal strip (through m_2) is allocated to B_j. The intersection of these two strips is m_1 (A_l) m_2 (B_j). In other words, intersection and interaction of Bel_1 and Bel_2 is $A_l \cap B_j$.

One subset of θ like A can be related with more than one above rectangles. So A total probability is as follow:

$$\text{Total probability } A = \sum_{A \cap B_j = A} m_1 (A_l)\, m_2 (B_j) \quad (6)$$

Only problem is that some rectangles allocate to ϕ. It is possible that A_l focal member from Bel_1 and B_j focal member from Bel_2 be $A_l \cap B_j = \phi$:

$$\sum_{A \cap B_j = A} m_1 (A_l)\, m_2 (B_j) > 0 \quad (7)$$

The solution is to neglect all rectangles that allocate to ϕ. So the remaining rectangles can be multiplied by a coefficient as the following equation till total basic probability function be equal to 1. In fact, the equation normalizes basic probability function.

$$\left(1 - \sum_{A \cap B_j = \phi} m_1 (A_l)\, m_2 (B_j)^{-1}\right) \quad (8)$$

As two above theorems show, the mentioned structure has led to a new basic probability contribution. Of course provided that, Bel_1 and Bel_2 do not fully negate each other.

New Theorem: Assume Bel_1 and Bel_2 are belief functions with basic probability contribution m_1 and m_2, focal member $A_{1, \ldots,} A_K$, $B_{1, \ldots,} B_P$.

Suppose the following equation holds:

$$\sum_{A \cap B_j = \phi} m_1 (A_l)\, m_2 (B_j) < 1 \quad (9)$$

Then $m : 2^\theta \rightarrow [0, 1]$ function defines with $\Omega(\phi) = 0$, and following equation is a basic probability contribution for total A subsets of θ.

$$m(A) = \frac{\sum_{A \cap B_j = A} m_1 (A_l) \cdot m_2 (B_j)}{1 - \sum_{A \cap B_j = \phi} m_1 (A_l) \cdot m_2 (B_j)} \quad (10)$$

Belief function core is intersection of Bel_1 and Bel_2. Belief function m is called Orthogonal Sum Bel_1 and Bel_2 and is indicated as $Bel_1 \oplus Bel_2$ (Amiri, 2007; Ltfy, 2011; Pasha, 2013; Dempster, 1997).

Incompatible Weight
Mentioned Normalize constant has insignificant role in measuring of the incompatibility between the two functions. In fact, according to Figure 5, ϕ rectangles show that subsets A_1 and B_j are totally incompatible, so k value is higher. This is stated in equation (11).

$$k = \sum_{A \cap B_j = \phi} m_1(A_1) \cdot m_2(B_j) \tag{11}$$

If $k = 1$, then Bel_1 and Bel_2 totally negate each other, and there is not $Bel_1 \oplus Bel_2$. If $k = 0$, then Bel_1 and Bel_2 do not have any compatibility with each other. This can be generalized to several belief functions Bel_1, Bel_2, …, Bel_n (Amiri, 2007; Ltfy, 2011; Pasha, 2013; Dempster, 1997).

Implementation and Results

First, required spatial data are prepared, and then implemented by DST algorithm. Marivan County is located in the west of Kurdistan province (Figure 6). Centre of this county is Marivan city. This county's neighbours include Saqqez County from the north, Sanandaj County from the east and southeast, Nowsoud Sector, Paveh County from the south, and are bounded to Iraq from west and northwest. According to three selected site selection standards in this study, the relevant data are given in Table 1 and shown in Figure 7. At first the data are prepared as raster spatial layers, then MATLAB software is used for conducting standards "if, then" rules operation and DST uncertainty equation (Fehr, 2007; Boone et al., 2008).

Running DST

As mentioned in the previous section, each criteria standard is converted into GIS layers, then layers are combined together according to standards structure and rules. Site selection Maps according to three standards EPAI, MPCA and MPOI are shown in Figures 8, 9 and 10, respectively.

The next step is questioning about three mentioned standards. In order to incorporate these standards, their weight are obtained via interviewing with 40 experts (Table 3). It should be noted that, weight is ranged from 1-5 (1 for lowest value, 5 for most and the rest are in between). After that weights are normalized (Mohebbi, 2015).

Table 3 shows that experts' opinions about standards value are not equal, so there is uncertainty in questioning and final weight. So DST and arithmetic mean is used for combining expert opinions.

Table 2: Required spatial layers data

Spatial layer	*Spatial layer*	*Spatial layer*
Distance from airport	Distance from the spring	Distance from lake
Distance from walkway	Distance of the aqueduct	Distance from river
Distance from earthquake zone	Distance from well	Distance from the swamp
Distance from urban and rural residential areas	Distance from karst	Distance from road
Hunting grounds and bird's habitat	Distance from fault	Distance from the aquifer

In order to gain main possible number of each criteria obtained by the evidence combination, that criteria corresponding columns numbers should be measured. The first row of Table 3 can be demonstrated as follows:

$m_1(\{C_1\}) = 0/33$, $m_1(\{C_2\}) = 0/22$, $m_1(\{C_3\}) = 0/45$

Number 1 in the m letter represents the first expert opinion; and there is the same order for the rest. For example, third expert is as follows:

$m_3(\{C_1\}) = 0/44$, $m_3(\{C_2\}) = 0/23$, $m_3(\{C_3\}) = 0/33$

In order to incorporate the experts' opinions, first and second expert opinions are combined and its result is combined by the third expert's opinion. This is the same for the rest of experts.

To combine the first and second experts' opinion, DST combination is used. Its calculation method for measuring main possible number is as follows:

$$m_{12}(C_1) = \frac{\sum_{A_i \cap B_j = C_1} m_1(A_i).m_2(B_j)}{1 - \sum_{A_i \cap B_j = f} m_1(A_i).m_2(B_j)}$$

$$= \frac{0.33 * 0.50}{1 - (0.33*0.2 + 0.33*0.3 + 0.22*0.5 + 0.22*0.3 + 0.45*0.5 + 0.45*0.2)} = 0.47$$

For calculating the denominator, each of first evidence is compared with each of the second evidence, the pair set with null intersection is selected, and the weights multiply by each other. Finally, sum of these multiplies is calculated and subtracted by 1. The next step is the integration of the composed result of the first and second evidence with the third evidence (the same is for the rest). Figure 11 shows its flowchart.

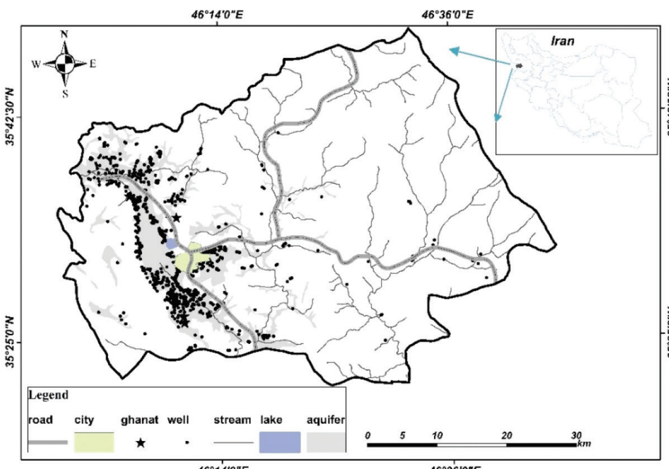

Figure 6: Study area: Iran-Sanandaj-Marivan.

After DST combination is done, weights are obtained in Table 2 last row. These weights are multiplied by standard layers and then are combined to each other. Figures 11 and 12 show the final map of the two combinations.

Sensitivity Analysis

As it can be seen, weight in Table 3 and each class covered area in Table 4 have difference for both methods (DST and the arithmetic mean), and this difference is the result of uncertainty. Arithmetic mean only considers experts weighted average and does not show sensitivity to tolerance, dispersion and skewness. The DST is very sensitive to these parameters; this sensitivity returns

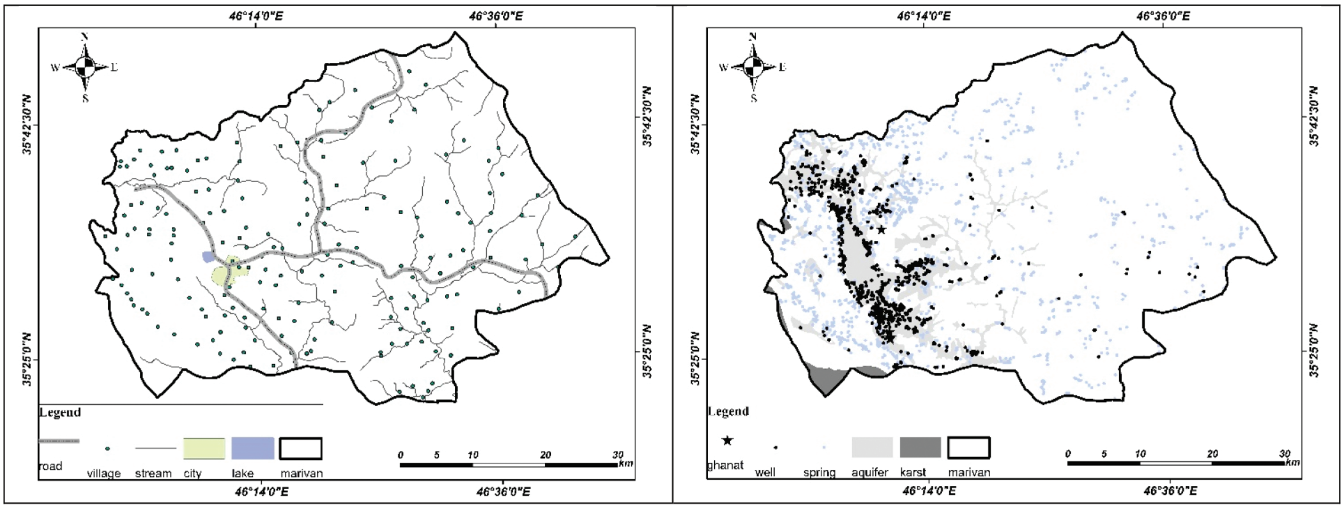

Figure 7: Required spatial data.

to the theory of combining this method (referred to in Dempster–Shafer Theory).

In DST, normal parameters such as mean deviation and dispersion around the mean are very important. In other words, a criterion (for example c_2) does not have normal distribution i.e. the standard have high range, high dispersion, and low minimum (Table 5). These parameters show high uncertainty in this standard. Finally in DST combination, weight does not have strong effect on the final result.

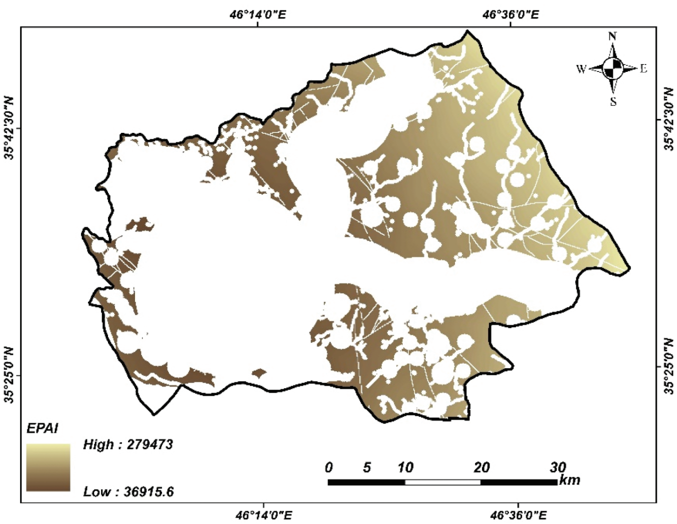

Figure 8: Waste disposal site selection map based on EPAI standards.

Conclusion

Waste disposal site selection decision-making process is complex and multifaceted issue, such that there are many national and international standards for it. Each standard considers certain criteria that leads to uncertainty in the results. DST combination is used to

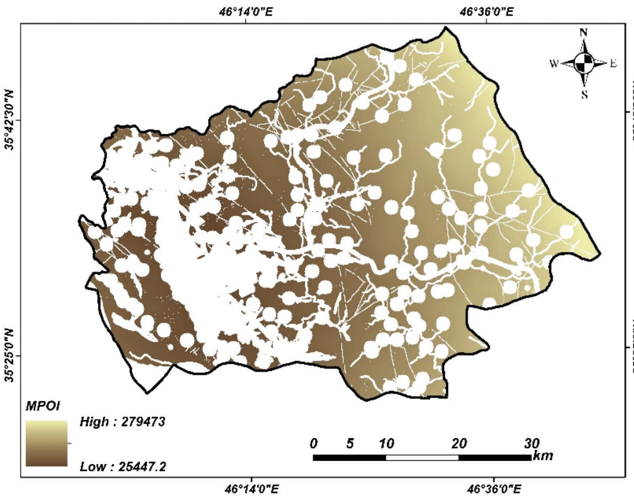

Figure 9: Waste disposal site selection map based on MOPI standards.

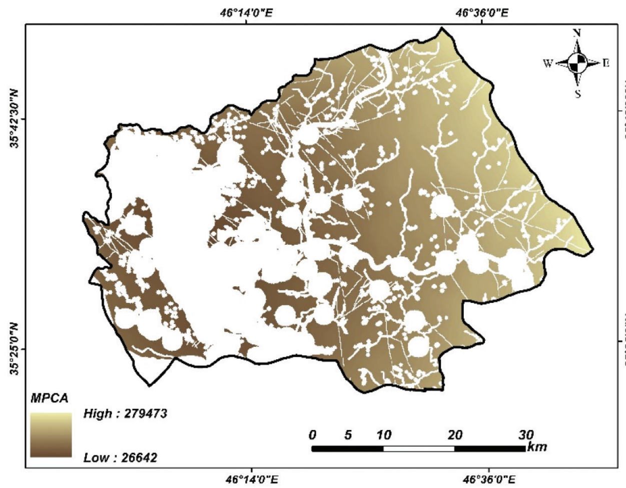

Figure 10: Waste disposal site selection map based on MPCA standards.

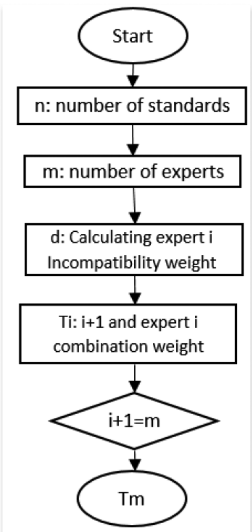

Figure 11: DST flowchart.

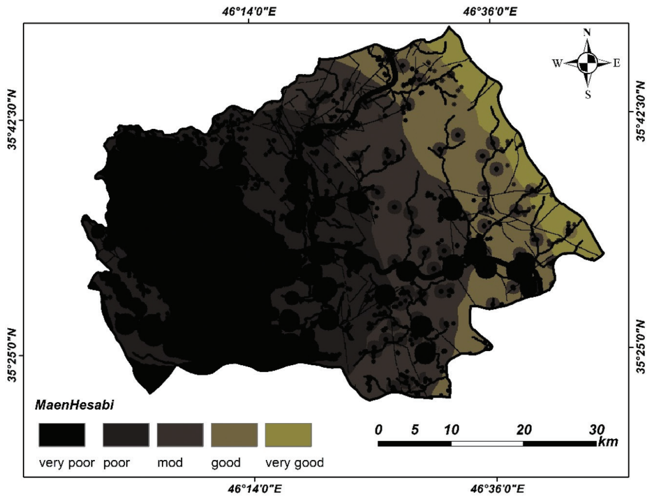

Figure 12: Marivan waste disposal location map resulted by standards arithmetic mean combination.

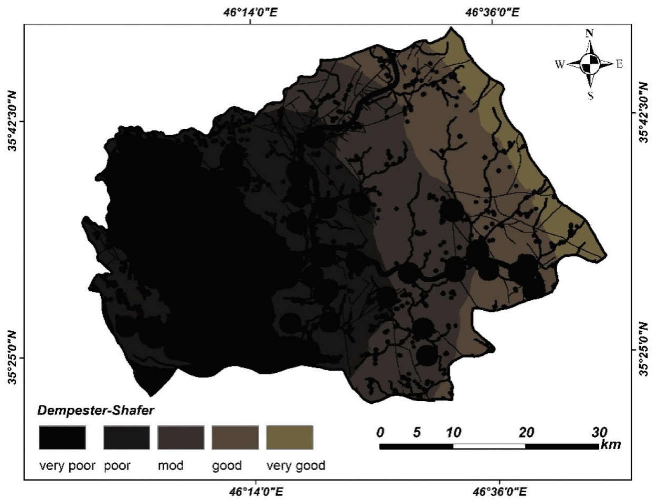

Figure 13: Marivan waste disposal location map resulted by DST standards combination.

reduce the uncertainty. Important criteria and factors are selected based on three standards MPCA, EPAI and MPOI. Because the standards do not have equal importance in the decision-making process, their weight and relative values should be assigned. For this reason, relevant expert's opinions are taken for assigning weight to standards. Finally, expert opinions are combined together based on DST, and the result are compared with the arithmetic mean. At the end, the best waste disposal location is selected. Considering algebraic equations, DST is very sensitive to normal parameters including, standard deviation and dispersion around the mean. In other words, DST reduces data uncertainties that have these features. The result shows that the standards that do not follow the normal parameters in questioning enter great uncertainty into calculations, and DST minimizes these impacts. On contrary arithmetic mean does not

Table 3: Waste disposal standards weights according to experts' opinion (evidence) for selecting best waste disposal location

Number of experts	*Belief of experts*	*EPAI (C_1)*	*MPOI (C_2)*	*MPCA (C_3)*
1	m_1	0.33	0.22	0.45
2	m_2	0.5	0.2	0.3
3	m_3	0.44	0.23	0.33
4	m_4	0.33	0.22	0.45
5	m_5	0.36	0.28	0.36
6	m_6	0.4	0.22	0.38
7	m_7	0.33	0.45	0.22
8	m_8	0.41	0.28	0.33
9	m_9	0.36	0.18	0.46
10	m_{10}	0.46	0.18	0.36
11	m_{11}	0.33	0.22	0.45
12	m_{12}	0.45	0.25	0.3
13	m_{13}	0.44	0.23	0.33
14	m_{14}	0.22	0.33	0.45
15	m_{15}	0.45	0.33	0.22
16	m_{16}	0.3	0.4	0.3
17	m_{17}	0.27	0.33	0.4
18	m_{18}	0.41	0.26	0.33
19	m_{19}	0.36	0.34	0.33
20	m_{20}	0.36	0.28	0.36
...	...	...	...	...
40	m_{40}	0.27	0.33	0.4
Dempster-Shafer final weight		0.74	0.2	0.24
Arithmetic mean		0.38	0.27	0.35

consider uncertainty. Eventually, the uncertainty should be considered in combining data that don't have close dispersion around the mean, and DST combination consider this uncertainty.

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Table 4: Pixel numbers of both arithmetic and DST combination class

Class	*Arithmetic mean*	*DST*	*Change percentage of Dempster-Shafer to arithmetic mean*
Very well	114750	113450	1.15
Well	40261	35981	11.9
Average	37384	39110	-4.41
Bad	27967	31500	-11.22
Very bad	11380	11691	-2.66

Table 5: Information on the statistical parameters of all three standards

Standards	*DS weight*	*Average weight*	*Skewness*	*Sum*	*Maximum*	*Minimum*	*Number*
C_1	0.74	0.38	0.29	7.51	0.5	0.22	40
C_2	0.02	0.27	1.06	5.38	0.45	0.18	40
C_3	0.24	0.35	-0.14	7.11	0.46	0.22	40

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