COMBINING MULTI CRITERIA DECISION MAKING AND DEMPSTER SHAFER THEORY FOR LANDFILL SITE SELECTION

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ABSTRACT:

This paper presents an integrated approach which utilizes multi criteria decision making (MCDM) alongside with Dempster Shafer Theory of evidence (DST) for the selection of landfill sites. It employs a two stage analysis for selecting landfill sites in urban region of Zanjan. The first-stage analysis makes use of the maps in Geospatial information system (GIS) in conjunction with different variables leading to support the second-stage analysis using the MCDM and DST as a tool. The purpose of GIS was to perform an initial process to eliminate unsuitable land followed by utilization of MCDM and DST method to identify the most suitable site using the information provided by the regional experts. Since it is not expected that all experts have the same information on the criteria, it is unavoidable to have uncertainty between expert's view points. In this paper, for modelling the uncertainty in expert's viewpoints, DST and analytical network process (ANP) have been implemented. Each expert's view is regarded as evidence. These evidences are integrated by DST integration rule to get an individual weight for each criterion. Furthermore, sensitivity analysis was performed using Monte Carlo simulation where the decision weights associated with all criteria were varied to investigate their relative impacts on the rank ordering of the potential sites in the second stage.

1. INTRODUCTION

Landfill site selection in an urban area is a critical issue because of its enormous impact on the economy and the environmental health of the region and many sitting factors and criteria should be carefully organized and analyzed. The landfill selection problems have often been tackled using multi criteria decision analysis (MCDA). Siddiqui et al. (1996) were the first to combine GIS and analytical hierarchical process (AHP) procedure to aid in site selection. Similarly, Charnpratheep et al. (1997) utilized fuzzy set theory with GIS for the screening of landfill sites in Thailand. Ishizaka and Tanaka (2003) discussed the subject of risk communication for the waste disposal system in Japan, considering public conflict in the site selection process. Pokhrel and Viraraghavan (2005) carried out an evaluation of solid waste management concerning the sitting of landfills in Nepal. Sener et al. (2006) integrated GIS and MCDA to solve the landfill site selection problem and developed a ranking of the potential landfill areas based on a variety of criteria. Al-Jarrah and Abu-Qdais (2006) focused on the problem of sitting a new landfill using an intelligent system based on fuzzy inference. Chang et al. (2008) combined GIS and fuzzy MCDM for landfill sitting in the suburban area of the City of Harlingen. Furthermore, several publications have tackled landfill sitting problems using GIS and MCDM or intelligent system approaches in Greece, Turkey, and Jordan (Vatalis and Manoliadis, 2002; Kontos et al., 2005; Al-Jarrah and Abu-Qdais, 2005). However, none of these studies consider uncertainty between expert's view points for landfill site selection.

Combination of GIS and multi criteria evaluation (MCE) has been routinely adopted as an approach to assess the suitability of an area to host a landfill (Buenrostro Delgado et al., 2008; Malczewski, 2006). Taking into account both technical elements and people's values and perceptions is essential to build consensus around a decision, to reduce conflicts, and consequently to pave the way to successful landfill sitting interventions (Higgs, 2006; Norese, 2006; Petts, 2001). Spatial MCE is commonly applied to land suitability analysis (Malczewski, 2004 and Collins et al. 2001), and specifically to landfill site selection studies (Sener et al., 2006; Mourmouris, 2006; Kontos et al., 2005; Calijuri et al., 2004; Vatalis and Manoliadis, 2002). However, relatively few studies incorporate uncertainty between expert's view points to select landfill sites. In most applications, the value-based input (e.g., weights of the different criteria; critical thresholds of the adopted indicators) is provided by the same authors or by a panel of technical experts, through techniques such as interviews or Delphi surveys (Buenrostro Delgado et al., 2008; Hatzichristos and Giaoutzi, 2006). Landfill site determination problem can be considered as a MCDM problem based on weighting the criteria by experts. However, since it is not expected that decision makers have enough knowledge regarding whole aspects of the problem and effective criteria, certainly we have uncertainty in the comparisons. Advanced algorithms, however, may further help justify the uncertainty in sitting new landfills. Beynon et al (2000) introduced a method to solve a MCDM problem called DST/AHP which combines aspects of the DST and AHP (Shafer, 1976). DST/AHP method differs from AHP in that it allows comparisons to be made between groups of alternatives instead of single alternatives, and it uses Dempster's rule of combination for aggregating the criteria instead of simple multiplications and additions.

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Our proposed method differs from the conventional methods of integrating GIS with MCDM for landfill selection because this paper presents an integrated approach for the selection of landfill sites via a two stage analysis. In the first stage, the geospatial data were analyzed using GIS was created that combines the environmental, transportation, social, and economic criteria for the selection of candidate sites. It eventually generates the landfill sites in based on different criteria involved collectively in an ANP and DST analysis. The case study was made for the city of Zanjan in west of Iran, which is rapidly evolving into a large urban. The whole blocks of the city are classified according to the criteria and weighted by DST of evidence and ANP. Every criterion allowed being evidence. Landfill sites have been determined by integrating the evidences. The method has been successfully implemented for production of a landfill sites map. Despite variations of the decision weights within a range of 15%, it shows that a landfill site remains its comparative advantage in the final site selection process.

In the rest of the paper, section 2, the proposed integrated approach is described. Sections 3 describe the formulation of ANP/DST models that are applied in the problem, and the result from the analysis is discussed in section 4. A brief conclusion is given in section 5.

2. METHODOLOGY

2.1 Data preparation

The criteria used for preliminary screening examine the proximity of potential sites with respect to geographic objects that may be affected by the landfill sitting or that may affect landfill operations (Fig. 1). Methodologies used are normally based on a composite suitability analysis using map overlays (O'Leary et al., 1986) and their extension to include statistical analysis (Anderson and Greenberg, 1982). The utilization of GIS for a preliminary process is normally carried out by creating buffer zones around geographic features to be protected. With the aid of this functionality, GIS have been used to facilitate and lower the cost of the process of selection of sites for building sanitary landfills in the last few years (Siddiqui et al., 1996; Kao et al., 1997).

2.2 Dempster Shafer theory of evidence (DST)

The Dempster-Shafer belief structure was introduced by Dempster (Dempster, 1967) and by Shafer (Shafer, 1976). Since then, a lot of new developments have been developed about it (Yager er al., 2008; 2004). It provides a unifying framework for representing uncertainty as it can include in the same formulation the cases of risk and ignorance. Obviously, the case of certainty is also included as it can be seen as a particular case of risk or ignorance. For the case of risk, we find a situation of certainty when the probability of some outcome is one. For the case of ignorance, we find a situation of certainty when there is only one element in the set of events. A Dempster-Shafer belief structure defined on a space X consists of a collection of n non-null subsets of X, B_j for j = 1,…,n, called focal elements and a mapping m, called the basic assignment function, defined as:

$$m: 2^X \to [0,1]$$

Such that: $\sum_{j=1}^{n} m(B_j) = 1$; and $m(A) = 0, \forall A \neq B_j$

For the case of risk, a belief structure is called Bayesian belief structure (Shafer, 1976) if it consists of n focal elements such that $B_j = \{x_j\}$, where each focal element is a singleton. Then, we can see that we are in a situation of decision making under risk environment as $m(B_j) = P_j = \Pr ob\{x_j\}$.

For the case of ignorance, the belief structure consists in only one focal element B, where $m(B)$ essentially is the decision making under ignorance environment as this focal element comprises all the states of nature. Thus, $m(B) = 1$. Other special cases of belief structures such as the consonant belief structure or the simple support function are studied in (Shafer, 1976). The two measures associated with these belief structures are the measures of plausibility and belief (Shafer, 1976). The plausibility measure Pl is defined as $Pl: 2^X \to [0,1]$ such that:

$$Pl(A) = \sum_{A \cap B_j \neq \phi} m(B_j) \tag{1}$$

The belief measure Bel is also defined as $Bel: 2^X \to [0,1]$ such that:

$$Bel(A) = \sum_{B_j \subseteq A} m(B_j) \tag{2}$$

Bel(A) represents the exact support to A and Pl(A) represents the possible support to A. With these two measures we can form the interval of support to A as [Bel(A), Pl(A)]. This interval can be seen as the lower and upper bounds of the probability to which A is supported. From this we see that Pl (A) ≥ Bel(A) for all A. Another interesting aspect about these two measures is that they are connected by Bel(A) = 1 – Pl($\bar{A}$) or by Pl(A) = 1 – Bel($\bar{A}$), where $\bar{A}$ is the complement of A.

DST provides a method to combine the measures of evidence from different sources, using the Dempster's rule of combination. This rule assumes that these sources are independent. Then the function: $m_1 \oplus m_2 : 2^X \to [0,1]$ defined by (Shafer, 1976):

$$m_1 \oplus m_2(C) = \frac{\sum_{A \cap B = C} m_1(A).m_2(B)}{1 - \sum_{A \cap B = \phi} m_1(A).m_2(B)} \tag{3}$$

The denominator interpreted as a measure of conflict between the pieces of evidence and evaluating the quality of combination (Fig. 1).

2.3 Analytical Network Process (ANP)/DST

The ANP has been proposed as a suitable MCDA tool to evaluate the alternatives during the landfill sites selection (Promentilla et al., 2005, 2006). ANP allows both interaction and feedback within clusters of elements and between clusters. The elements in a cluster may influence other elements in the same cluster and those in other clusters with respect to each of several properties. Although, the super matrix approach which became popularly known as the ANP approach is becoming an attractive tool to understand more of the complex decision

problem as it overcomes the limitation of the AHP's linear hierarchy structure (Saaty, 1996, 2001), the ANP-based decision model seems to be ineffective in dealing with the inherent uncertainty in judgment during the pair wise comparison process. Although the use of the discrete scale of 1–9 to represent the verbal judgment in pair wise comparisons has the advantage of simplicity, it does not take into account the uncertainty associated with the mapping of one's perception or judgment to a number. In real-life decision making situation, the decision makers could be uncertain about their own level of preference, due to incomplete information or knowledge, complexity and uncertainty within the decision environment. Such conditions may occur when managing landfill sites particularly during the selection stage. Therefore, this paper proposes an integrating of ANP and DST approach to select the landfill sites (Fig. 1).

2.4 Sensitivity analysis

In a landfill selection process, it is necessary to assess the reliability of the method involved in identification of the candidate site. A small perturbation in the decision weights may have a significant impact on the candidate sites. Therefore, sensitivity analysis using Monte Carlo simulation was performed to determine the probability of changes in candidate sites. Hence, the decision weights were systematically varied to investigate the relative impacts of the weights on the candidate sites of the landfill sites (Fig. 1).

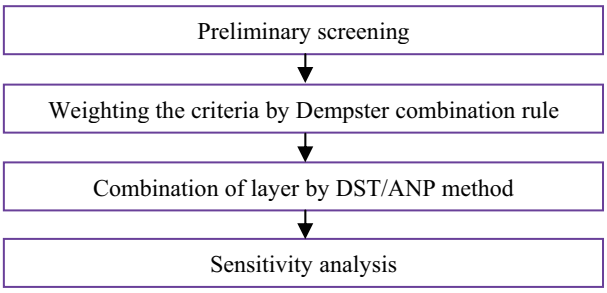


Figure 1. Conceptual scheme of our proposed approach

3. DATA AND STUDY AREA

Zanjan has an area of 22,164 km², occupying 1.34% of the Iranian territory. The average population density in Zanjan is 4.25 people per km located North West of Iran; Zanjan covers joint borders with seven provinces (Fig. 2).

Figure 2. Study area

4. IMPLEMENTATION

We used four criteria in the computation process, which were divided into two main groups. The first group includes environmental criteria that limit the analysis to particular geographic areas. The second group is economic factors. The examined criteria were selected based on the relevant international literature (Kontos et al., 2005; Al-Jarrah and Abu-Qdais, 2006; Sener et al., 2006) and the regulations in Iran on landfill sitting. All criteria are shown in Table 1.

Firstly, we must weigh the criteria based on expert's opinions and then determine the grade of landfill site of each urban block. Weighting of landfill site criteria is achieved by Dempster combination rule. In the next stage, specifying the landfill site grade of urban blocks is performed by DST/ANP method. In the process of weighting landfill site criteria, we used opinions of a number of experts. Each of the experts considered as an independent source (evidence) and then Dempster combination rule combines the expert's opinions which results to final weights criteria. In order to get the landfill site grade of each urban block, every criterion is regarded as evidence and finally using Beynon relations and Dempster rule of combination, a landfill site zoning map is produced. The whole operation in this paper has been illustrated as follow.

Table 1. Criteria for landfill site selection

Landfill suitability (A)		Level 1
Economic Criteria (B_1)	Environmental Criteria (B_2)	Level 2
Distance from roads (C_1)	Distance from residential areas (C_3)	Level 3
Distance from waste centres (C_2)	Slope (C_4)	Level 3

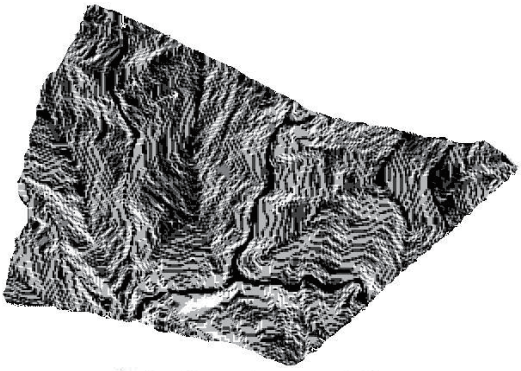
4.1 Data preparation

In this study, four input map layers including residential areas, slope, waste production centers, and road. The land use map was obtained from the National Cartographic Center. Its scale is 1:25,000. For all criteria, standard criteria for pollution control on the landfill site were used. According to Iran waste management law and waste landfill criterion, a sanitary landfill cannot be located within 1 km of residential areas. In order to have more certainty about our selection, a 2 km buffer zone was applied for present urban and industrial areas. So, areas within a 2 km buffer zone are not appropriate for landfill site selection and areas outside buffer zone are appropriate for landfill site selection (Fig. 3a).

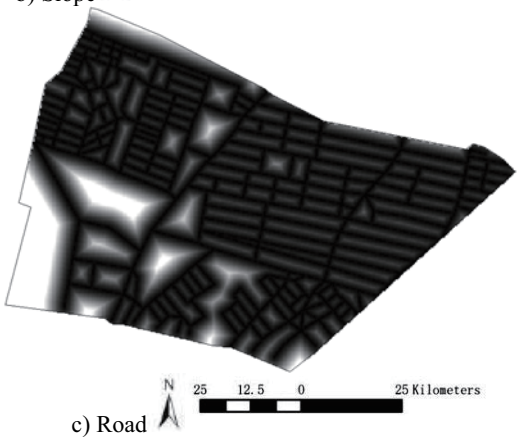
The slope of the land surface was calculated on the pixel basis using the Digital Elevation Model (DEM) of the study area (Fig. 3b), as a percentage ranging from 0 to 50%. So, the high values of the slope of the land surface are not appropriate for landfill site selection. In addition, a 1 km buffer zone was set on each side of highways and railways. The closer the distance to highways and railways are more appropriate for landfill site (Fig. 3c) but Roads other than highways and railways were treated as contraries; the closer the distance is not appropriate for landfill site (Fig. 3c).

When considering economic feasibility of a candidate landfill site, the proximity to waste production sources is an important factor; landfill sites close to the waste production centers will decrease transportation costs. In order to determine the landfill site for the whole study area, we analyzed the buffer zone for the existing landfill and transfer station, which means the sites are more suitable and given higher score when they are closer to these facilities. A buffer zone with 1 km radium is not appropriate for landfill site because it is near existing other landfill sites (Fig. 3d).

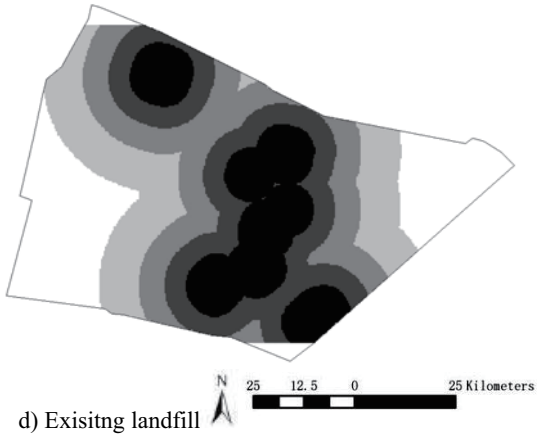
a) Residential areas



b) Slope



c) Road



d) Exisitng landfill

Figure 3. (a) Residential areas, (b) slope of the land surface (c) road, (d) existing landfill

5. RESULTS AND DISCUSSIONS

5.1 Assigning weight with DST

Pair wise comparisons of all related attribute values were used by three experts to establish the relative importance of elements (Tayyebi et al., 2009). Decision makers evaluated the importance of pairs of grouped elements in terms of their contribution. Finally, all the values for a given attribute were pair wise compared (Tables 2). Then, DST was used to get final weight the criteria for landfill site selection. The following example (see Table 2) shows how this theory is applied for weighting the four criteria C_1, C_2, C_3 and C_4. In table 2, the criteria weights assigned by experts using a pair wise matrix is illustrated. The viewpoint of each expert is considered as evidence. Also the experts are requested to assign a weight to ambiguity (Q) to estimate the total ambiguity of the landfill site.

Table 2: The weights assigned to the criteria according to the expert's opinion

	C_1	C_2	C_3	C_4	Ambiguity (Q)
Expert 1	0.15	0.10	0.25	0.40	0.10
Expert 2	0.10	0.10	0.30	0.30	0.20
Expert 3	0.15	0.15	0.20	0.35	0.15

In Table 3 the combination of views provided by expert 1 and expert 2 (evidence1 and evidence 2) are observed.

Table3: Combination of expert1 and expert2 opinions

Expert1		Expert2	The result of combination
$\{C_1\}=0.15$		$\{C_1\}=0.10$	$\{C_1\}=0.14$
$\{C_2\}=0.10$		$\{C_2\}=0.10$	$\{C_2\}=0.12$
$\{C_3\}=0.25$	$\oplus$	$\{C_3\}=0.30$	$\{C_3\}=0.28$
$\{C_4\}=0.40$		$\{C_4\}=0.30$	$\{C_4\}=0.38$
$\{Q\}=0.10$		$\{Q\}=0.20$	$\{Q\}=0.08$

Table 4 represents the result of combination of expert 3's views (evidence 3) and Table 3. Table 4 shows the final weights calculated by Dempster combination rule.

Table4: Combination of expert1 and expert2 opinions

Expert1		Expert2	The result of combination
$\{C_1\}=0.14$		$\{C_1\}=0.15$	$\{C_1\}=0.16$
$\{C_2\}=0.12$		$\{C_2\}=0.15$	$\{C_2\}=0.14$
$\{C_3\}=0.28$	$\oplus$	$\{C_3\}=0.20$	$\{C_3\}=0.32$
$\{C_4\}=0.38$		$\{C_4\}=0.35$	$\{C_4\}=0.36$
$\{Q\}=0.08$		$\{Q\}=0.15$	$\{Q\}=0.02$

In this research, the weights achieved for landfill site criteria for Zanjan consists of weights for residential area: 0.16, mean slope: 0.14, road: 0.32 and existing landfill: 0.36, respectively. An amount of 0.02 is assigned to ambiguity.

5.2 Aggregation procedure with DST/ANP

DST/ANP method was introduced by Benyon in 2000. It has two main differences with ANP method. DS/ANP method allows comparisons to be made between groups of alternatives

instead of single alternatives and uses Dempster's rule of combination for aggregating the criteria instead of simple multiplications and additions. In DS/ANP method for each criterion, decision makers, have a number of choices. In this paper because the number of choices (Zanjan blocks) is very large so grouping of the choices is undertaken using done by ArcGIS software. For grouping the blocks a unified scale is utilized. Three unit scales are considered for discerning levels of landfill sites between the groups of urban blocks (Table 5).

Table5: Three unit scales for discerning the landfill site grade of urban blocks

Scale number	Landfill site grade
1	Best
2	Good
3	Unsuitable

After grouping blocks based on the criteria, each block has an integer number from 1 to 3. Then Beynon formula has been employed to normalize the integer numbers to the blocks so that the sum of numbers for each criterion is equal to one. In this step each criterion plays a witness role. The following two formulas are used to calculate the basic probability numbers for each group of urban blocks (Beynon, 2000):

$$m(s_i) = \frac{a_i p}{\sum_{j=1}^{d} a_j p + \sqrt{d}} \; ; \; i = 1,2,\ldots,d \qquad (4)$$

$$m(\Theta) = \frac{\sqrt{d}}{\sum_{j=1}^{d} a_j p + \sqrt{d}} \qquad (5)$$

where: p: criterion weight
d: number of groups blocks
$a_1, a_2 \ldots a_d$: relative importance values of each group (three unit scale); and
$s_1, s_2 \ldots s_d$: group of blocks.

In this problem, the number of groups (d) of urban blocks for each criterion is 3. $m(s_i)$ is related to the decimal number of group s_i calculated using Beynon formula. Therefore, the value of the basic probabilistic number of each block is computed with the above relations (Table 6).
Values of the column show the real belief of urban blocks based on composing of evidence from the four criteria. In the other words, these values exhibit landfill sites of urban blocks. Value of vagueness (Θ=0.02) is smaller than all individual criteria. Also the value of the conflict in judged to be equal to 0.8947 showing conflict between the criteria. The final suitability map (Fig. 4) is produced by aggregation procedure based on weight. The final suitability results were divided into three discrete categories: best landfill areas, good landfill areas, and unsuitable landfill areas, as shown in Fig. 4. The map can have many applications in urban planning which are crucial in ensuring adequate social, economic and environmental conditions.

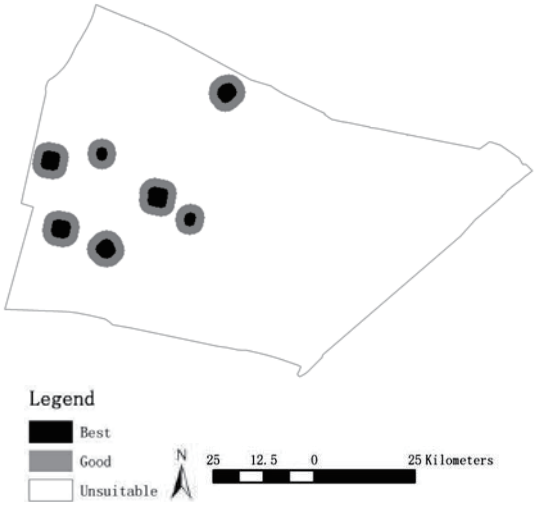


Figure 4. Final landfill site in Zanjan city

5.3 Sensitivity analysis

The sensitivity of the landfill sites with respect to a change in the priority "weight" was studied. The results showed that the landfill sites were robust with no evidence of rank reversal in almost all the cases. This confirmed the superiority of the ANP weights in relation to the other methods. The weights for the four different criteria provided by the experts as triangular fuzzy set were varied within a range of 15% provided that a latin hypercube sampling of the inputs was used to conduct such a simulation. The fact that the perturbation of the decision weights has a small impact on the ranking of the candidate sites reveals that the degree of domination of the candidate sites is almost independent of changes in the decision weights associated with selected criteria.

6. CONCLUSIONS

Site selection is an important issue for waste management in fast-growing urban areas. Because of the complexity of waste management systems, the selection of the appropriate landfill site requires consideration of multiple alternative solutions and evaluation criteria. Selection of a landfill site involves both qualitative and quantitative criteria and heuristics. This paper reports on an integration of MCDM and DST methods to support selection of an optimal landfill site. Our developed approach was applied to a real site, and the results demonstrated the strengths of the developed system on selecting landfill sites. Research findings show that a proposed approach gives essential support to the decision maker in the assessment of the waste management problem so that a higher level of understanding can be reached in regard to environmental decisions. In order to gain an all-inclusive perspective, the process of decision making consisted of a two-stage analysis, beginning with an initial site screening followed by a detailed assessment of the suitability of the candidate sites using a ANP/DST approach guided by a panel of experts in the site selection process.
The first-stage analysis was successful in preliminary landfill site screening leading to exclude the sensitive areas while retaining sufficient areas for further evaluation at the same time. Within the ANP/DST in the second-stage analysis, MCDM method smoothly incorporated the information provided by three experts leading to fulfil the ranking of the alternatives with respect to four different criteria. In consequence, ANP/DST may strengthen the generation and evaluation of

alternatives by providing an insight of the problem among the varied objectives and granting essential support to the process of decision making under uncertainty (Malcezwki, 2004). With such an effort, it is concluded that site located near is the most suitable site for landfill based on an integrated GIS and ANP/DST analysis. A sensitivity analysis was conducted to assess the reliability of the ranking of the candidate sites using a Monte Carlo simulation by changing the decision weights associated with selected criteria. The results indicated that the candidate site still completely dominate the other sites despite variations of the decision weights within a range of 15%.

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