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The consensus of local stakeholders and outside experts in suitability modeling for future camp development

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ABSTRACT

With the emergence of geographic information systems (GIS), suitability analysis has become a modeling practice that facilitates the process of multi-criteria decision making (MCDM) by simulating the suitability of a land unit in supporting a physical or socioeconomic phenomenon. To identify and quantify the contribution of various criteria for land-use planning, however, suitability modeling relies heavily on the expert knowledge in weight assignment. Little is known about at what rate the diverse input from outside experts and local stakeholders would propagate into the suitability model and come to a consensus. The objective of this study was to investigate the development of weight assignment and suitability modeling through iterative surveying between the local stakeholders and outside experts. This research surveyed eleven field experts about the areas best suitable for future development of a scout camp in Kalkaska, MI. The expert knowledge was consulted by using the analytical hierarchy process (AHP) and a direct method of weight table. The results of suitability modeling revealed that the weight assignment between the direct method and AHP method became more different as the survey progressed. It was also observed that the most suitable area for future development slowly emerged to a consensus between the outside experts and local stakeholders through iterative survey. This research illustrated the usefulness of the Delphi method within MCDM and highlighted patches of areas adjacent to the Grass Lake that are suitable for future development.

1. Introduction

Land conservation has become increasingly important as urbanization continues to reduce the quantity and quality of undisturbed places. Planners and resource managers often confront land use changes by striking a balance between urbanization and conservation. To be effective in land management, it is important to solicit the support from the field experts, local residents and stakeholders by integrating their inputs throughout the process of decision making (Store and Kangas, 2001; Duke and Aull-Hyde, 2002; Strager and Rosenberger, 2006; Burger et al., 2007). In land-use planning, multi-criteria decision making (MCDM) provides a framework to systematically incorporate the opinions from multiple perspectives into ranked criteria to resolve potential conflicts among various interest groups (Bojórquez-Tapia et al., 1994).

The strength of MCDM lies in its ability to provide a scientific analysis of infinite “what-if” scenarios by considering the bio-physical factors as well as social opinions. Planners and resource managers explore and evaluate feasible land-use strategies in MCDM by conducting suitability analysis (Prato, 2003). With the emergence of geographic information systems (GIS), suitability analysis becomes a modeling practice that facilitates the process of MCDM by simulating the suitability of a land unit in supporting a physical or socioeconomic phenomenon (Malczewski, 1999, 2004). Many studies have utilized GIS-based suitability modeling for site assessment and land-use planning (Tiwari et al., 1999; Wang et al., 2004; Gemitzi et al., 2007; Zucca et al., 2008; Thapa and Murayama, 2008).

1.1. Suitability modeling

Suitability modeling is a simulation procedure in MCDM to determine the suitability of a land unit in supporting a physical or socioeconomic phenomenon, which typically involves many factors that affect the final decision. Based on the spatial and/or attribute characteristics, the factors (i.e. map layers in GIS) are reclassified into numeric ratings that indicate the aptness for the desired use. The reclassified ratings are then combined together to compute the overall suitability score. In general, the higher the suitability score, the more appropriate it is for a land unit to support the desired activity. To conduct suitability modeling, similar to any computer simulation, one must be careful in selecting the

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Table 1
The fundamental scale for pair-wise comparisons in the analytic hierarchy process (Saaty, 1980).

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment moderately favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity *i* has one of the above numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

model parameters to model the simplified reality. Inappropriate selection of factors (e.g. not considering soil type in an analysis of land capacity for farming) negates any results produced from the ensuing analysis.

In MCDM, each and every criterion is given a weight to represent its genuine importance in the phenomenon. Owing to the imperfection of knowledge about the operating phenomenon, however, the weights are often difficult to quantify and can vary subjectively (among people) and spatio-temporally (at a different time/place). Therefore, it is important to include the values and interests of field experts who have intimate knowledge of the process or land in question (Amir and Gidalizon, 1988; Bojórquez-Tapia et al., 1994; Jakeman et al., 2006). When using suitability modeling for MCDM, expert knowledge is essential to weight the factors according to their relative importance to provide a better representation of suitability (Makropoulos and Butler, 2006). To implement suitability modeling in a GIS, the weighted linear combination (WLC) method is typically used to calculate the weighted suitability score. Based on the spatial and/or attribute characteristics, the factors (i.e. map layers) are reclassified into numeric ratings and weighted by an arbitrary numerical "impact factor". Thus, the suitability of a given area can be assessed by adding up the weighted scores. As such, the results, as well as the quality, of suitability modeling are primarily dependent on the identification and quantification of the contributions made by various factors for land-use planning. In such an endeavor, the most controversial issue in the process of planning often originates from the weight assignment of contributing factors (Malczewski, 1999).

1.2. Analytic hierarchy process

A common method to solicit and quantify expert input into weight assignment for suitability modeling is analytic hierarchy process (AHP), a structured technique to allow the decision makers to simplify the process of a complex decision by using iterative pair-wise comparisons (Saaty, 1980, 2000). AHP is an integrated assessment approach to decision making, one that can account for the complexity of multiple criteria and the uncertainty of unstructured or unquantifiable knowledge (Duke and Aull-Hyde, 2002; Wu and Wang, 2007).

When using AHP, factors are categorized into separate branches based on a user-defined measurement of similarity. The field experts are consulted to provide individual or group input of direct comparisons between similar factors based on a scale of 1–9 (1 being equally important, 9 being extremely more important—see Table 1). This means that direct comparisons are not made between dissimilar attributes. Once internal attributes are compared, the general categories into which these attributes were placed are compared against one another.

Typically, a reciprocal matrix (A) is created based on the pair-wise comparison by the experts:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \qquad (1)$$

where a_{ij} is the comparison rating between attribute i and attribute j, and n is the total number of attributes. The reciprocal matrix is then normalized to compute the priority vector for each attribute. This process can be repeated for each hierarchy structure and cross-multiplied with the criteria eigenvector to compute the relative weights among the attributes. This process allows weights to be assigned to each category, from which weights are then assigned to internal attributes. For group decision making, the overall relative weights of attributes can be determined by obtaining the geometric mean (Duke and Aull-Hyde, 2002) or arithmetic mean (Thapa and Murayama, 2008). In site assessment, compromise programming can be used to evaluate the site suitability to the ideal location by computing the distance metrics (Zeleny, 1982; Bojórquez-Tapia et al., 2005). Other integrative approaches include variance and percentile (Ayyub, 2001; Ban and Ahlqvist, 2008), confusion index (Burrough and McDonnell, 1998), and neighborhood statistics (Zhang et al., 2007).

In AHP, it is important to verify the internal consistency of comparison matrices provided by the experts. Saaty (1980) showed that the maximum eigenvalue of the weighted sum vector (λ_{max}) can be determined by:

$$\lambda_{\max} = \sum_i \sum_j a_{ij} w_i \qquad (2)$$

where w_i is the priority vector for each attribute. The consistency index (CI) for an $n \times n$ comparison matrix is:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \qquad (3)$$

By comparing CI to a random consistency index (RI) of an $n \times n$ matrix as reference (Saaty, 1980), the consistency ratio (CR) is given as $CR = CI/RI$. A CR of ≤ 0.1 indicates consistent comparison ratings given by the experts.

One of the strengths of AHP is that it allows one or many stakeholders the opportunity to derive a solution to a problem based on their own experience, broadening the opportunities for common stakeholders to provide input in planning issues (Saaty, 1980; Duke and Aull-Hyde, 2002). As it was developed as an individual decision-making method, sample size does not pose the same problem in AHP as in other statistical calculations.

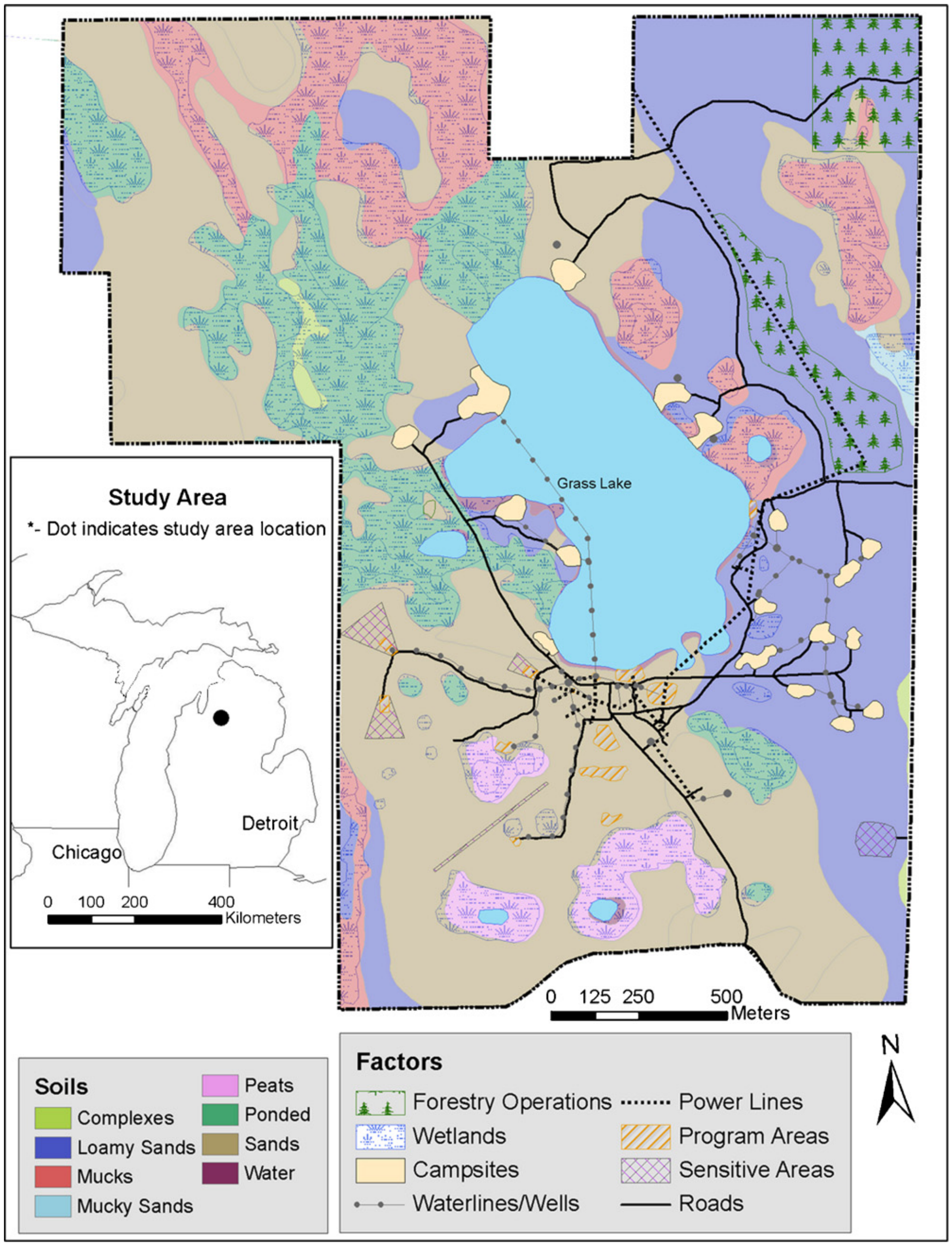

Fig. 1. A reference map of Camp Tapico in Kalkaska, MI.

1.3. Expert knowledge

In some instances, suitability modeling might be more sensitive to the weights measured in relative or absolute terms than the choice of weighting method (Triantaphyllou and Sanchez, 1997). The primary source of weight assignment – the "experts"—are acknowledged to have the most experience and knowledge about the specific phenomenon operating in the area of interest (Bojórquez-Tapia et al., 1994; Strager and Rosenberger, 2006). Thus, the resulting model is more likely to represent a snapshot of experts' viewpoint (Jakeman et al., 2006; Zucca et al., 2008) than if arbitrary weight assignments were given to the factors under study, since the experts are those who are involved in the development process.

In suitability modeling, experts can be classified into local stakeholders who have the most intimate experience about the area of interest or the outside experts who in general have superb knowledge about the phenomenon (McCall, 2003; Fraser and Lepofsky, 2004). The inclusion of stakeholders' opinions was suggested to be valuable not only in the final reporting but also in various stages of the research implementation, including problem formulation, experiment design, and research execution (Burger et al., 2007). The overall quality of investigation would be improved by enhancing the transparency, engaging the stakeholders and raising the ownership throughout the decision process. In general, the knowledge of local stakeholders is thought to be location-specific while the knowledge of external experts tends to be more "universal". Depending on the interest of each stakeholder group (e.g. environmental- or economical-driven), however, it is not uncommon that the weight and criteria will be different within and among the stakeholder groups (Himes, 2007). Typically, the derived output would favor the options consistent with their own interest (Ananda and Herath, 2003).

Strager and Rosenberger (2006) statistically compared the weight assignment surveyed between the outside experts and local stakeholders—the latter group consisting of board members and local residents. The authors reported that 14 assigned weights out of 32 factors were significantly different between the outside experts and local stakeholders, while the local residents and board members differed on only 2 factors, differences suggesting an importance to understand alternative viewpoints of potential respondents when preparing for analysis.

Bojórquez-Tapia et al. (2005) provided a framework for incorporating differing opinions to build consensus among members of differing interest groups in sensitivity analysis. To compensate for inconsistencies in AHP classification, the authors utilized a multi-tiered approach to data collection. Experts were placed into sub-groups according to their specialty. Teamwork was encouraged to develop appropriate hierarchy structure and pair-wise comparisons. Experts also worked individually on another AHP structure to justify previously asserted opinions. This was concluded by a plenary session where all experts developed an agreed-upon hierarchy structure with alternatives based on experts' differing viewpoints. Their research presented an integrated procedure of sensitivity analyses and compromise programming to explore the uncertainty of hierarchical structure. Eigenvectors were produced 30,000 times in a computer program and those with high levels of inconsistency (>0.1) were thrown out. This allowed the researchers to assert the probability of rank-reversals and problems with transitivity for reaching consensus.

These studies were concerned with the incorporation of expert knowledge in building consensus within and among experts. It was argued that important elements in bridging the consensus of stakeholders, experts and decision makers include communication, transparency, and trust (Burger et al., 2007). Little is known about at what rate the diverse input from outside experts and local stakeholders would propagate into the suitability model and come to a consensus. The objective of this study was to investigate the development of weight assignment and suitability modeling through iterative surveying between the local stakeholders and outside experts.

2. Materials and methods

This study implemented a GIS-based suitability model to assess the areas best suited for future development in a camping facility in MI. In order to quantify the criteria for suitability assessment, nine factors were evaluated and their corresponding factor ratings were assigned to each variable based on ground distance or their suitability for future program development (Fig. 1). The nine factors included the soil type and the proximity to the following features: wetlands, forestry operations, roads, waterlines or wells, power lines, existing program areas, campsites, and specified "sensitive" areas. These factors may be viewed as favorable or less favorable to future program development as a function of distance. Sensitive areas include the shot fall areas for firing ranges, an old railroad grade, and the camp dump. The distance threshold values for program areas and campsites differ because new development is not desired near campsites (it is thought to take away from the wilderness aspect of camping).

The factor ratings for each of the nine factors were then weighted and added to receive a sum-total "suitability score," as indicated by WLC equation:

$$S_{x,y} = \sum_{i}^{n} F_{x,y,i} \times W_i \quad (5)$$

where $S_{x,y}$ is the suitability score at coordinates x and y, n is the total number of factors, F and W are the factor rating and weight of the factor I, respectively. Based on the input from expert knowledge, the WLC method accounts for unequal weights among various factors. In order to integrate the diverse weight assignment by experts, MCDM often pre-processes the weight assignment to synthesize expert opinions in suitability modeling. This research adopted the Delphi method to solicit expert knowledge by iteratively reviewing collected results and revising to a final consensus among the experts (Hsu, 1999; Ayyub, 2001; Taleai and Mansourian, 2008). To aggregate the diverse weight assignments, this research assumed the experts to act as separate individuals and hence adopted the method of Aggregation of Individual Priorities (AIP) (Forman and Peniwatib, 1998).

2.1. Study area

The study area is Camp Tapico in Kalkaska, MI (Fig. 1). It lies on 1283 acres of largely coniferous forest with a 120-acre lake at the center. The soils are a mix of loamy sands, loose sands, and mucks. The camp is located on gentle rolling ground with a mean slope of 4.8% (or 2.7°) and elevation ranges between 361 and 370 m. The property has been owned exclusively by the Boy Scouts of America since the early 1940s. Because of the continuous land ownership of this property, it has largely retained its wilderness character. Recent growth in scouting within the council has increased the demand for camp facilities.

The need for employing a modeling procedure to assert a conclusive evaluation of Camp Tapico's natural resources is important because of the relative inexperience of existing resource managers in regards to computer generated suitability modeling. Jakeman et al. (2006) noted that resource managers often have little experience with modeling, and may read too much into a poorly designed model. By analyzing the diverse expert knowledge and their gradual consensus reflected from the suitability model, the resource managers can collaborate and apply expert knowledge towards future planning in a more consistent and transparent manner.

2.2. Survey

In this research, the source of expert knowledge came from a group of experts within the Tall Pine Council who have 5–40 years of experience in camp properties planning. The surveyed experts include: the ecology director, the camp ranger, council executives, and members of the council properties committee. The council is directly responsible for camp growth with a focus on wilderness preservation. These experts have worked together with environmental consultants to build the "master plans" of the council camps, and have hands-on knowledge of the requisites of intelligent planning.

This research employed two surveying methods to collect the weight assignment from experts, including: (1) analytical hierarchy process (AHP), and (2) direct method—whereby experts were asked to dole out 100 points among the nine factors based on how important each factor was in direct relation to the others.

In the process of AHP, the first task was to classify and group all nine factors into nominal categories based on their relative similarity. In this research, three factors each were grouped into three categories: environmental impacts, infrastructure factors, and anthropological issues. The next task was to ask the field experts to decide which category was the most important by comparing each category "head-to-head" against each of the other two categories. After deciding which category was more important, the experts would then indicate their level of preference for the chosen category on a scale of 1–9, 1 being equally important, 9 being absolutely more important. Table 1 presents a nominal description

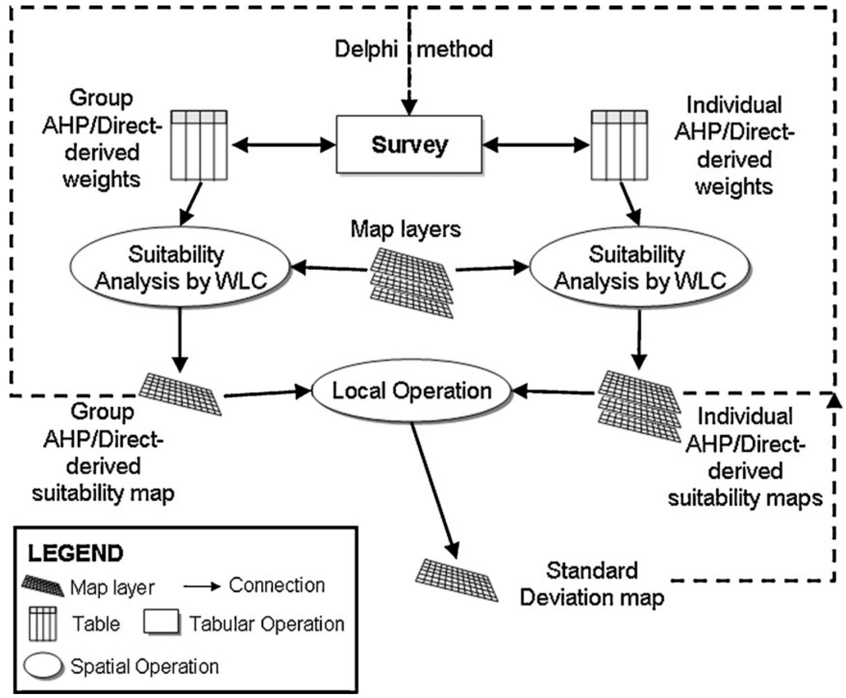

Fig. 2. A data flow diagram of the proposed framework.

of the scale used in AHP. The experts then compared each of the factors within the same category on a scale of 1–9 to rate their preference for one factor over another. That is, a factor from the environmental impacts category would not be directly compared to a factor from the anthropological issues category. Once the ordinal hierarchy within and among all categories and factors was established, AHP computes the priority vector and the relative weights that could be used for suitability modeling.

To provide a more straight-forward alternative to the AHP survey, the direct method utilizes an empty table for experts to precisely weigh the factors. Each respondent was asked to allocate a total of 100 points to all factors based on how important a factor is in direct comparison to all other factors. In other words, a location with a maximum rating on each would receive a perfect score of 100 in the final suitability map based on this weighting scheme.

This research executed three rounds of Delphi approach survey, which contains the two surveying methods aforementioned in each round as well as aggregated results from the previous round if available, to collect the expert knowledge for the weight assignment in suitability modeling (Hsu, 1999; Ayyub, 2001; Taleai and Mansourian, 2008). There were 11 members of the council who responded to all 3 rounds of survey. Among the respondents, 6 were considered to be outside experts while the remaining 5 were local stakeholders (McCall, 2003; Fraser and Lepofsky, 2004). Outside experts include the ecology director, camp rangers and conservation officials who have training or working experience in camp management and planning. They were generally current and past employees of the camp. On the other hand, local stakeholders were members of the council properties committee with a long-term interest in camp development.

In the first round, the respondents were given detailed instructions regarding the AHP and direct method for the suitability modeling process. The collected AHP matrices were then verified to have a consistency ratio less than 0.1 to make sure there was no internal inconsistency (Saaty, 1980). Based on the surveyed input, individual and group suitability maps were then created to model the most desirable locations for future development. As in a typical Delphi approach survey, the individual- and group-level weight assignments as well as suitability maps were then presented to individual experts for their review and revision in the next round. By examining the output and referencing alternative weight assignments suggested by their peers, the experts were given the freedom to keep their original input or revise as appropriate. The data flow diagram of this procedure is illustrated in Fig. 2.

At the end of each round of surveys, a local operation of map algebra was evaluated from the individual AHP/direct-derived suitability maps to calculate a standard deviation of the suitability scores at each pixel (Zhang et al., 2007):

$$\sigma_{x,y} = \sqrt{\frac{\sum_i^n (S_{x,y,i} - \bar{S}_{x,y})^2}{n}} \quad (6)$$

where $\sigma_{x,y}$ is the standard deviation of the suitability score S at the pixel (x, y), S is the mean suitability score at pixel (x, y) of all respondents n, and i is the individual expert. The mean suitability score of the resulting standard deviation map provided a quantitative measurement to assess the variation of suitability scores based on individual AHP/direct-derived weight assignment, similar to the variance index used elsewhere (Ban and Ahlqvist, 2008). Statistically speaking, the mean standard deviation represents 68% of suitability scores across the entire study area that are within the threshold of deviation from the mean suitability score under the assumption of normal distribution.

3. Results

3.1. Surveyed weights

The survey weights were obtained by compiling responses and averaging the scores for the AHP and direct methods accordingly (Table 2). The weights were normalized to a scale of 100 percent for ease of processing. In all three factors under the anthropological issues category, including program areas, campsites and sensitive areas, scores are higher based on the direct method than the AHP. The infrastructure factors have a mixed result—with a

Table 2
Weight assignment of the nine variables by outside experts (OE) and local stakeholders (LS) in the third round.

Category	Factor	Mean direct-derived Weights (%)			Mean AHP-derived weights (%)		
		All	OE	LS	All	OE	LS
Environmental Impacts	Wetlands	14.4	14.5	14.2	22.6	27.0	17.4
	Soil type	5.1	5.3	4.8	6.3	7.6	4.7
	Forest operations	9.2	10.7	7.4	7.1	7.0	7.2
Infrastructure Factors	Roads	17.3	17.7	16.8	23.9	20.8	27.8
	Waterlines/wells	12.1	11.0	13.4	14.8	13.2	16.7
	Power lines	11.2	10.8	11.6	9.4	10.5	8.1
Anthropological Issues	Program areas	10.5	9.5	11.6	2.9	2.2	3.7
	Campsites	7.2	6.2	8.4	3.3	2.4	4.3
	Sensitive areas	13.2	14.3	11.8	9.7	9.3	10.2

Table 3
Summary table of paired *t*-test significance between AHP and direct method weight assignment*.

Category	Factor	All			Outside experts			Local stakeholders		
	Round	1	2	3	1	2	3	1	2	3
Environmental Impacts	Wetlands	**0.04**	**0.01**	**0.01**	0.05	**0.02**	**0.02**	0.40	0.30	0.22
	Soil type	0.33	0.10	0.36	0.24	0.18	0.32	0.74	0.46	0.94
	Forest operations	0.98	0.95	0.16	0.38	0.09	0.00	0.49	0.56	0.95
Infrastructure Factors	Roads	0.27	0.90	**0.05**	0.47	1.00	0.36	0.47	0.89	0.09
	Waterlines/wells	0.64	0.36	0.13	0.99	0.63	0.46	0.31	0.48	0.14
	Power lines	0.81	0.72	0.11	0.26	0.23	0.79	0.51	0.58	0.07
Anthropological Issues	Program areas	0.09	**0.01**	**0.00**	**0.02**	**0.00**	**0.00**	0.39	0.27	**0.01**
	Campsites	0.21	**0.04**	**0.01**	0.97	0.39	**0.00**	0.09	0.06	0.20
	Sensitive areas	**0.00**	**0.00**	**0.01**	**0.01**	**0.01**	**0.00**	0.11	**0.04**	0.47

* Bold characters indicate two tailed *t*-test significance at $P < 0.05$ level.

higher weight for the proximity to roads and waterlines/wells but lower weights for the proximity to power lines when comparing the AHP method with the direct method. Factors in the environmental impacts category also show mixed results, with wetlands and forestry operations scoring higher in AHP and forestry operations scoring higher in the direct method. Despite differences in weights within categories, patterns emerged that indicated wetlands, roads, and waterlines/wells were the most important factors. These patterns were very similar between the outside experts and local stakeholders.

The paired *t*-test revealed that the weight assignment between the direct method and AHP method became more different as the survey progressed. Among all the experts surveyed, the weights of wetlands, roads, and all anthropogenic issues (i.e. program areas, campsites and sensitive areas) were significantly different at the 0.05 level between the two methods in the last round (Table 3). Within the outside expert group, similar statistical differences between the two methods were noted in the aforementioned variables except that forestry operations replaced the proximity to roads. On the other hand, the weight assignments from the local stakeholders were not significantly different except proximity to campsites in the second round and program areas in the last round. Among all factors, the wetland and anthropogenic issues appear to be more different between the methods especially among the outside experts.

Table 4 presents the *t*-tests of weights between the outside experts and local stakeholders. It was observed that the null hypothesis of the direct-derived weights in forestry operations was rejected throughout for all 3 iterations of the survey. The direct-derived weight of program areas diverged only in the last round of the survey. There was no significant difference in any attribute weights collected by the AHP method. The non-parametric Mann–Whitney testing of the expert groups produced similar results in that the direct-derived forestry operations variable was only significant in the 2nd round and the program areas was significant in the last round. The patterns and implications of results were similar between the parametric and non-parametric tests and hence were not shown. An ANOVA test did not suggest

Table 4
Summary table of *t*-test significance of weight assignment between outside experts and local stakeholders*.

Category	Factor	Direct method			AHP method		
	Round	1	2	3	1	2	3
Environmental Impacts	Wetlands	0.93	0.79	0.72	0.48	0.48	0.07
	Soil type	0.71	0.36	0.36	0.17	0.21	0.25
	Forest operations	**0.04**	**0.04**	**0.05**	0.91	0.79	0.96
Infrastructure Factors	Roads	0.80	0.44	0.67	0.94	0.72	0.20
	Waterlines/wells	0.32	0.36	0.16	0.85	0.69	0.39
	Power lines	0.54	0.94	0.60	0.40	0.46	0.24
Anthropological Issues	Program areas	0.12	0.11	**0.02**	0.26	0.34	0.38
	Campsites	0.12	0.15	0.20	0.96	0.79	0.27
	Sensitive areas	1.00	0.26	0.19	0.95	0.43	0.77

* Bold characters indicate two tailed *t*-test significance at $P < 0.05$ level.

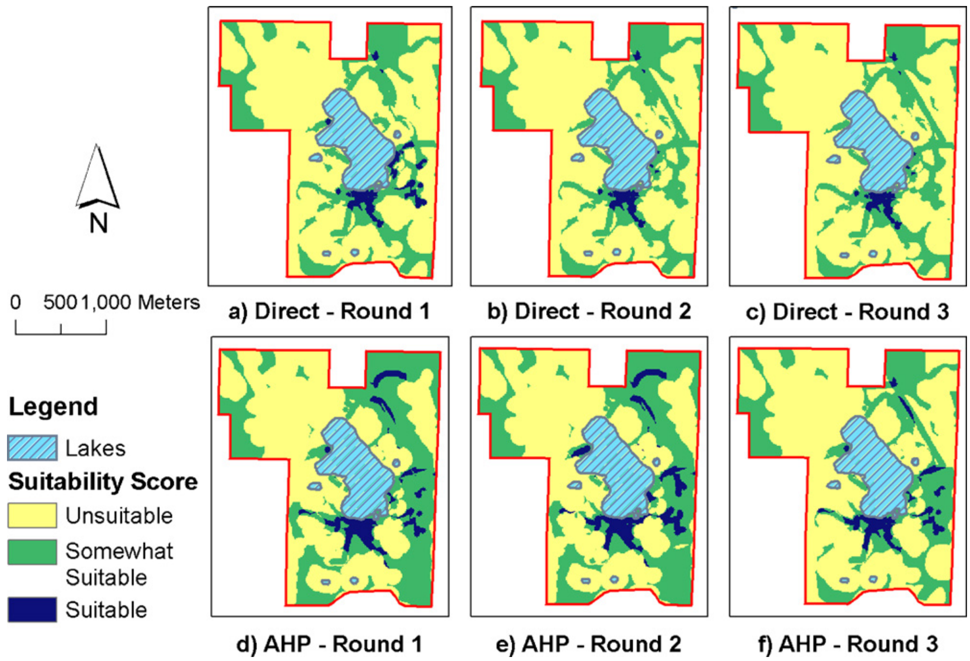

Fig. 3. The suitability maps of outside experts created by (a) direct method in the 1st round, (b) direct method in the 2nd round, (c) direct method in the 3rd round, (d) AHP method in the 1st round, (e) AHP method in the 2nd round, (f) AHP method in the 3rd round.

any significance in the within-subjects effect of the three rounds among all attributes (not shown).

3.2. Suitability maps

The resulting suitability maps effectively incorporated the diverse weight assignment and reflected the corresponding expert knowledge. The AHP-derived and the direct-derived maps among the outside experts, local stakeholders and all experts (Figs. 3–5, respectively) provide the spatial data that describes the subjective judgment of the factor weights for suitability modeling of new development for Camp Tapico. Each figure also includes separate suitability maps representing different phases of the survey. Results are divided into outside expert and local stakeholders groups to display differences in perceptions of suitability between the groups.

In general, similarities among all maps in Figs. 3–5 indicate an agreement between the AHP-derived and direct-derived weights collected from the survey. The maps agree that it is strongly unsuitable to disturb and change the existing landscape of wetlands around the camp (Fig. 1). On the other hand, it is very favorable to place future development close to existing program areas, especially along the road corridors running from the center of camp (at the south side of the lake). Despite the similarities, there are some differences between the AHP and direct meth-

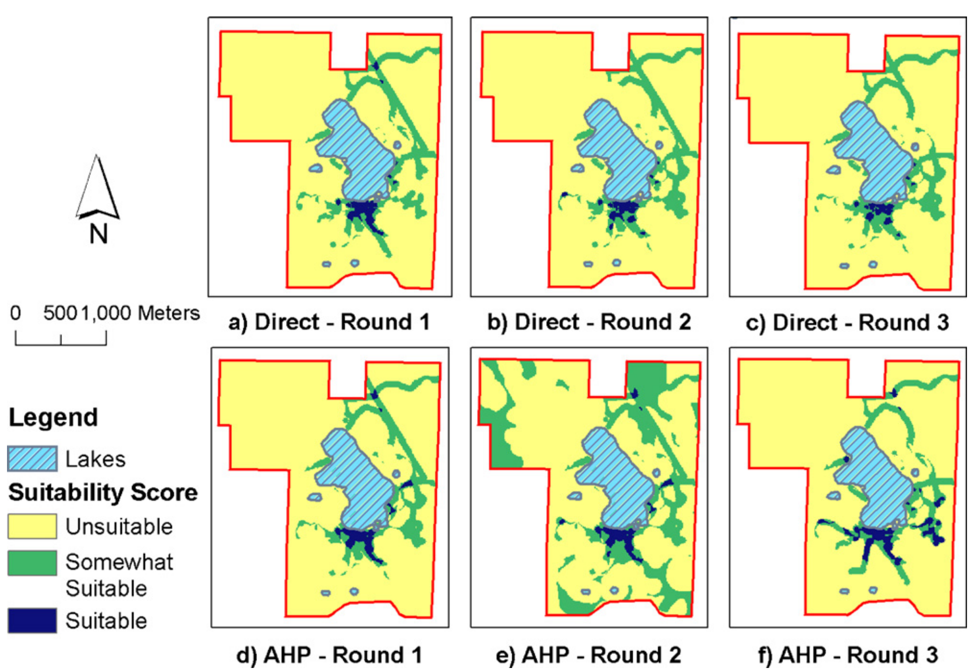

Fig. 4. The suitability maps of local stakeholders created by (a) direct method in the 1st round, (b) direct method in the 2nd round, (c) direct method in the 3rd round, (d) AHP method in the 1st round, (e) AHP method in the 2nd round, (f) AHP method in the 3rd round.

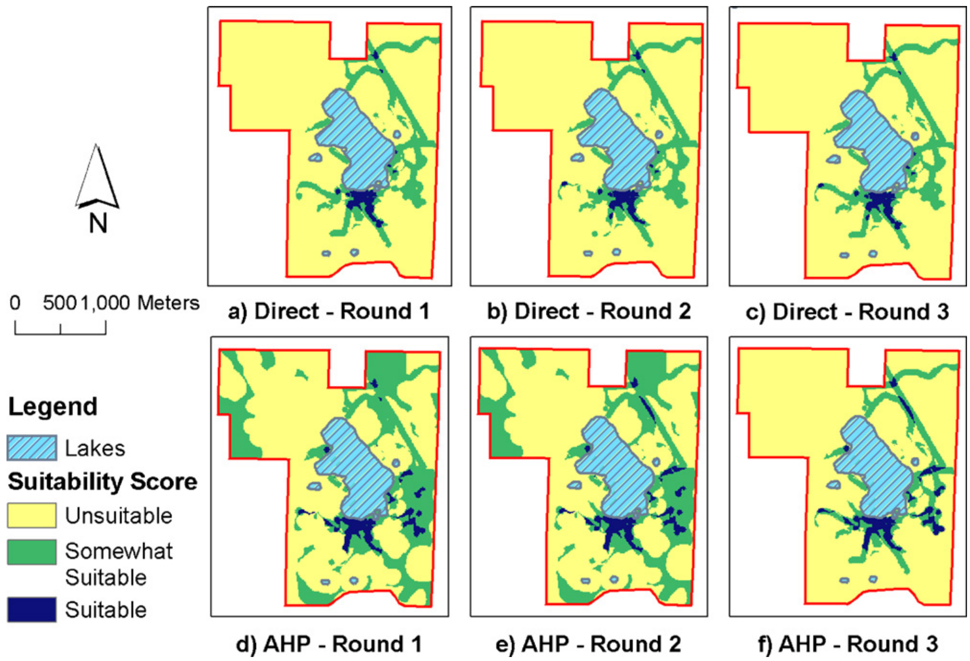

Fig. 5. The suitability maps of all experts created by (a) direct method in the 1st round, (b) direct method in the 2nd round, (c) direct method in the 3rd round, (d) AHP method in the 1st round, (e) AHP method in the 2nd round and (f) AHP method in the 3rd round.

ods. The AHP-derived maps (Figs. 3d–f, 4d–4f and 5d–f) suggest more and larger patches of somewhat suitable and suitable areas for future development area than the direct-derived counterparts (Figs. 3a–c, 4a–c and 5a–c). This pattern can be observed in all three rounds regardless of the expert background. The proximity to utilities, including roads, power lines, and waterlines/wells, are important factors for future planning, as AHP and direct-derived maps in Figs. 3–5 portray patches of suitable area in the eastern side of the lake. Proximity to campsites also plays a stronger role in AHP-derived maps than direct-derived maps, perhaps suggesting an intrinsic desire to not locate near campsites that is not represented the same in the AHP derivation. The proximity to forestry

Table 5
Mean standard deviation of the suitability maps.

Round	Method	All	Outside experts	Local stakeholders
1	Direct	9.8	10.1	8.4
	AHP	16.8	14.3	18.1
2	Direct	6.7	4.7	7.5
	AHP	13.9	10.3	16.4
3	Direct	4.7	5.0	2.4
	AHP	9.4	10.0	7.2

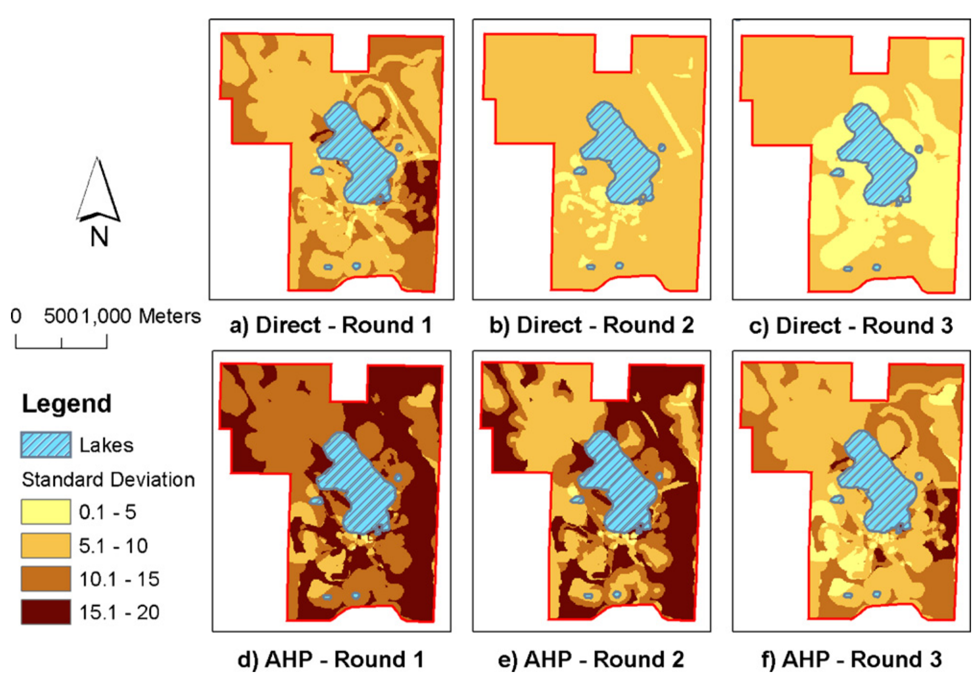

Fig. 6. Standard deviation maps of suitability scores created by (a) direct method in the 1st round, (b) direct method in the 2nd round, (c) direct method in the 3rd round, (d) AHP method in the 1st round, (e) AHP method in the 2nd round and (f) AHP method in the 3rd round.

Table 6
Percentile ranking of the actual and permuted difference of surveyed weights between outside experts and local stakeholders.

Category	Factor	Direct method			AHP method		
		Round 1	Round 2	Round 3	Round 1	Round 2	Round 3
Environmental Impacts	Wetlands	42%	31%	55%	77%	80%	96%
	Soil type	22%	73%	69%	95%	89%	86%
	Forest operations	96%	96%	95%	59%	41%	50%
Infrastructure Factors	Roads	54%	79%	65%	57%	61%	9%
	Waterlines/wells	73%	6%	4%	41%	34%	19%
	Power lines	57%	44%	24%	21%	26%	88%
Anthropological Issues	Program areas	4%	0%	0%	4%	10%	22%
	Campsites	4%	5%	7%	46%	35%	12%
	Sensitive areas	40%	88%	91%	50%	79%	37%

operations and sensitive areas are shown to have minor impact on the derived suitability maps.

In the direct-derived suitability map series, there were some subtle differences between the outside and local experts in the most suitable area for future development. Their opinions diverge in the medium suitable areas around the fringe area of the camp (Figs. 3a–c and 4a–c). In the first round, the outside experts favored the eastern side of the lake in addition to the southern cluster (Fig. 3a). It is interesting to note that those patches were later diminished (Fig. 3b and c) to compromise with the local stakeholders' input (Fig. 4a–c) after a couple rounds of revision. This trend was reversed, however, in the AHP-derived suitability maps. During the first two rounds, suitable areas suggested by local stakeholders include only very small patches along the eastern lakeshore (Fig. 4d and e), though they slowly emerged into a consensus with the outside experts in the third round (Figs.4f and 3d–f). On the other hand, small patches of suitable area in the northeastern corner suggested by the outside experts (Fig. 3d and e) were also adjusted to reflect the local stakeholders' input (Figs. 3f and 4d–f). The suitability map series of all experts (Fig. 5a–f) reveal a compromise of the two groups and portray the spatial "intersection" of both inputs.

The standard deviation maps (Fig. 6a–f) indicates the standard deviation of the suitability scores at each pixel Eq. (6). In general, the maps show a progressive consensus of suitable areas for future program development in both the direct and AHP methods. Assuming a normal distribution in the samples, the standard deviation is the probability of suitability scores within a certain range from the mean (e.g. 1 step of standard deviation approximates 68% of sampled suitability score). The mean standard deviation of suitability score determined by the direct method was consistently lower than the AHP-derived products (Table 6). Based on the results of mean standard deviation, it was not clear if either expert group had an advantage in conglomerating into a consensus (in terms of rounds of surveys needed and the degree of diversity in the weight assignment).

4. Discussions and conclusions

The results of weight assignment (Table 2) and paired *t*-tests (Table 3) reveal distinct patterns between the AHP and direct method. Regardless of the expert background, AHP consistently produce greater areas of suitable land and less areas of unsuitable land than the direct method in all 3 rounds (Figs. 3–5). Similarly, AHP produces greater areas of somewhat suitable land than the direct method in the first two rounds but only in the outside expert group in the last round. To the experts examined in this study, AHP might be perceived to be a less explicit method than the direct method, which may explain the AHP-derived suitability maps being less spatially specific to the area south of Grass Lake. Depending on how well the AHP weight assignment reflects the expert principles in future development planning, the AHP-derived suitability maps decently describe their favorable future program areas, though they also suggest other new sites. On the other hand, the direct method remains a simple and effective method to model suitable areas.

It was also observed that more attributes were significantly different between the two weight assignment methods following the Delphi approach of iterative surveying (Table 3). This was especially the case among the outside experts. This might be attributed to the fact that some respondents felt more comfortable with one weight assignment method than another. Implementing the two weight assignments through iterative surveying was challenging in this research, as most of the experts were not familiar with GIS-based suitability modeling. Despite the usefulness of AHP in MCDM, the process of AHP might be perceived as a deceptive "black box" (Bojórquez-Tapia et al., 2005). Moreover, the Delphi method did not confine the potentially suitable areas with fewer candidates for future development due to the iterative process of weight assignment revision. In other words, there were new patches of potential suitable areas for future development as the Delphi approach to surveying unfolded. This might be attributed to the fact that this exercise simulates any potential areas based on the principles defined by the experts, as opposed to an alternative exercise of site assessment at given locations. Given the intention of the Delphi method to assist the convergence of expert opinions, the result of increased suitable areas is not as important a finding as the increased agreement between groups (as shown by the decreasing of standard deviation scores from round to round in Table 5 and as spatially represented in Fig. 6).

The divergence between the outside experts and local stakeholders in their weight assignment was consistent with previous findings (Strager and Rosenberger, 2006). Despite the statistical differences between the outside experts and local stakeholders, however, it was interesting to note that the standard deviations of suitability scores were progressively lower (Table 5 and Fig. 6). The consensus of both expert groups in perceiving wetlands, roads, and forestry operations as being the most important factors (Table 2) might explain the nature of equifinality in the suitability maps. Similar to the conclusion suggested by Strager and Rosenberger (2006), the suitability maps (Figs. 3 and 4) between the expert groups also revealed more spatial sensitivity in the high priority areas (i.e. suitable and somewhat suitable) in this research.

A limitation of this research was the relatively small sample size in the expert pool. The sample sizes of outside experts and local stakeholders were 6 and 5, respectively. Bootstrapping was performed to further investigate if the sampled weights from the outside experts and local stakeholders were significantly different from random group re-distribution. Table 6 revealed the results from 10,000 permutations of surveyed weight re-distribution and the percentile ranking of weight difference between the outside experts and local stakeholders. The results found the weight difference of forestry operations and program areas between the expert groups were with 90% confidence level (i.e. 0.05 and 0.95 quantiles). It also implied some confidence in the statistical indifference of waterlines/wells and campsites in certain rounds as well. In general, the bootstrapping results do not invalidate the statistical findings. While the sample of experts was small, it represented a high percentage of potential respondents, as the council plans in a relatively intimate setting, and appropriate populations for each group number no more than 12 each. The normal distribution assumption among the examined variables was assessed within each group by using histograms and quantile–quantile (Q–Q) plots. Despite the limited size of active council members who participated the iterative surveying, the sample resembled a good representation of the Tall Pine Council as all resulting suitability maps modeled the south side of the Grass Lake being a suitable area for future development. This coincides with the tentative plan of the Tall Pine Council to concentrate development near existing infrastructure and camp buildings (personal communication).

The final composite maps seen in Fig. 5c and f integrate multiple sets of weight assignment and provide the understanding that an iterative process such as the Delphi method has the capacity to increase or decrease areas of suitability while improving agreement between potentially divergent groups. Given that the suitability maps (Fig. 5) and standard deviation maps (Fig. 6) are the end result of an arduous process of data solicitation to key members of the council, they allow camp decision makers to observe the most suitable sites for future development in light of expert knowledge from their local stakeholders as well as outside experts. This research also presented an alternative framework to scenario-based or sensitivity analysis approaches of soliciting expert knowledge to obtain a conglomerate end product that improves the potential imprecision of expert knowledge in MCDM. The ranking of sites as unsuitable, somewhat suitable, and suitable simplifies the analysis in that future decision makers will not be required to convey a strong understanding of the process in order to utilize the maps. This provides a scientific methodology in seeking a balance and convergence of the opinions from multiple groups of stakeholders.

It is important to note that expert knowledge derived by either weight assignment method adopted in this research may not perfectly reflect opinions about suitability for development. In order to assess the accuracy of expert knowledge, the final map(s) of suitability modeling would need to be validated against some existing sources of reference data, such as a master plan. Unfortunately, there was no reliable source of an approved master plan before the initiation of this research in Camp Tapico. There have been continual efforts to assist experts at Camp Tapico in putting together a master map for future planning. The suitability maps, decision criteria and factor constraints adopted in this research laid down an established framework and quantitative measurement to meet the objectives of future development.

In conclusion, this research illustrated the usefulness of the Delphi method within MCDM by quantitatively defining the increased agreement among experts from the first round to the third. Based on the two weight assignment methods adopted in this research, the final maps are useful to the resource managers at Camp Tapico by highlighting isolated patches of areas adjacent to Grass Lake that are suitable for future development. This can be used in concert with future master plan documents to highlight those areas defined by the council as being relevant to consider for development in the future.

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References

Amir, S., Gidalizon, E., 1988. Expert-based method for the evaluation of visual absorption capacity of the landscape. J. Environ. Manage. 30, 251–263.
Ananda, J., Herath, G., 2003. The use of analytical hierarchy process to incorporate stakeholder preferences into regional forest planning. Forest Policy Econ. 5, 13–26.
Ayyub, B.M., 2001. Elicitation of Expert Opinions for Uncertainty and Risks. CRC Press, Boca Raton, 302 pp.
Ban, H., Ahlqvist, O., 2008. Representing and negotiating uncertain geospatial concepts—where are the exurban areas? Comput. Environ. Urban Syst. 33 (4), 233–246.
Bojórquez-Tapia, L.A., Ongay-Delhumeau, E., Ezcurra, E., 1994. Multivariate approach for suitability assessment and environmental conflict resolution. J. Environ. Manage. 41 (3), 187–198.
Bojórquez-Tapia, L.A., Sanchez-Colon, S., Martinez, A.F., 2005. Building consensus in environmental impact assessment through multicriteria modeling and sensitivity analysis. J. Environ. Manage. 36 (3), 469–481.
Burger, J., Gochfeld, M., Powers, C.W., Kosson, D.S., Halverson, J., Siekaniec, G., Morkill, A., Patrick, R., Duffy, L.K., Barnes, D., 2007. Scientific research, stakeholders, and policy: continuing dialogue during research on radionuclides on Amchitka Island, Alaska. J. Environ. Manage. 85, 232–244.
Duke, J., Aull-Hyde, R., 2002. Identifying public preferences for land preservation using the analytic hierarchy process. Ecol. Econ. 42, 131–145.
Forman, E., Peniwatib, K., 1998. Aggregating individual next term judgments and previous term priorities next term with the analytic hierarchy process. Eur. J. Oper. Res. 108 (1), 165–169.
Fraser, J., Lepofsky, J., 2004. The use of knowledge in neighborhood revitalization. Community Dev. J. 39 (1), 4–12.
Gemitzi, A., Tsihrintzis, V.A., Christou, O., Petalas, C., 2007. Use of GIS in siting stabilization pond facilities for domestic wastewater treatment. J. Environ. Manage. 82 (2), 155–166.
Himes, A.H., 2007. Performance indicators in MPA management: using questionnaires to analyze stakeholder preferences. Ocean Coast. Manage. 50, 329–351.
Hsu, T.-H., 1999. Public transport system project evaluation using the analytic hierarchy process: a fuzzy Delphi approach. Transport. Plann. Technol. 22, 229–246.
Jakeman, A.J., Letcher, R.A., Norton, J.P., 2006. Ten iterative steps in development and evaluation of environmental models. Environ. Modell. Softw. 21 (5), 602–614.
Malczewski, J., 1999. GIS and Multicriteria Decision Analysis. John Wiley and Sons, New York.
Malczewski, J., 2004. GIS-based land-use suitability analysis: a critical overview. Prog. Plann. 62 (1), 3–65.
Makropoulos, C.K., Butler, D., 2006. Spatial ordered weighted averaging: incorporating spatially variable attitude towards risk in spatial multi-criteria decision-making. Environ. Modell. Softw. 21 (1), 69–84.
McCall, M.K., 2003. Seeking good governance in participatory-GIS: a review of process and governance dimensions in applying GIS to participatory spatial planning. Habitat Int. 27, 549–573.
Prato, T., 2003. Multiple-attribute evaluation of ecosystem management for the Missouri River system. Ecol. Econ. 45, 297–309.
Saaty, T.L., 1980. The Analytic Hierarchy Process. McGraw-Hill Inc.
Saaty, T.L., 2000. Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process. RWS Publication, Pittsburgh.
Store, R., Kangas, J., 2001. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modeling. Landscape Urban Plann. 55, 79–93.
Strager, M.P., Rosenberger, R.S., 2006. Incorporating stakeholder preferences for land conservation: weights and measures in spatial MCA. Ecol. Econ. 57, 627–639.
Taleai, M., Mansourian, A., 2008. Using Delphi-AHP method to survey major factors causing urban plan implementation failure. J. Appl. Sci. 8 (15), 2746–2751.
Tiwari, D.N., Loof, R., Paudyal, G.N., 1999. Environmental-economic decision-making in lowland irrigated agriculture using multi-criteria analysis techniques. Agric. Syst. 60 (2), 99–112.
Thapa, R.B., Murayama, Y., 2008. Land evaluation for peri-urban agriculture using analytical hierarchical process and geographic information system techniques: a case study of Hanoi. Land Use Policy 25, 225–239.
Triantaphyllou, E., Sanchez, A., 1997. A sensitivity analysis approach for some deterministic multicriteria decision making methods. Decision Sci. 28 (1), 151–194.
Wang, X., Yu, S., Huang, G.H., 2004. Land allocation based on integrated GIS-optimization modeling at a watershed level. Landscape Urban Plann. 66 (2), 61–74.
Wu, Q., Wang, M., 2007. A framework for risk assessment on soil erosion by water using an integrated and systematic approach. J. Hydrol. 337, 11–21.
Zeleny, 1982. Multiple Criteria Decision Making. McGraw-Hill.
Zhang, C., Jordan, C., Higgins, A., 2007. Using neighborhood statistics and GIS to quantify and visualize spatial variation in geochemical variables: an example using Ni concentrations in the topsoils of North Ireland. Geoderma 137, 466–476.
Zucca, A., Sharifi, A., Fabri, A., 2008. Application of spatial multi-criteria analysis to site selection for a local park: a case study in the Bergamo Province, Italy. J. Environ. Manage. 88 (4), 752–769.

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