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An analytical approach with a reliable logic and a ranking policy for post-mining land-use determination

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ABSTRACT

Because it is the post-mining land-use that prescribes the methods, the measures and the costs of mine reclamation, a major implicit goal of mine reclamation is to determine an after-use option. Therefore, there should be an analytical approach to optimize the determination of post-mining land-use. A Mined Land Suitability Analysis (MLSA) framework, which had been previously derived from reclamation practice reports of mines and other disturbed lands, is used in combination with two Multi-Attribute Decision-Making (MADM) techniques to provide the required analytical approach. In the proposed approach the decision makers consist of the most related experts and the identified stakeholders. The Analytical Hierarchy Process (AHP) method is used to determine global weights of MLSA framework attributes via pair-wise comparison matrixes composed by each individual expert. Once the global weight vector of the attributes is calculated using AHP, they are incorporated into the decision matrices composed by stakeholders and passed to the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), which is a distance-based MADM technique and is used to determine preference order of post-mining land uses.

Introduction

Mining is a temporary use of land and; mine sustainability, dictate to achieve an acceptable land-use (Cao, 2007). So the core of reclamation is to identify the potential of mined lands for some environmental and socioeconomic productive uses. The process of determining the fitness of a given tract of land [e.g. a mined land] for a defined use is named Land Suitability Analysis (LSA) (Mu, 2006).

Since the 1950s, LSA frameworks have been used in land evaluation processes in several countries of North America and Europe. In the beginning, there was no conformity in the standards and methods used in LSA process. Since the LSA approaches varied from country to country, information exchange was rather difficult. It was not until 1976 that the fundamental document for land evaluation, proposed by the FAO (Food and Agriculture Organization of the United Nations), "A Framework for Land Evaluation", was published. A universally accepted and systematic standard for the LSA was the most important contribution of this framework (Brinkman, 1976). From then on, for example, Knabe (1984) invented a system of mined land evaluation based on the FAO to determine capability of mined lands for agricultural uses through dividing them into four classes namely: (a) good for agriculture; (b) usable for forestry; (c) sterile or barren; (d) toxic.

There can be found several other examples in the literature that have assessed suitability of mined lands for post-mining land-uses, and mentioned the effective criteria in the evaluations. For instance, Coppin and Bradshaw (1982); Monterroso et al. (1998); Chen et al. (1998); Askenasy et al. (1998); Howat (2000); Maiti and Ghose (2005); Tafi et al. (2006) and Carrick and Kruger (2007) have evaluated the factors limiting plant growth on mined soils and mentioned the most serious soil limitations. Some other researchers e.g. Hindle and Grosskopf (2000); Miao and Marrs (2000); Messing and Hoang (2001); Mchaina (2001); Hill (2003); Gizikoff (2004) and Zavadskas and Antucheviciene (2006) have investigated on so many other factors such as topography, climate, environment, society, economy, etc. which arise in land-use evaluations of mined or other disturbed lands. Moreover, Cairns (1982); Alexander (1996); Wisconsin (2000); Coppin and Box (1999); Errington (2001); Paschke et al. (2003); Stellin et al. (2005); Meech et al. (2006); Li (2006) and Cao (2007) have focused on special post-mining land-uses that were exercised in some mine sites.

In this study, a process for post-mining land-use determination is developed in which, a Mined Land Suitability Analysis (MLSA) framework is utilized. The MLSA is based on the LSA frameworks and is composed of fifty numbers of most significant attributes in the post-mining land-use decision making. This framework

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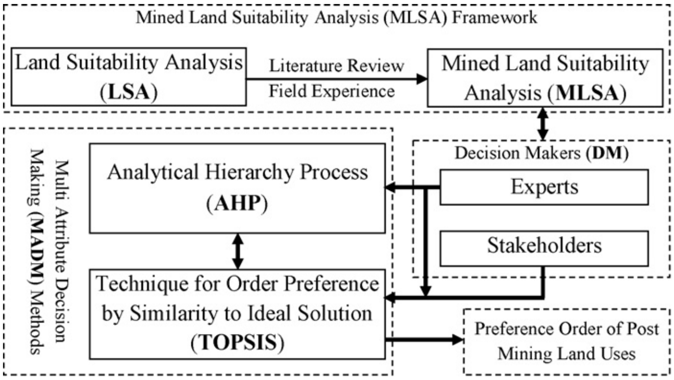

Fig. 1. Mutual relationships between techniques used in this study.

which had also been introduced in previous works of the authors (Soltanmohammadi et al., 2008a,b,c) has been devised to be used in combination with Multi-Attribute Decision-Making (MADM) methods by the most related experts and stakeholders. MADM is a technique employed to solve problems involving selection from among a finite number of alternatives (Venkata, 2007). These techniques can assure sustainability of the total system and objectivity of the solution because they are based on mathematical methods.

The whole process applied and the mutual relationships between techniques used in this study can be summarized as the scheme shown in Fig. 1. The MLSA framework and its attributes are developed on the basis of existing LSA frameworks in combination with literature review and field experience of the decision makers (DMs). The DMs consist of two main groups i.e. the most related experts and the identified stakeholders. The Analytical Hierarchy Process (AHP) method is used to determine global weights of MLSA attributes via pair-wise comparison matrixes composed by each individual expert. Once the global weight vector of the attributes is calculated using AHP, they are incorporated into the decision matrixes composed by stakeholders (under supervision of the experts) and passed to the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), which is a distance-based MADM technique and can determine preference order of post-mining land uses.

Hwang and Yoon, 1981 developed TOPSIS based on the concept that the optimal alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution of a DM. However recently, Shih et al., 2007 have extended the TOPSIS method so that a group of DMs can contribute effectively in the decision making.

The hybrid AHP-TOPSIS approach was chosen in this study to derive preference order of alternatives that would provide the optimum after-use of a hypothetical mined land example from one DM's point of view. However, as this problem is subject to the influence of at least four major stakeholders, the group AHP and TOPSIS procedures are suggested to be incorporated in the proposed approach.

Exercised post-mining land-uses

In general, mine site should be reclaimed so that the ultimate land-use and morphology of the site are compatible with either the current land-use in the surrounding area, or with the pre-mining environment. The area could be maintained as an industrial or commercial site if it is appropriate (Mchaina, 2001). In British Columbia, diversity of post-mining land-uses has been chosen for mined lands. 53% of them were proposed for wildlife habitats, 22% for forestry, 9% for pasture and 16% for some other land-uses (Errington, 2001). Alexander (1996); hints that the activities found in the mined lands include the use of ponds for water supply, fish farms and recreation; brick and block making is also common and then adds: The major activity that can be found in mined areas, is irrigated arable agriculture, which is centered around the flooded mining paddocks and the associated water courses.

Table 1
Some exercised post-mining land-uses (reproduced from Soltanmohammadi et al., 2008a).

Land-use types	Exercised post-mining land-uses	Abbreviations
(1) Agriculture (A)	Arable farmland	A-F
	Garden	A-G
	Pasture or hay-land	A-P
	Nursery	A-N
(2) Forestry (F)	Lumber production	F-L
	Woodland	F-W
	Shrubs and native forestation	F-S
(3) Lake or pool (L)	Aquaculture	L-A
	Sailing, swimming, etc.	L-S
	Water supply	L-W
(4) Intensive recreation (IR)	Sport field	IR-S
	Sailing, swimming or fishing pond, etc.	L-S
	Hunting	IR-H
(5) Non-intensive recreation (NIR)	Park and open green space	NIR-P
	Museum or exhibition of mining innovations	NIR-M
(6) Construction (CT)	Residential	CT-R
	Commercial (shopping center, etc.)	CT-C
	Industrial (factory, brick and block making, etc.)	CT-I
	Educational (University, etc.)	CT-E
	A sustainable community	CT-S
(7) Conservation (CV)	Wildlife habitat	CV-W
	Water supply (surface and groundwater)	L-W
(8) Pit backfilling (B)	Possibility of landfill (as a last resort)	B

In addition, reclaimed sites have a wide range of potential functions such as, hayland, recreational areas, wetlands, and swimming pools (Cao, 2007); and although the initial impression in much of the landscape created by mining is one of desolation and dereliction, closer study shows that intensive use has been, and is increasingly being, made of these areas (Alexander, 1996). Even, Meech et al. (2006); provided a research paper in which, derelict Britannia mine is converted to a clean, livable, sustainable community. As discussed, one of the objectives of that project had been education of mining. Then, different components of the mine site, were suggested to use as museums and exhibitions of mining innovations.

An eight-group orderly form of feasible post-mining land-uses that literature addressed them, containing 21 individual land-uses with their assigned abbreviations are shown in Table 1.

Nevertheless, closer studies show that in cases without an MLSA process, sometimes obtained result is not acceptable, and merits of a standardized MLSA framework for post-mining land-use selection are well denoted. For example, the primary objective at Blayney Copper Mine of Australia (NSW Minerals Council, 2006) was to remediate the site to a level suitable for residential land-use, given the proximity of the site to the town of Blayney. However, the high level of investigation and remediation required to achieve residential standards was cost prohibitive. Then parks and open space

Table 2
MLSA framework attributes.

	Criteria	Attributes	Sub-Attributes	Abbreviations
1	Economical factors	Costs	Maintenance and monitoring costs	MMC
2			Capital costs	CAC
3			Operational costs	OPC
4		Potential of investment absorption		PIA
5		Increase in governmental incomes		IGI
6		Increase in income of local community		IIL
7		Changes in real estate value		CRE
8	Social factors	Effects on immigration to the area		EIA
9		Need to specialist workforces		NSW
10		Changes in livelihood quality		CLQ
11		Employment opportunities		EO
12		Serving the public education		SPE
13		Frequency of passing through mine site		FPT
14		Eco-tourism	Ecological acceptability	EA
15			Tourism attraction	TA
16		Land ownership		LO
17		Proximity of mine site to population centers		PMP
18		Geography	Location towards nearest town	LNT
19			Accessibility or road condition	Acc.
20		Legislation requirements	Mining company policy	MCP
21			Government policy	GP
22			Zoning by-laws	ZB
23		Consistency with local requirements		CLR
24	Technical factors	Shape and size of mined land		SSL
25		Availability of reclamation techniques		ART
26		Closeness to nearest water supply		CNW
27		Market availability		MA
28		Current land-use in surrounding areas		CLU
29		Prosperity in the mine area		PMA
30		Structural geology		SG
31		Distance from special services		DSS
32		Outlook of future businesses		OFB
33		Environmental contaminations		EC
34		Extreme events potential		EEP
35		Reusing potential of mine facilities		RPM
36		Landscape quality		LQ
37	Mine site factors	Soil	Soil's physical properties	SPP
38			Soil's chemical properties	SCP
39		Climate	Evaporation	Eva.
40			Frost free days	FFD
41			Precipitation	Pre.
42			Wind speed	WS
43			Air moisture	AM
44			Temperature	Tem.
45			Hydrology of surface and groundwater	HSG
46		Topography	Surface relief	SR
47			Slope	Slop
48			Elevation	Ele.
49			Exposure to sunshine	ES
50			Physical properties of mine components	PPM

land-use were subsequently adopted, ensuring that the site would be safe for occasional use by the local community and grazing livestock.

As another example, the original aim of reclamation at Jos Plateau of Nigeria had been to restore the mined areas for agriculture, and a series of trials was established in 1949 to assess how this could best be achieved. After 3 years of trials, the Mines Land Reclamation Unit argued that it was both impractical and uneconomic to attempt to raise the fertility of the reclaimed spoil to the point at which it could sustain traditional arable agriculture. Hence the alternative policy of establishing eucalypt plantations was introduced (Alexander, 1996).

Therefore developing a comprehensive MLSA framework with a hierarchical structure was taken into consideration to facilitate making more established decisions about post closure land-use of a mine site. Fig. 1 shows that this hierarchy consists of economical, social, technical, and mine site criteria.

MLSA attributes

The MLSA framework was built to allow analyzing the suitability of mined lands, with distinct characteristics, in conformity with MADM approaches. Table 2 shows the fifty attributes with their abbreviations that have been categorized into four criteria groups as economical, social, technical, and mine site factors.

The economical factors are of a great importance in mined land suitability analysis and because of their uncontrollability play a deterministic role in most MLSA processes.

The society i.e. government, community and stakeholders should be consulted during the process of mined land suitability analysis, especially if a post-mining land-use is different to the premining land-use. Even in some situations for small and isolated mines, the existing land owner and neighbors would constitute the primary groups to be consulted. Then as well as meeting the eco-

Table 3
Manner of assigning performance scores to the attributes i against land-uses j.

Extremely low	→									*Extremely high*
Post-mining land-uses	1	2	3	4	5	6	7	8	9	Attributes
Farmland					■					Capital costs
Industrial		■								Ecological acceptability
Landfill									■	Environmental contaminations

nomical requirements, it is critical that the post-mining land-use is acceptable to the society.

A technical attribute corresponds to constraints that may lead each DM to prefer a specific individual post-mining land-use, based on the fact that it best satisfies some technological requirements, which are associated with those constraints.

And finally, the mine site factors are intrinsic and site-specific attributes that affect the decision. They comprise three groups of attributes namely soil, climate and topography.

Applying MADM techniques and MLSA framework within an illustrative example

In this section, a relatively simple example of a typical mined land with hypothetical data and information is analyzed with the intention of illustrating the way of applying the proposed approach for mined land suitability analysis.

In the considered example, pre-mining land-use of the mine site has been *wildlife habitat*, but mining activities have now severely damaged major portions of it. The original ecosystem is assumed to have been rich in native flora, and that some rare medicinal plants still exist in the area. The implemented feasibility studies show that some other land-uses such as *pasture*, *farmland*, *forestry*, *lake*, *sport field*, *park*, *residential*, *commercial*, *industrial*, *educational*, *sustainable community*, and *landfill* can also be developed for this mined ecosystem after mine closure. In other words, the management options that are listed as possible goals for mine closure planning can be cited as follows (Soltanmohammadi et al., 2008d):

1. Restoration of the ecosystem to *wildlife habitat* (CV-W);
2. Rehabilitation of the ecosystem by planting, stabilizing, and reproducing some scarce medicinal plants in a *nursery* (A-N);
3. Adoption of alternative ecosystems and converting the damaged ecosystem to either of other land-uses including: *pasture* (A-P), *farmland* (A-F), *forestry* (F), *lake* (L), *sport field* (IR-S), *park* (NIR-P), *residential* (CT-R), *commercial* (CT-C), *industrial* (CT-I), *educational* (CT-E), *sustainable community* (CT-S), and *landfill* (B).

The AHP-TOPSIS hybrid approach is applied here to analyze the above example, on the basis of the MLSA framework, where fourteen anticipated land-uses will be ranked by integrating these two MADM methods. Details of the proposed approach and applied steps on the considered example are discussed in the following sections.

Individual evaluations according to judgments of each DM

In a real MLSA application, the most relevant stakeholders (DMs) are: (1) mining company representative, (2) government representative (probably a land manager), (3) environment agency, and (4) community representative. In this way, in the MLSA example studied in this paper, it is assumed that these four stakeholder groups participate in the required decision making judgments. Performance scores can be assigned to the attributes with respect to judgments of each DM on the mined land through the MLSA framework. Thus, for each alternative $j \in J$, the performance scores f_{ji}^{k} are assigned to attributes $i \in n$ by every four involved DM^k ($k = 1, \ldots, 4$) to form a decision matrix F^k according to Eq. (1):

$$F^k = \begin{bmatrix} f_{11}^k & f_{12}^k & \cdots & f_{1n}^k \\ f_{21}^k & f_{22}^k & \cdots & f_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ f_{J1}^k & f_{J2}^k & \cdots & f_{Jn}^k \end{bmatrix} \tag{1}$$

The authors have recommended here the fundamental nine-point scale defined by Saaty (Saaty and Vargas, 1994), be used by DMs to assess performance scores of the attributes. In the proposed scale of quantification, score equal to 1 signifies *extremely low* and score equal to 9 signifies *extremely high* condition of every attribute against each alternative (Table 3).

Some of the assumed performance scores for the studied example according to subjective judgments of DM$_1$ have been cut in a fragmented decision matrix as shown in Table 4. The highlighted rows represent cost attributes and must be minimized while the others represent benefit attributes and must be maximized in the MLSA process.

Weighting the attributes using AHP

The weights of attributes are calculated by means of AHP method developed by Saaty (Saaty and Vargas, 1994). The procedure of AHP weighting can be summarized as follows:

Firstly, pairs of elements of the n-attribute hierarchical framework are compared within pair-wise comparison matrixes A, according to Eq. (2):

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

$$a_{iz} = \frac{1}{a_{zi}}, \quad a_{ii} = 1, \quad i, z = 1, 2, \ldots, n. \tag{2}$$

Where the element a_{iz} can be interpreted as the degree of preference of ith attribute over zth attribute; and vice versa.

Secondly, each column of the pair-wise comparison matrix is divided by sum of entries of the corresponding column to obtain the normalized comparison matrix. The eigen-values λ_i of this matrix would give the relative weight of attribute i.

Finally, the obtained relative weight vector is multiplied by the weight coefficients of the elements at the higher levels, until the top of the hierarchy is reached. The result is global weight vector W of the attributes and can be shown as Eq. (3):

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \tag{3}$$

Table 4
Scores of land-uses $j \in J$ assigned to the attributes $i \in n$ according to judgment by DM_1.

i	j	A-F	A-P	A-N	F	L	IR-S	NIR-P	CT-R	CT-C	CT-I	CT-E	CT-S	CV-W	B	Weights
1	MMC	7	8	6	9	9	3	6	7	5	2	5	8	9	9	0.04060
2	CAC	5	3	2	4	2	6	5	7	8	8	7	9	4	1	0.03383
3	OPC	4	2	4	7	9	6	4	7	2	8	7	9	5	2	0.03383
4	PIA	2	2	7	1	8	8	7	4	8	9	4	3	9	2	0.02827
5	IGI	7	7	5	8	8	8	1	3	8	9	2	4	6	4	0.02274
46	SR	7	2	2	1	7	1	1	9	8	6	8	8	1	3	0.01214
47	Slop	7	2	1	1	1	1	2	9	7	2	7	8	2	8	0.02167
48	Ele.	5	3	3	3	8	9	3	5	5	3	5	6	2	8	0.00898
49	ES	8	8	8	8	7	8	8	5	5	5	5	8	8	5	0.01000
50	PPM	9	7	5	6	2	2	2	8	7	2	8	7	8	3	0.02165

AHP also calculates an inconsistency index CI to reflect the consistency of DM's judgments during the evaluation phase. The inconsistency index in pair-wise comparison matrixes can be calculated by means of Eq. (4):

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}. \tag{4}$$

Where $\lambda_{\max}$ is the highest eigen-value of the pair-wise comparison matrix. The closer the inconsistency index is to zero, the greater the consistency so the relevant index should be lower than 0.10 to accept the AHP results as consistent.

With standing to the fact that, such a procedure is common in mathematics, Expert Choice software was used in this study, which is a multi-objective decision support tool. Descending order of the calculated weights for the studied example according to subjective judgments of DM_1 has been illustrated in Fig. 2. According to Eq. (4), an acceptable overall inconsistency index of 0.02 motivated the authors to accept final weighting result of the AHP method.

For the sake of simplicity, the above weighting result was accepted for the next calculations. But, it should be noted that, in a real situation, calculations of this phase must be performed by a team of DMs consisting of the most related experts. There are different ways for aggregation of individual judgments in AHP group decision making (Forman and Peniwati, 1998; Escobar et al., 2004). Two methods, known to be most useful, are Aggregation of Individual Judgments (AIJ), and Aggregation of Individual Priorities (AIP). Owing to the fact that, in MLSA process the group decision has to be made as separate individual DMs, for this case, the AIJ is more suitable than the AIP (Forman and Peniwati, 1998). Therefore, in this phase, the experts in the decision making team are given the task of forming individual pair-wise comparison matrix by using Saaty's nine-point scale. According to Eq. (5), weighted geometric mean of these judgments can be found to obtain the pair-wise comparison matrix on which there is a consensus.

$$a_{iz}^{g} = \prod_{x=1}^{X} (a_{iz}^{x})^{w_x} \tag{5}$$

in Eq. (5), a_{iz}^{g} refers to the group judgment on the relative importance of attributes i and z, a_{iz}^{x} refers to expert x's (DM_x) judgment on the relative importance of attributes i and z, w_x is the normalized weight of DM_x, and X is the number of DMs.

Normalization of the performance scores

Because the attributes are of benefit and cost types, a basic task in MADM is normalizing the decision matrix. Thus, normalized rating for each element in the decision matrix F^k should be calculated. The normalized values r_{ji}^{k} can be calculated as:

$$\begin{cases} r_{ji}^{k} = \dfrac{f_{ji}^{k}}{\sqrt{\sum_{j=1}^{J} (f_{ji}^{k})^2}}, \quad i = 1, \ldots, n; j = 1, \ldots, J; k = 1, \ldots, K \\ \text{for benefit attributes;} \\ r_{ji}^{k} = \dfrac{1/f_{ji}^{k}}{\sqrt{\sum_{j=1}^{J} (1/f_{ji}^{k})^2}}, \quad i = 1, \ldots, n; j = 1, \ldots, J; k = 1, \ldots, K \\ \text{for cost attributes.} \end{cases} \tag{6}$$

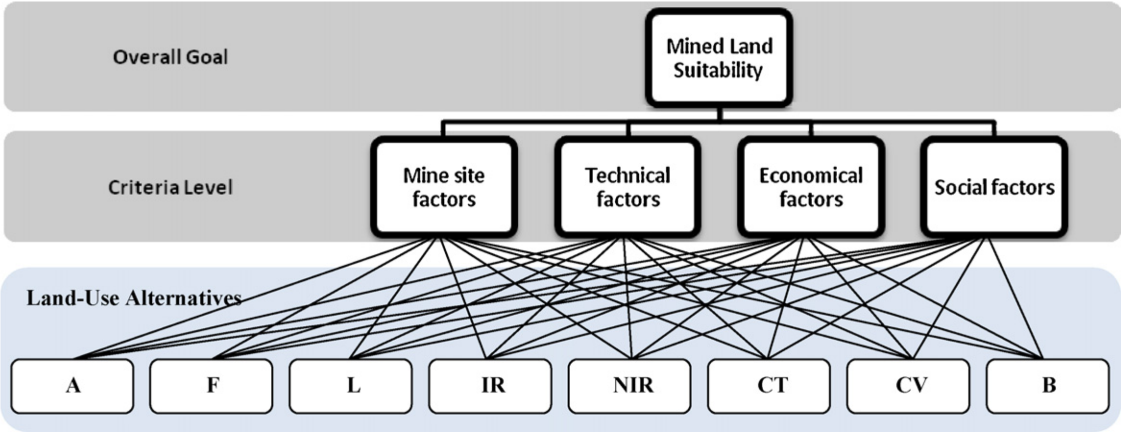

Fig. 2. Hierarchical structure of MLSA fifty-attribute framework.

Table 5
Normalized values in a fragmented decision matrix.

	MMC	CAC	OPC	PIA	IGI	IIL	CRE	EIA	Tem.	HSG	SR	Slop	Ele.	ES	PPM
Farmland	0.1661	0.2313	0.3101	0.0518	0.3015	0.4015	0.3260	0.3449	0.2005	0.2675	0.0988	0.0926	0.2294	0.3106	0.0000
Pasture	0.0830	0.3470	0.4341	0.0518	0.3015	0.4015	0.2794	0.3449	0.3509	0.3121	0.3457	0.3243	0.3441	0.3106	0.1213
Nursery	0.2491	0.4048	0.3101	0.3111	0.2010	0.3513	0.0931	0.0493	0.4010	0.3121	0.3457	0.3706	0.3441	0.3106	0.2425
Forestry	0.0000	0.2892	0.1240	0.0000	0.3518	0.0000	0.3260	0.2463	0.3509	0.3567	0.3951	0.3706	0.3441	0.3106	0.1819
Lake or pool	0.0000	0.4048	0.0000	0.3629	0.3518	0.0502	0.3260	0.2463	0.1003	0.1338	0.0988	0.3706	0.0574	0.2662	0.4244
Sport field	0.4983	0.1735	0.1861	0.3629	0.3518	0.3011	0.1863	0.0985	0.2005	0.3567	0.3951	0.3706	0.0000	0.3106	0.4244
Park	0.2491	0.2313	0.3101	0.3111	0.0000	0.0000	0.1863	0.197	0.2506	0.3567	0.3951	0.3243	0.3441	0.3106	0.4244
Residential	0.1661	0.1157	0.1240	0.1555	0.1005	0.2509	0.3726	0.3449	0.0000	0.0000	0.0000	0.0000	0.2294	0.1775	0.0606
Commercial	0.3322	0.0578	0.4341	0.3629	0.3518	0.3513	0.3260	0.2956	0.2005	0.0892	0.0494	0.0926	0.2294	0.1775	0.1213
Industrial	0.5813	0.0578	0.0620	0.4148	0.4020	0.4015	0.2329	0.2956	0.3509	0.2675	0.1482	0.3243	0.3441	0.1775	0.4244
Educational	0.3322	0.1157	0.1240	0.1555	0.0503	0.2008	0.2794	0.3449	0.2005	0.3567	0.0494	0.0926	0.2294	0.1775	0.0606
Community	0.0830	0.0000	0.0000	0.1037	0.1508	0.2008	0.3726	0.3941	0.0000	0.0000	0.0494	0.0463	0.1721	0.3106	0.1213
Wildlife habitat	0.0000	0.2892	0.2481	0.4148	0.2513	0.1506	0.0931	0.1478	0.3509	0.3567	0.3951	0.3243	0.4015	0.3106	0.0606
Landfill	0.0000	0.4627	0.4341	0.0518	0.1508	0.1004	0.0000	0.0000	0.3008	0.0000	0.2963	0.0463	0.0574	0.1775	0.3638

the normalized decision matrix R^k, can be written as Eq. (7):

$$R^k = \begin{bmatrix} r_{11}^k & r_{12}^k & \cdots & r_{1n}^k \\ r_{21}^k & r_{22}^k & \cdots & r_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ r_{J1}^k & r_{J2}^k & \cdots & r_{Jn}^k \end{bmatrix},$$

$$i = 1, 2, \ldots, n; j = 1, 2, \ldots, J, \; k = 1, \ldots, 4. \tag{7}$$

some normalized scores of the studied example obtained using Eq. (6), have been shown in Table 5 as a fragmented decision matrix.

Application of dominance rule on the normalized decision matrix

Dominance analysis narrows down the focus of the decision to the Pareto optimal set, which is the subset of alternatives consisting of those that are not dominated by other alternatives according to the evaluation attributes. The use of dominance analysis in choice-making is common in literature related to MADM (Naresh, 2003); because it rationally should be verified if there is any dominated alternative among the possible solutions.

As stated by the dominance rule; alternative *j* dominates alternative *l*, if and only if *j* is at least as good as *l* in all the attributes *i*, and there is at least one attribute *z*, in which *j* is strictly better than *l*. In other words;

$$(j \text{ dominates } l) \Leftrightarrow (r_{ij} \geq r_{il}) \wedge \exists z (r_{zj} > r_{zl}). \tag{8}$$

For the studied example, with reference to normalized decision matrix shown in Table 5 and also using Eq. (8) there has been no dominated alternative among the judged solutions by DM*1*. As a result, the normalized values were confirmed for the next stages without decrease in the number of possible post-mining land-uses.

Calculation of the weighted normalized decision matrix

The values of weighted normalized decision matrix v_{ji}^k are calculated using Eq. (9):

$$v_{ji}^k = r_{ji}^k \times w_i^k = \begin{pmatrix} r_{11}^k w_1^k & \cdots & r_{1n}^k w_n^k \\ \vdots & \ddots & \vdots \\ r_{J1}^k w_1^k & \cdots & r_{Jn}^k w_n^k \end{pmatrix}$$

$$i = 1, \ldots, n; j = 1, \ldots, J; k = 1, \ldots, K. \tag{9}$$

fragments of weighted normalized ratings for DM_1 are shown in Table 6.

Identification of the positive and negative ideal solutions

The positive ideal solution A^{k*} (PIS) and the negative ideal solution A^{k-} (NIS), are determined respectively, for each DM^k. For DM^k, his/her PIS and NIS are identified as:

$$A^{k*} = \{v_1^{k*}, v_2^{k*}, \ldots, v_n^{k*}\} = \{(\max_j v_{ji}^k \,|\, i \in I'), (\min_j v_{ji}^k \,|\, i \in I'')\}. \tag{10}$$

$$A^{k-} = \{v_1^{k-}, v_2^{k-}, \ldots, v_n^{k-}\} = \{(\min_j v_{ji}^k \,|\, i \in I'), (\max_j v_{ji}^k \,|\, i \in I'')\}. \tag{11}$$

Table 6
Weighted normalized values and ideal solutions in a fragmented decision matrix.

	MMC	CAC	OPC	PIA	IGI	IIL	CRE	EIA	Tem.	HSG	SR	Slop	Ele.	ES	PPM
Farmland	0.0067	0.0078	0.0105	0.0025	0.0068	0.0087	0.0053	0.0071	0.0028	0.0045	0.0012	0.0020	0.0021	0.0031	0.0000
Pasture	0.0034	0.0117	0.0147	0.0025	0.0068	0.0087	0.0046	0.0071	0.0050	0.0052	0.0042	0.0070	0.0031	0.0031	0.0026
Nursery	0.0101	0.0137	0.0105	0.0088	0.0049	0.0077	0.0020	0.0018	0.0057	0.0052	0.0042	0.0080	0.0031	0.0031	0.0053
Forestry	0.0000	0.0098	0.0042	0.0013	0.0078	0.0010	0.0053	0.0053	0.0050	0.0058	0.0048	0.0080	0.0031	0.0031	0.0039
Lake or Pool	0.0000	0.0137	0.0000	0.0101	0.0078	0.0019	0.0053	0.0053	0.0014	0.0026	0.0012	0.0080	0.0005	0.0027	0.0092
Sport field	0.0202	0.0059	0.0063	0.0101	0.0078	0.0068	0.0033	0.0026	0.0028	0.0058	0.0048	0.0080	0.0000	0.0031	0.0092
Park	0.0101	0.0078	0.0105	0.0088	0.0010	0.0010	0.0033	0.0044	0.0035	0.0058	0.0048	0.0070	0.0031	0.0031	0.0092
Residential	0.0067	0.0039	0.0042	0.0050	0.0029	0.0058	0.0059	0.0071	0.0021	0.0006	0.0000	0.0000	0.0021	0.0019	0.0013
Commercial	0.0135	0.0020	0.0147	0.0101	0.0078	0.0077	0.0053	0.0062	0.0028	0.0019	0.0006	0.0020	0.0021	0.0019	0.0026
Industrial	0.0236	0.0020	0.0021	0.0113	0.0088	0.0087	0.0039	0.0062	0.0050	0.0045	0.0018	0.0070	0.0031	0.0019	0.0092
Educational	0.0135	0.0039	0.0042	0.0050	0.0020	0.0048	0.0046	0.0071	0.0028	0.0058	0.0006	0.0020	0.0021	0.0019	0.0013
Community	0.0034	0.0000	0.0000	0.0038	0.0039	0.0048	0.0059	0.0079	0.0000	0.0006	0.0006	0.0010	0.0015	0.0031	0.0026
Wildlife habitat	0.0000	0.0098	0.0084	0.0113	0.0059	0.0039	0.0020	0.0035	0.0050	0.0058	0.0048	0.0070	0.0036	0.0031	0.0013
Landfill	0.0000	0.0157	0.0147	0.0025	0.0039	0.0029	0.0007	0.0009	0.0043	0.0006	0.0036	0.0010	0.0005	0.0019	0.0079
PISs	0.0236	0.0157	0.0147	0.0113	0.0088	0.0087	0.0059	0.0079	0.0057	0.0058	0.0048	0.0080	0.0036	0.0031	0.0092
NISs	0.0000	0.0000	0.0000	0.0013	0.0010	0.0010	0.0007	0.0009	0.0000	0.0006	0.0000	0.0000	0.0000	0.0019	0.0000

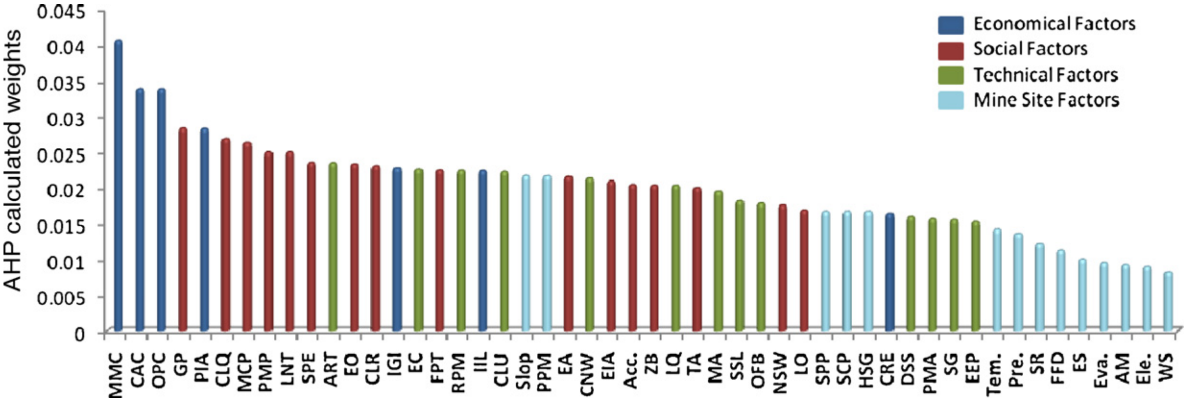

Fig. 3. Global weights of the evaluation attributes calculated using AHP method.

where I' is associated with benefit attributes, and I'' is associated with cost attributes.

Table 6 also shows the PIS and NIS sets for DM^1.

Calculation of the individual separation measures

The separation measures $D^k{}_j{}^*$ and $D^k{}_j{}^-$ from PIS and NIS are calculated individually for each four stakeholder using the n-dimensional Euclidean distance:

$$D_j^{k*} = \sqrt{\sum_{i=1}^{n}(v_{ij}^k - v_i^{k*})^2}, \quad j = 1, \ldots \mathrm{J};\ k = 1, \ldots, K. \tag{12}$$

$$D_j^{k-} = \sqrt{\sum_{i=1}^{n}(v_{ij}^k - v_i^{k-})^2}, \quad j = 1, \ldots \mathrm{J};\ k = 1, \ldots, K. \tag{13}$$

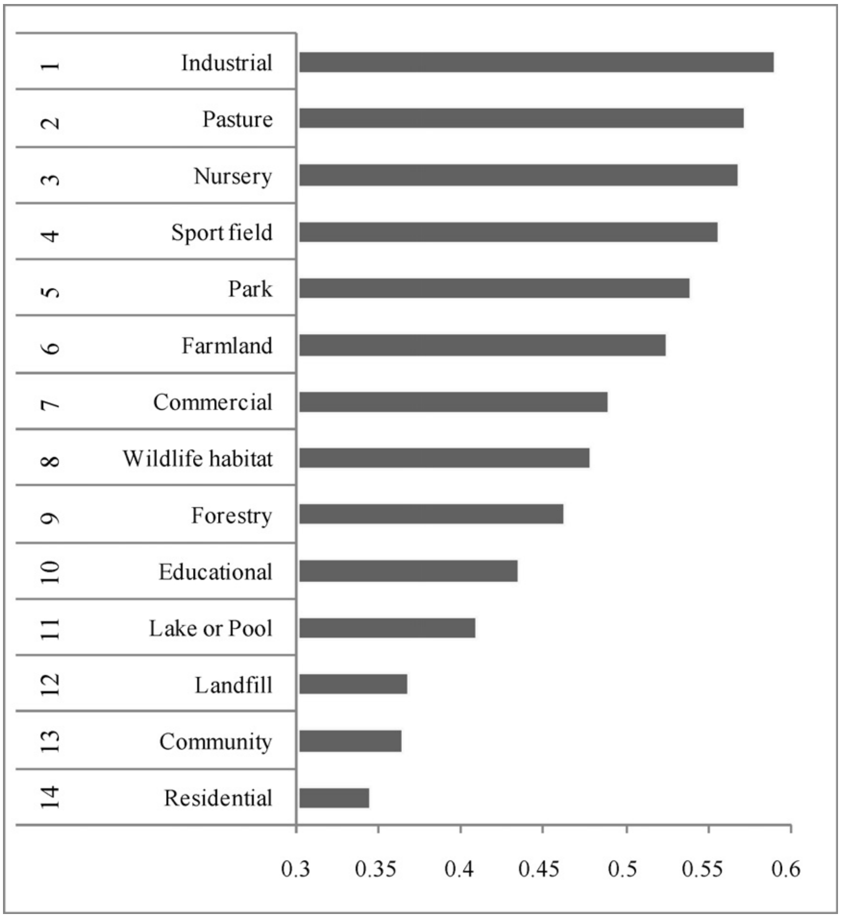

Fig. 4. Descending preference order of post-mining land-use alternatives.

Table 7
Separation measures, relative closeness indexes and ranks of the alternatives.

Land-uses	dj+	dj−	cj	Rank
Farmland	0.0335	0.0370	0.5247	6
Pasture	0.0317	0.0423	0.5716	2
Nursery	0.0300	0.0393	0.5676	3
Forestry	0.0409	0.0351	0.4622	9
Lake or Pool	0.0469	0.0324	0.4086	11
Sport field	0.0331	0.0413	0.5556	4
Park	0.0326	0.0380	0.5384	5
Residential	0.0458	0.0240	0.3439	14
Commercial	0.0379	0.0361	0.4884	7
Industrial	0.0322	0.0463	0.5897	1
Educational	0.0406	0.0313	0.4347	10
Community	0.0465	0.0266	0.3641	13
Wildlife habitat	0.0409	0.0375	0.4781	8
Landfill	0.0501	0.0290	0.3668	12

Table 7 shows the calculated individual separation measures for DM^1.

Calculation of group separation measures

The separation measures from PIS and NIS are calculated for the group of stakeholders. The group measures, from PIS and NIS are the geometric mean of all individual measures:

$$\overline{D_j^*} = \left(\prod_{k=1}^{K} (D_j^{k*})^{m_k}\right)^{1/\sum m_k} \tag{14}$$

$$\overline{D_j^-} = \left(\prod_{k=1}^{K} (D_j^{k-})^{m_k}\right)^{1/\sum m_k} \tag{15}$$

where m_k is the importance factors or weights assigned to each stakeholder (DM^k).

Since the input data in this example are hypothetical, the calculations of this step could be left out. Therefore for the sake of simplicity and avoiding use of excessive hypothetical data in this particular example, the individual separation measures should be accepted for the group of stakeholders without calculation of geometric mean of individual measures.

Calculation of the relative closeness index

The relative closeness of the jth alternative with respect to PIS can be expressed as:

$$\overline{C_j^*} = \frac{\overline{D_j^-}}{(\overline{D_j^*} + \overline{D_j^-})}, \quad j = 1, \ldots, \mathrm{J}. \tag{16}$$

where $0 \leq \overline{C_j^*} \leq 1$. The larger the index value, the better the performance of the alternative.

Table 7 shows the relative closeness indexes and ranks of the alternatives for DM^1.

In TOPSIS method, the chosen alternative has the maximum value of C^*_j with the intention to minimize the distance from the ideal solution and to maximize the distance from the negative ideal solution. A descending order of the ranked alternatives is also illustrated in Fig. 3 to indicate the keen competition between them. As can be seen, the industrial land-use has maximum value of relative closeness to ideal solution and is the most preferable alternative of this MLSA example (Fig. 4).

Conclusions

In this study combination of group versions of AHP and TOPSIS techniques helped to determine a preference ranking list for possible post-mining land uses of a hypothetical mined land based on the MLSA framework. This ranking list was obtained with the aid of TOPSIS on the basis of data in the decision matrices and weights resulted from AHP. The industrial land-use was chosen as the most suitable post-mining land-use for this hypothetical mined land.

However, comparison of results of this study with the previous studies (Soltanmohammadi et al., 2008b,c) shows that in addition to the numerous conflicting criteria, the MADM method utilized for aggregation of performance scores of mined land have also an influence on selection of optimal land-use(s).

Three MADM techniques (PROMETHEE, ELECTRE, and TOPSIS) have been used for this purpose in separate studies with similar data. PROMETHEE and ELECTERE are two outranking techniques that may contain more realistic information through the indication of incomparability between alternatives and therefore are well suited for conditions that exist in the MLSA framework. On the other hand, according to Shih et al. (2007), at least three TOPSIS advantages can be identified: (1) a sound logic that simulates the rationale of human choice; (2) a scalar value that accounts for both the best and worst alternatives simultaneously; and (3) a simple computation process that can be easily programmed into a spreadsheet. TOPSIS also has the fewest rank reversals among the common MADM methods. In general, the contrast between advantages of these methods would compel the decision makers to make a deliberate attempt to represent the most suitable MADM technique for aggregation of criteria scores of a typical mined land.

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