Proceedings of the World Congress on New Technologies (NewTech 2015)
Barcelona, Spain – July 15 - 17, 2015
Paper No. 151

Application of ANP And ELECTRE for the Assessment of Different Site Remediation Technologies

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Abstract **–**The main objective of this study was to select the appropriate site remediation technologies for metal contaminated soils. For this purpose, six different technologies were evaluated by Analytic Network Process (ANP)and ELimination and Choice Expressing the REality (ELECTRE III) methods which are two well-known Multi Criteria Decision Making (MCDM) methods. These technologies are biological treatment, electrokinetic, phytoremediation, physical isolation, soil flushing and vitrification. Eleven criteria by means of benefit, cost and risk used for evaluation. According to the evaluations, similar results were obtained using both techniques and phytoremediation was found to be the most appropriate remediation option. The main factors influencing this result were low cost and high benefit.

Keywords**:** ANP, ELECTRE III, Heavy Metal, MCDM, Soil, Treatment.

1. Introduction

Nowadays soil pollution increase rapidly due to uncontrolled urbanization, industrial and hazardous wastes, transporting activities, agricultural activities and mining activities. The successful treatment of a contaminated site depends on proper selection, design, and adjustment of the remediation technology's operations based on the properties of the contaminants and soils and on the performance of the system (Khan et al., 2004).

Multi-criteria decision making (MCDM) which were used in this study has become an important part of decision sciences. MCDM techniques can be applied in many decision problems in several environmental studies (Özkan, 2013; Tran et al., 2004, Acar et al., 2003; Banar et al., 2010; Khelifi et al., 2006; Agarwal et al., 2013). ANP and ELECTRE were chosen to be used in this study. ANP is based on the utility function that aggregates different criteria (points of view) into one global criterion. ELECTRE III, another MCDM method, is one of the multiobjective ranking methods based on outranking relations. Indifference, weak preference, strong preference, and incomparability are used for the extended model of the DM's local preferences in ELECTRE III. The difference between ANP and ELECTRE is incomparability among the alternatives; specifically, ANP eliminates incomparability between alternatives, while ELECTRE III takes it into account. Hence, ANP and ELECTRE III were considered in this study because of their different viewpoints.

2. Methodology

This study was realized for contaminated site with metal processing plant sludge including lead and cadmium in Eskisehir/Turkey. The contaminated site' area is 5 decare, soil properties are salt-free, medium lime level, alkaline, clayey-loamy and polluted site depth is 20 cm. For remediation of this site, two MCDM methods were employed: ANP and ELECTRE III. These methods are dynamic research methods and offer to numerical results via mathematical approaches to decision makers. The alternatives and criteria – which were the same in both cases – were set out initially, followed by the MCDM methods. The alternative technologies were selected for evaluation according to a survey of the relevant literature. In this context, biological treatment (a1), electrokinetic (a2), phytoremediation (a3), physical isolation (a4), soil flushing (a5) and vitrification (a6) were used as alternative technologies. These technologies is defined average or above average for inorganics according to remediation technologies screening matrix by Environmental Protection Agency (EPA).

The criteria used in this study are given in Table 1. The same criteria were used for ANP and ELECTRE III studies. In addition, for the 'Benefit Opportunity Cost Risk (BOCR)' analysis in ANP, each alternative was evaluated in terms of its benefits, costs and risks; the opportunity cluster was not considered. For ELECTRE III studies, the units of the quantitative criteria and the scores for the qualitative criteria are given in this table.

Table. 1. The criteria and their properties.

No	Name	Weight	**(for ELECTRE III)**	
			Ascending order	Unit
Benefit Cluster (for ANP)				
g1	Remediation time	10	decreasing	day
g2	Chemical usage	10	decreasing	Score (1-9)
g3	Easy application	20	increasing	Score (1-9)
g4	Effiency	5	increasing	%
Cost Cluster (for ANP)				
g5	Operation cost	5	decreasing	$\$/m^3$
g6	Preoperation cost	10	decreasing	$\$/m^3$
g7	Capital cost	10	decreasing	$\$/m^3$
Risk Cluster (for ANP)				
g8	Effective depth	5	increasing	m
g9	Climate conditions	5	decreasing	Score (1-9)
g10	Waste generation	10	decreasing	Score (1-9)
g11	Destroying of soil quality	10	decreasing	Score (1-9)

2. 1. ANP Method

The ANP was developed by Thomas L. Saaty and provides a way to input judgments and measurements to derive ratio scale priorities for the distribution of influence among the factors and groups of factors in the decision. Whereas the basic ANP structure consists of only one network, the most complex one can analyse the benefit, opportunity, cost and risk that each alternative can cause together.

Super Decision software was used and BCR analysis was conducted to apply ANP. The 'benefits costs risks' model was used to determine the values presented in Table 1. It was pointed out that the consistency ratios were less than 10% due to the nature of the method; a self-evident fact.

In ANP, significance and impact weighting between each criterion may be determined by the decision maker. In this study, the significance of the weighting of the chosen criteria was been formulated in the program as a*dditive (reciprocal)*

Formula: $bB + oO + c\,(1/C) + r\,(1/R)$

with $r = 1/2$; $c = 1/3$; $b = 1/6$; and $o = 0$.

In this context, first of all each cluster is rated separately. Then, these ratings are combined using the cluster weighting and the formulas including that to multiply the benefit ratios, reciprocals of cost and risk ratios. Finally these raw results are normalized and the values can be used as percentages for the evaluation of the alternatives (Saaty, 2001).

2. 2. ELECTRE III Method

ELECTRE III, which was developed by Bernard Roy in 1968, was built based on the outranking relation for modelling the decision maker's preferences. The method is based on pair-wise comparison. Performance values and thresholds of the criteria are given in Table 2. Firstly, the ascending orders were considered for the evaluation of the criteria with nonnumerical values, and the decision makers were asked to assign first place to the least important criterion. The other importance values were then assigned based on how many times more important they appeared as compared to the least important criterion. Thus, if a criterion was considered, for example, 3 times more important than the least important criterion, 3 was the value to be assigned to that criterion.

Table. 2. Performance values of criteria.

	g1	**g2**	**g3**	**g4**	**g5**	**g6**	**g7**	**g8**	**g9**	**g10**	**g11**
a1	180	5	3	65	15	30	15	1	8	2	3
a2	90	7	2	95	45	30	60	50	1	8	4
a3	180	2	9	65	10	20	10	1	6	2	1
a4	730	1	5	80	20	50	75	50	1	2	9
a5	180	9	4	95	50	30	140	15	1	8	3
a6	20	6	2	95	500	200	150	50	1	5	4
βq	10	1	1	5	10	10	10	5	1	2	1
βp	20	2	3	10	30	20	30	20	3	3	5

Nonnumerical values were scaled from 1 to 9, where Excellent = 9, Very good = 8, Good = 7, More or less good = 6, Indifferent = 5, Somewhat bad = 4, Bad = 3, Very bad = 2, and Awful = 1 for increasing ascending order, and Excellent = 1, Very good = 2, Good = 3, More or less good = 4, Indifferent = 5, Somewhat bad = 6, Bad = 7, Very bad = 8, and Awful = 9 for decreasing ascending order.
βq, coefficient for indifference threshold; βp, coefficient for preference threshold

3. Results and Discussion

The alternatives for choosing the most site remediation technology for contaminated sites with heavy metals were evaluated with ANP and ELECTRE III techniques. For ANP, according to the criteria and the formula above, the appropriate order of the alternatives were evaluated and is presented in the Fig. 1. According to the figure, phytoremediation (a3) is the most suitable by means of benefit and cost, electrokinetic (a2) is the most suitable technology by means of risk. For ELECTRE III, the concordance index and outranking degree means credibility matrix were obtained using an Excel worksheet that was developed by the researchers for similar MCDM problems (Table 3). Since the veto threshold was not used in this study, a discordance matrix was not calculated. The credibility matrix that gave the outranking degree was equal to the concordance matrix because the discordance matrix was not used. The value that approaches 1 gives the most preferable alternative.

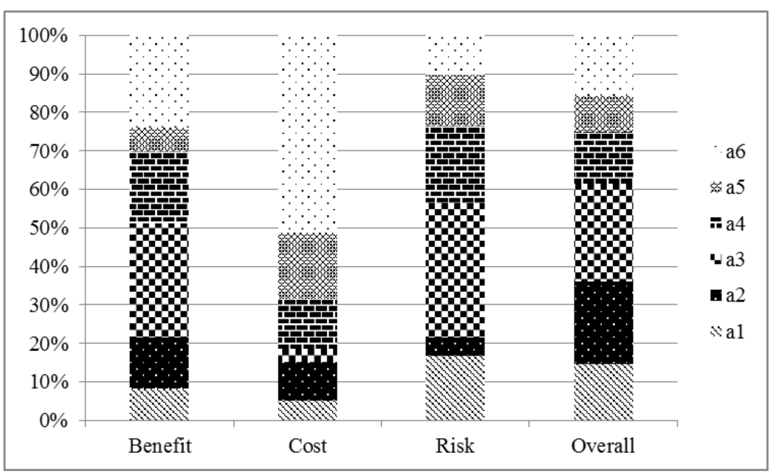

Fig. 1. ANP results in terms of benefit, cost, risk and overall

The results of both methods are compared in Table 4. According to the results, a3 (phytoremediation) was the most appropriate technology for remediation of heavy metal contaminated sites. There were changes in the ranking of some alternatives because of different mathematical approaches of the methods. In the ANP technique, relations and directions between components represent a network. On the other hand, although ELECTRE III does not cover the abovementioned network, there are preference and indifference thresholds for all criteria (Banar, 2010).

Table. 3. Concordance matrix.

	a1	**a2**	**a3**	**a4**	**a5**	**a6**
a1	1	0.75	0.65	0.65	0.87	0.75
a2	0.65	1	0.4	0.5625	0.9	0.8
a3	1	0.75	1	0,85	0.87	0.75
a4	0.6	0.625	0,4	1	0.65	0.75
a5	0.65	0.65	0.425	0.6	1	0.65
a6	0.65	0.75	0.3	0.35	0.75	1

Table. 4. Comparison of ANP and ELECTRE III results.

Site remediation technologies	**ANP**	**ELECTRE III**
Biological treatment (a1)	4	3
Electrokinetic (a2)	2	2
Phytoremediation (a3)	**1**	**1**
Physical isolation (a4)	5	3
Soil flushing (a5)	6	4
Vitrification (a6)	3	3

4. Conclusion

Several remediation technologies are available for contaminated sites. However, no single technology is appropriate for all contaminant types. Technical (effective depth, chemical usage, etc) and economical (operation costs, capital costs, etc.) criteria should be considered to choice a remediation technology. At this point, MCDM methods help to decision makers for similar problems. In the present study, ANP and ELECTRE III were used to decide between site remediation technologies. According to the evaluations, similar results were obtained using both techniques and phytoremediation was found to be the most appropriate remediation option. The main factors influencing this result were low cost and high benefit.

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