Use of the Analytic Hierarchy Process Technique for Land-use Analysis

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ABSTRACT

The AHP (Analytic Hierarchy Process) is a useful tool in decision making method for land-use planning. Hillside development often contains environmental constraints because of hilly topography. Planners and decision makers have a limited opportunity to implement innovative approaches in land-use planning decision making process. This paper discusses on a possible MCDA (Multi Criteria Decision Analysis) method of land suitability analysis for sustainable hillside development. A hierarchical structure model is developed for the land suitability analysis. Land-use planners can get benefit from MCDA techniques for hillside development projects and various kinds of land-use planning problems. Criteria are prioritized by the experts and a number of sub-criteria are set in order to select the best alternatives for sustainable hillside development by using AHP method. Various techniques and modules are available that can check uncertainty of a computed final decision by experts. CR (Consistency Ratio) method is used to examine the uncertainty in decision obtained by the experts. If CR is more than required CR standards that it can revise weights with minor changes in criteria judgements to check uncertainty in decision-making of land suitability analysis. The AHP steps can be used by using the EC (Expert Choice) decision support software automatically or manually. This paper intends to introduce MCDA as a policy design tool for planners and decision makers like an AHP application in land-use planning.

Key Words: **Analytic Hierarchy Process, Land suitability, Hillsides, Expert Choice.**

1. INTRODUCTION

The AHP is an eigenvalue technique for the pair-wise comparisons approach. AHP offers a mathematical scale which ranges from 1 to 9 in order to standardize quantitative and qualitative performances of scale importance shown in Table 1 [1]. Decision-makers were facing the problem of taking decision about present, future land-use planning and trends of development. Many land-use models are implementing in planning through various MCDA methods to see variation and future trends of the land. However, AHP technique explicitly shows an significance in urban planning and development decision-making process [2]. AHP gives a useful environment for the decision-making process that manages the land suitability analysis problems. At present, it is recognized as the integrated MCDA

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TABLE 1. AHP SCALE OF PREFERENCES [24-26]

Scale	Verbal Judgements of preferences
1	Equal Importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Extreme Importance
2,4,6,8	Intermediate values
The reciprocals	For inverse comparison

method which is used in spatial problems to determine sustainable sites for development [3,4]. Recently, many studies applied for land suitability evaluation methods in the allocation of land for recreational activities [5-8]; in the selection of sustainable industrial areas by Chen and Delaney [9-11]; and various other land suitability analysis problems [12-19]. Integration of MCDA approach is an important step for spatial problems that employs a sustainable land-use planning approach [20-23]. In this paper, decision-making method is demonstrated to meet land suitability analysis criteria. The AHP breaks a problem into different levels such as problem (aim), criteria and sub-criteria (alternatives). At the end, all levels aggregate into a final decision. This paper aims to encourage the application of AHP in various kinds of land-use planning issues.

1.1 Analytic Hierarchy Process

The AHP is a straightforward MCDA method for land suitability of hillside planning demonstrates for illustration purpose in this paper [27]. The criteria and sub-criteria were used in the land suitability analysis example for hillside development are accessibility PR (Primary Road) and SR (Secondary Road), topography (EL is Elevation, SL is Slope, AS is Aspect and land cover (AL is Agriculture Land, FR is Forest Land, ER is Existing Residential, WL is Wet Land and SW is Surface Water). Further, criteria can be considered or omitted if necessary, based on a requirement of site environment. The MCDA is structured as a decision making method using expert judgments as follows in the following major steps. The calculation of judgments can be performed manually or automatically by the pairwise comparison matrices in EC decision support software. The following steps are used of the AHP as a decision-making process:

1. To build a structure of a problem with a model that presents the significance level of problems.
2. To elicit judgements that reflect knowledge.
3. To signify those judgements with meaningful numbers.
4. To use these numbers to calculate the priorities of the fundamentals of the hierarchy pyramid.
5. To aggregate synthesize results to make it single outcome.
6. To check uncertainty by applying CR of CI (Consistency Index), the eigenvalue (λ_{max}-n) is used to determine the consistency, to calculate consistency index, CI as follows: CI=(λ_{max}-n)/(n-1) , where n is the number of criteria in matrix. Judgement consistency can be checked by taking the CR of CI with the proper value from random indexes table. CR can be computed by taking value from 1-10 as shown in random indexes Table 2. CR formula can be written as: CR=CI/RI. If CR is more than 0.10, it means judgement is inconsistent. By obtaining consistent outcome, matrix should be revisited or improved [24]. Existing site selection criteria can be changed according to the situation. The construction of the problem hierarchy is developed as depicted in Fig. 1.

The CI of a randomly generated reciprocal matrix shall be called to the RI (Random Index), with reciprocals forced.

TABLE 2. RANDOM INCONSISTENCY INDICES [28]

Size of Matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

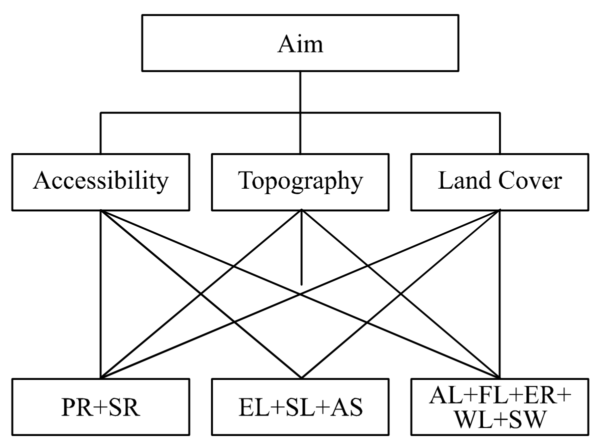

FIG. 1. HIERARCHICAL STRUCTURAL MODEL FOR LAND SUITABILITY ANALYSIS

2. RESULTS AND DISCUSSION

An example of determined priority vector for the land suitability criteria is shown in Table 3. These include three suitability criteria: accessibility (0.067), topography (0.467) and land cover (0.467). In this case, topography and land cover obtained high priorities among the three criteria. Therefore, both criteria were environmentally sensitive when considering the suitability of the hillside development.

A derivation of relative weighting for sub-criteria for hillside land suitability analysis is shown in Tables 4-6. The Tables 4-6 show that six sub-criteria received high priority weighting namely: PR (0.667), SR (0.333), SL (0.200), AS (0.200), AL (0.603), FL (0.136) and ER (Existing Residential (0.206). These sub-criteria obtained important consideration in selection of hillside land by the experts. Therefore, these sub-criteria consideration increase the significance of hillside land-use planning and development.

TABLE 3. DERIVATION OF RELATIVE WEIGHTS OF LAND SUITABILITY CRITERIA

Suitability Criteria	Accessibility	Topography	Land Cover	Priority Vector
Accessibility	1	0.14	0.14	0.067
Topography	7	1	1	0.467
Land Cover	7	1	1	0.467
				∑=1

TABLE 4. DERIVATION OF RELATIVE WEIGHTS OF LAND SUITABILITY SUB-CRITERIA OF ACCESSIBILITY

Suitability Sub-Criteria	Primary Road	Secondary Road	Priority Vector
Primary Road	1	2	0.667
Secondary Road	½	1	0.333
			∑=1

TABLE 5. DERIVATION OF RELATIVE WEIGHTS OF LAND SUITABILITY SUB-CRITERIA OF TOPOGRAPHY

Suitability Sub-Criteria	Elevation	Slope	Aspect	Priority Vector
Elevation	1	3	3	0.600
Slope	1/3	1	1	0.200
Aspect	1/3	1	1	0.200
				∑=1

2.1 Aggregation

The aggregation method aggregates the priority vectors (weights) of all pairwise comparison matrices criteria and sub-criteria into single outcome with normalization of sum of the weights to 1 in the equation. EC software was used in synthesizing all pairwise matrices weights by using Equation (1). An example of synthesize results is shown in Fig 2. Commutative CR was computed 0.07 in EC decision-making software by using Equation (2) which is less than from threshold CR value 0.10 [29]. This is a classical AHP method for aggregation of many pairwise comparison matrices to make it single outcome.

$$P_i = \sum_j wj.lij \tag{1}$$

$$CR = \frac{CI}{RI} \tag{2}$$

Where *Pi* is the synthesized priority of the alternative I; *lij* is the priority vector (weight) of sub-criteria and wj is the weight of the criterion j.

TABLE 6. DERIVATION OF RELATIVE WEIGHTS OF LAND SUITABILITY SUB-CRITERIA OF LAND COVER

Suitability Sub-Criteria	AL	FL	EL	WL	SL	Priority Vector
AL	1	7	7	9	9	0.603
FL	1/7	1	1/3	9	9	0.136
ER	1/7	3	1	9	9	0.206
WL	1/9	1/9	1/9	1	1	0.028
SW	1/9	1/9	1/9	1	1	0.028
						∑=1

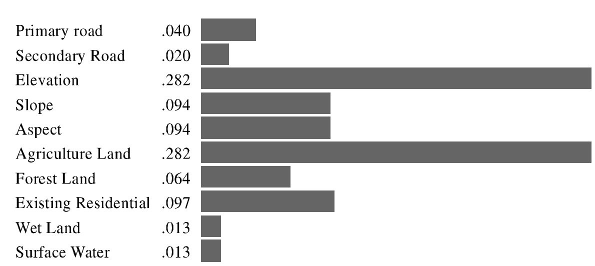

FIG. 2. SYNTHESIZE PRIORITY VECTORS

The Fig. 2 shows that ten sub-criteria received priority weighting namely: PR (0.040), SR (0.020), EL (0.282), SL (0.094), AS (0.094), AL (0.282), FL (0.064), ER (0.097), WL (0.013) and SW (Surface Water) (0.013). Two sub-criteria obtained high priority weights after derivation of Relative Weights of Land suitability sub-criteria in the aggregation analysis.

3. CONCLUSION

It is concluded that AHP as a MCDA approach provides a simplified platform to decision-makers in decision-making of hillside land suitability analysis for development. This paper aims that AHP as a MCDA decision-making process can resolve hillside land suitability problems for future hillside development. AHP is the collaborative planning process which can find a solution of hillside land-use planning at certain level. The MCDA can also ease to managing land suitability relevant problems that cannot settle by policy makers. MCDA shows a quality of land suitability analysis environment in various kinds of spatial planning fields like hillsides development by using AHP approach. AHP is a well-known method to implement land-use planning decisions of hillside development and to give opportunity to understand hillside planning problems. Therefore, GIS can be integrated with MCDA methods such as AHP for hillside land suitability analysis which has made more strengthen to the MCDA approaches.

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REFERENCES

[1] Saaty, T.L., "Decision Making with the Analytic Hierarchy Process", Intetnational Journal of Services Sciences, Volume 1, pp. 83-98, 2008.

[2] Pettit, C.J., "An Overview of Planning Support Systems", Asian Journal of Geoinformatics, Volume 7, pp. 3-12, 2007.

[3] Mohit, M.A., and Ali, M.M., "Integrating GIS and AHP for Land Sutiabiltiy Analysis for Urban Development in a Secondary City of Bangladesh", Jurnal Alam Bina, Volume 8, pp. 1-19, 2006.

[4] Duc, T.T., "Using GIS and AHP Technique for Land-Use Suitability Analysis", International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences, pp. 309-318, Shanghai, China, 2006.

[5] Greene, R., Luther, J.E., Devillers, R., and Eddy, B., "An Approach to GIS-Based Multiple Criteria Decision Analysis that Integrates Exploration and Evaluation Phases: Case Study in a Forest-Dominated Landscape", Forest Ecology and Management, Volume 260, pp. 2102-2114, 2010.

[6] Zucca, A., Sharifi, A.M., and Fabbri, A.G., "Application of Spatial Multi-Criteria Analysis to Site Selection for a Local Park: A Case Study in the Bergamo Province, Italy", Journal of Environmental Management, Volume 88, pp. 752-769, 2008.

[7] Bunruamkaew, K., and Murayam, Y., "Site Suitability Evaluation for Ecotourism Using GIS & AHP: A Case Study of Surat Thani Province, Thailand", Procedia - Social and Behavioral Sciences, Volume 21, pp. 269-278, 2011.

[8] Miller, W., Collins, M.G., Steiner, F.R., and Cook, E., "An Approach for Greenway Suitability Analysis", Landscape and Urban Planning, Volume 42, pp. 91-105, 1998.

[9] Chen, F., and Delaney, J., "Expert Knowledge Acquistion: A Methodlology for GIS Assisted Industrial Land Suitability Assessment", Urban Policy and Research, Volume 16, pp. 301-315, 1998.

[10] Fernández, I., and Ruiz, M.C., "Descriptive Model and Evaluation System to Locate Sustainable Industrial Areas", Journal of Cleaner Production, Volume 17, pp. 87-100, 2009.

[11] Ruiz, M.C., Romero, E., Pérez, M.A., and Fernández, I., "Development and Application of a Multi-Criteria Spatial Decision Support System for Planning Sustainable Industrial Areas in Northern Spain", Automation in Construction, Volume 22, pp. 320-333, 2012.

[12] Carr, M.H., and Zwick., P., "Using GIS Suitability Analysis to Identify Potential Future Land Use Conflicts in North Central Florida", Journal of Conservation Planning, Volume 1, pp. 58-73, 2005.

[13] Jafari, S., and Zaredar, N., "Land Suitability Analysis Using Multi Attribute Decision Making Approach", International Journal of Environmental Science and Development, Volume 1, pp. 441-445, 2010.

[14] Lotfi, S., Habibi, K., and Koohsari, M.J., "An Analysis of Urban Land Development Using Multi-Criteria Decision Model and Geographical Information System: A Case Study of Babolsar City", American Journal of Environmental Sciences, Volume 5 pp. 87-93, 2009.

[15] Tudes, S., and Yigiter, N.D., "Preparation of Land Use Planning Model Using GIS Based on AHP: Case Study Adana-Turkey", Buletinl Engineerin Geological Environmental, Volume 65, pp. 235-245, 2010.

[16] Feizizadehab, B., and Blaschkeb, T., "Land suitability analysis for Tabriz County, Iran a Multi-Criteria Evaluation Approach using GIS", Journal of Environmental Planning and Management, Volume 56, No. 1, pp. 1-23, 2013.

[17] Walke, N., Obi Reddy, G.P., Maji, A.K., and Thayalan, S., "GIS-Based Multicriteria Overlay Analysis in Soil-Suitability Evaluation for Cotton (Gossypium Supplementary): A Case Study in the Black Soil Region of Central India", Computers & Geosciences, Volume 41, pp. 108-118, 2012.

[18] Liu, Y., Lv, X., Qin, X., Guo, H., Yu, Y., and Wang, J., "An Integrated GIS-Based Analysis System for Land-Use Management of Lake Areas in Urban Fringe", Landscape and Urban Planning, Volume 82, pp. 233-246, 2007.

[19] Yang, F., Zeng, G., Du, C., Tang, L., Zhou, J., and Li, Z., "Spatial Analyzing System for Urban Land-Use Management Based on GIS and Multi-Criteria Assessment Modeling", Progress in Natural Science, Volume 18, pp. 1279-1284, 2008.

[20] Mendas, A., and Delali, A., "Integration of MultiCriteria Decision Analysis in GIS to Develop Land Suitability for Agriculture: Application to Durum Wheat Cultivation in the Region of Mleta in Algeria", Computers and Electronics in Agriculture, Volume 83, pp. 117-126, 2012.

[21] Store, R ., and Kangas, J., "Integrating Spatial Multi-Criteria Evaluation and Expert Knowledge for GIS-Based Habitat Suitability Modeling", Landscape and Urban Planning, Volume 55, pp. 79-93, 2001.

[22] Santé-Riveira, I., Crecente-Maseda, R., and Miranda-Barrós, D., "GIS-Based Planning Support System for Rural Land-Use Allocation", Computers and Electronics in Agriculture, Volume 63, pp. 257-273, 2008.

[23] Zhang, Y. J., Li, A.J., and Fung, T., "Using GIS and Multi-criteria Decision Analysis for Conflict Resolution in Land Use Planning", Procedia Environmental Sciences, Volume 13, pp. 2264-2273, 2012.

[24] Saaty, T.L., “The Analytic Hierarchy Process”, McGraw Hill, New York, 1980.

[25] Saaty, T.L., "How to Make a Decision: The Analytic Hierarchy Process", Interfaces, Volume 24, pp. 19-43, 1994.

[26] Saaty, T.L., "Decision-Making with the AHP: Why is the Principal Eigenvector Necessary?", European Journal of Operational Research, Volume 145, pp. 85-89, 2003.

[27] Chandio, I.A., Matori, N.B., WanYusof, K.B., Talpur, M.A.H., Balogun, A.L., and Lawal, D.U., "GIS-Based Analytic Hierarchy Process as a Multicriteria Decision Analysis Instrument: A Review", Arabian Journal of Geosciences, pp. 1-8, 2012.

[28] Malczewski, J., “GIS and Multicriteria Decision Analysis”, John Wiley and Sons, Inc, Cananda , 1999.

[29] Chandio, I.A., Matori, A.N., Lawal, D.U., and Sabri, S., "GIS-Based Land Suitability Analysis Using AHP for Public Parks Planning in Larkana City", Modern Applied Science, Volume 5, pp. 177-189, 2011.