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LAND SUITABILITY ASSESSMENT OF GREEN INFRASTRUCTURE DEVELOPMENT

A CASE STUDY OF PENDIK DISTRICT (TURKEY)

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ABSTRACT

Urban green space, an integral part of urban ecosystems, provides important environmental and social services that mitigate environmental problems caused by rapid urbanisation and urban sprawl. Urban planning and policy aim at optimising the benefits obtained from urban green spaces. The analytic hierarchy process (AHP) is a commonly used technique for suitability assessment of land uses. The traditional AHP method is criticised for its subjectivity and uncertainty. Considering this, Fuzzy-AHP has been introduced as an advanced methodology in dealing with the uncertainty in the decision making process. In this study, we compared the two methods of AHP and fuzzy-AHP integrated with Geographic Information Systems (GIS) for the suitability assessment of Pendik district, Istanbul regarding green space development. First, criteria and sub-criteria were determined and the corresponding weights were assigned based on literature and experts' knowledge. This is followed by preparation of spatial maps integrated with the corresponding weights and development of final suitability maps in both methods of AHP and fuzzy-AHP. Our results show that high suitability areas are mainly distributed in the southern part of Pendik district around the existing urban green infrastructure. In both maps obtained from AHP and fuzzy-AHP, more than 30 percent of the study area has the potential for green space development.

KEYWORDS:
Urban Green Space; Land Suitability Analysis; AHP; Fuzzy-AHP; GIS; Turkey

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开发绿色基础设施的土地适宜性评估

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摘要

城市绿色空间作为城市生态系统的一个组成部分，为我们提供了能缓解快速城镇化和城市扩张所带来的环境问题的重要环境和社会服务。城市规划和政策的目标，是对城市绿色空间创造的效益进行优化。层次分析法（AHP）是一项常用的土地利用适宜性评估技术。传统的AHP法因其主观性和不确定性而备受批判。考虑到这一点，我们引入了模糊层次分析法，作为处理决策过程不确定性的一种更高级的方法。本研究对比了两种方法：AHP法和模糊AHP与地理信息系统（GIS）相结合的方法，将其分别用于评估伊斯坦布尔彭蒂克区的绿色空间开发适宜性。首先，基于文献和专门知识，确定一级和二级准则，并指定相应的权重。然后，根据相应权重绘制空间地图，`并用AHP和模糊AHP法分别绘制最终的适宜性地图。我们的研究结果显示，适宜性较高的区域主要分布在彭蒂克南部现有城市绿色基础设施的周边地区。在通过AHP法和模糊AHP法分别制成的两个地图上，具有绿色空间开发潜能的研究地区都超过30%。

关键词:
城市绿色空间；土地适宜性分析；层次分析法；模糊层次分析法; 地理信息系统; 土耳其

1 INTRODUCTION

Since cities face with rapid urbanisation that is associated with urban sprawl and the decrease of urban green space, there is increased pressure on urban ecological environment. Urban green spaces, an important part of urban ecosystems, provide significant benefits that contribute to preservation of biodiversity and quality of life in urban areas (Sreetheran, 2017; Uy & Nakagoshi, 2008). Urban green spaces generally improve urban environmental conditions by regulating temperature and microclimates, sequestering CO_2, reducing air pollution and noise, maintaining diversity, and providing recreational and social values (Armson, Stringer & Ennos, 2013; Hamada & Ohta, 2010). Development of urban green spaces has become an integral part of any urban policy and city planning. Determining suitable locations for urban green infrastructure (UGI) development is therefore an important task to support urban policy and planning aimed at improving urban ecological environment (Li et al., 2018; Zhou & Wang, 2011).

Land suitability analysis specifies the degree of land usefulness for potential land development by land requirement and qualities (Malczewski, 2004). Multi-criteria evaluation (MCE) method that is integrated with Geographical Information System (GIS) has been increasingly used for land suitability analysis. MCE focuses on different criteria such as bio-physical, socio-economic and policy related factors in decision making process to assess different land problems considering the alternatives (Pramanik, 2016). GIS is a technique to investigate the geo-spatial data with great flexibility and high precision in the land suitability assessments (Malczewski, 2006). Therefore, the integrated methodology where the MCE method is integrated with GIS involves utilisation of geographical data and assessment of various criteria based on decision makers preferences and specified decision rules (Malczewski, 2004).

Analytic hierarchy process (AHP), first developed by Saaty (1980), is a multi-criteria decision making model that composes complex decision making problems of land management (Malczewski, 2006). In the traditional AHP, the weight of importance of different land uses is determined based on pairwise comparisons of different parameters considered in the analysis. AHP is criticised due to its inability to deal with complexity and uncertainty of the evaluation parameters. Regarding real world problems, some of the decision data can be precisely assessed while some others cannot. In Leung and Chao's (2000) explanation, the uncertainty in preference judgements give rise to uncertainty in the ranking of alternatives and difficulty in assessing consistency of the preferences. Fuzzy-AHP has been introduced as an advanced methodology in dealing with the uncertainty and vagueness of the mathematical terms developed in the decision making process. The current study focuses on comparison of the two MCE methods (i.e. AHP and fuzzy-AHP approaches) integrated with GIS to assess the suitable sites for urban green infrastructure (UGI) development in Pendik district which is located in eastern part of Istanbul, Turkey. Considering adverse impacts of rapid urbanisation and high rates of population growth observed in Pendik, it is vital to assess and plan suitable sites for green space development in the area.

2 METHODOLOGY

2.1 SPECIFICATIONS AND ASSESSMENT OF CRITERIA

To acquire suitable land for amenity-led growth, local environmental and socio-economic conditions are essential factors. Opportunities for UGI development are related to environmental features like geophysical limitations, topographical and climatic features, proximity to lakes and rivers, and attractive landscapes due to their aesthetic value (Van Berkel & Verburg, 2012). Physical features can become amenities through the provision of protected areas, and the construction of urban green facilities that are linked to local demand for recreation and leisure activities (Van Berkel et al., 2014). Transportation infrastructure that increases accessibility to amenities is also of great significance. Therefore, recent land-use/cover and other environmental and geophysical data are required for the identification of suitable amenity-led growth (Pramanik, 2016).

To identify the most suitable sites for green infrastructure development, the study focuses on 5 main criteria and 17 sub-criteria which were prepared as GIS-based layers. The selection of the criteria is based on a comprehensive literature review, expert opinions and specific conditions observed in the region (Tab. 1). The ranks of each criterion were determined based on the literature provided in the last column of Tab. 1 by using (1-7) scale. Weighting to sub-criteria was performed based on pair-wise comparison technique in AHP and using fuzzy-AHP values.

Weighting in analytic hierarchy process

As a decision analysis tool, AHP was first developed by Saaty (1980) for analysing complex decisions involving different criteria. In AHP, a matrix is generated as a result of pair-wise comparisons which help decision makers to assign different levels of importance of factors included in the analysis. The assigned ranks (1-7) indicate the strength and dominance of the criterion (Tab. 2). There are four steps for the calculation of weights in pair-wise comparison matrix (PCM) (Zolekar & Bhagat, 2015): (1) formation of judgements, (2) calculation of assigned ranks, (3) development of normalised pair-wise comparison matrix, and (4) calculation of weights. Accordingly, the cell values of PCM are divided by sum of each column and averaged across rows to calculate weights for each criterion. Consistency ratio (CR) is used for the determination of accuracy of the calculated weights (Saaty, 1980). In Saaty's (1980) explanation, the CR has the upper limit value of 0.10 implying that the values greater than 0.10 are inconsistent. In the present analysis, the CR is 0.07 therefore we concluded that there is no inconsistency of the judgements and the selected criteria are acceptable.

Weighting in fuzzy analytic hierarchy process

There is vast literature indicating that comparison ratios are imprecise judgements. According to Leung and Chao (2000), the fuzziness and vagueness in the preference judgements of decision makers in conventional AHP approaches leads to uncertainty in the ranking of alternatives, and causing difficulty in determining consistency of preferences. Fuzzy-AHP has been developed as an alternative to traditional AHP approach is considered as an advanced analytical method. According to fuzzy theory, any field X and theory Y can be fuzzified by replacing the concept of a crisp set in X and Y by that of a fuzzy set (Isabels & Uthra, 2012). A fuzzy set can be defined by assigning each individual in the universe of discourse a value representing its grade of membership in the fuzzy set. The fuzzy membership function is defined from X to [0,1].

Fuzzy-AHP is based on a series of pair-wise comparisons indicating the relative preferences of between pairs of criteria in the same hierarchy. Using triangular fuzzy values for the linguistic variables, the fuzzy pairwise comparison matrix $X = (x_{ij})$ is constructed. The ratio for the pair-wise comparisons indexed i and j can be modelled through a fuzzy scale value.

Each element of X is a fuzzy number defined as:

$$X = (x_{ij}(l_{ij}, m_{ij}, u_{ij}))$$

Where:

- l is the lower limit value;
- m is the most possible value;
- u is the upper limit value.

MAIN CRITERIA	SUB-CRITERIA	SCORE	REFERENCES
Geo-physical			
Slope (degree)	2-5	7	Li et al., 2018; Dagistanlı et al., 2018
	5-10	6	
	10-15	5	
	15-20	4	
	>20	3	
Elevation (m)	0-100	7	Bunruamkaew & Murayama, 2011
	100-300	4	
	>300	1	
Aspect	135-225	7	Mahdavi & Niknejad, 2014; Pramanik, 2016
	45-135	5	
	225-315	3	
	315-45	1	
Erosion risk	Very low or low	7	Dagistanlı et al., 2018; Piran et al., 2013
	Moderate	5	
	High	3	
	Very high	1	
Land capability	Hard rocks	7	Peng et al., 2016; Piran et al., 2013
	Rocks	6	
	Soft rock, very dense soil	5	
	Stiff soil	4	
	Soft soil	3	
	Others	1	
Accessibility			
Distance from highways (m)	<2000	7	Bunruamkaew & Murayama, 2011
	2000-5000	4	
	>5000	1	
Distance from roads (m)	<200	7	Yousefi et al., 2016
	200-300	6	
	300-400	5	
	400-500	4	
	500-600	3	
	600-700	2	
	>700	1	
Distance from bus stops (m)	<300	7	Yigitcanlar et al., 2007
	300-400	6	
	400-800	5	
	800-1000	4	
	1000-1200	3	
	>1200	2	
Distance from metro stop (m)	<600	7	El-Geneidy et al., 2014
	600-800	6	
	800-1000	5	
	1000-1200	4	
	1200-1400	3	
	>1400	2	
Blue and green infrastructure			
Distance from reservoir (m)	<250	7	Dagistanlı et al., 2018; Kienast et al., 2012
	250-500	6	
	500-750	5	
	750-1000	4	
	1000-1500	3	
	1500-2000	2	
	>2000	1	
Distance from water courses (m)	<50	7	Kienast et al., 2012; Li et al., 2018
	50-100	6	
	100-300	5	
	300-500	4	
	500-700	3	
	700-1000	2	
	>1000	1	
Distance from coastline	<50	7	Li et al., 2018
	50-100	6	
	100-300	5	
	300-500	4	
	500-1000	3	
	1000-2000	2	
	>2000	1	

MAIN CRITERIA	SUB-CRITERIA	SCORE	REFERENCES
Distance from urban green (m)	<100	7	Li et al., 2018; Morckel, 2017
	100-300	6	
	300-500	5	
	500-1000	4	
	1000-1500	3	
	1500-2000	2	
	>2000	1	
Urban land			
Distance from commercial centers (m)	<250	7	Malmir et al., 2016; Zhang et al., 2013
	250-500	6	
	500-1000	5	
	1000-1500	4	
	1500-2000	3	
	2000-2500	2	
	>2500	1	
Distance from high density residential centers (m)	<100	7	Dagistanlı et al., 2018; Yousefi et al., 2016
	100-150	6	
	150-200	5	
	200-250	4	
	250-300	3	
	300-400	2	
	>400	1	
Vegetation			
Land use/land cover	Natural vegetation	7	Li et al., 2018, Mahdavi & Niknejad, 2014
	Water bodies	6	
	Forest	4	
	Agricultural land	3	
	Urban land use/ cover	2	
Agricultural land suitability	Very high	6	Steiner et al., 2000
	High	5	
	Moderate	4	
	Low	3	
	Very low	2	

Tab. 1 Weights of the criteria and sub-criteria in the study

RELATIVE IMPORTANCE	DEGREE OF PREFERENCES
1	Equal
3	Moderate
5	Strong
7	Very strong
9	Extreme
2, 4, 6, 8	Intermediate
Reciprocals	Less importance

Tab. 2 The rating scale for pairwise comparison matrix. Source: Saaty, 1980

Given the fuzzy theory, the membership function is defined as follows:

$$\mu(x) = \{(x-l)/(m-l) \quad \text{if } l \leq x \leq m \qquad (1)$$

$$(u-x)/(u-m) \quad \text{if } m \leq x \leq u \qquad \text{Otherwise} \}$$

The pair-wise comparisons are described by values that are converted into the following scale given in Tab. 3 including triangular fuzzy numbers (Fig. 1) developed by Chang (1996). More details on fuzzy theory can be seen in Chang (1996).

TRIANGULAR FUZZY SCALE	FUZZY NUMBERS	DEFINITION
(1,1,1)		Equal (E)
(1/2,1, 3/2)	1	Equally important (EI)
(1, 3/2, 2)	3	Weak (W)
(3/2, 2, 5/2)	5	Fairly strong (FS)
(2, 5/2, 3)	7	Very strong (VS)
(5/2, 3, 7/2)	9	Absolutely more important (AI)

Tab. 3 Triangular Fuzzy values used in the study. Source: Mahdavi & Niknejad, 2014

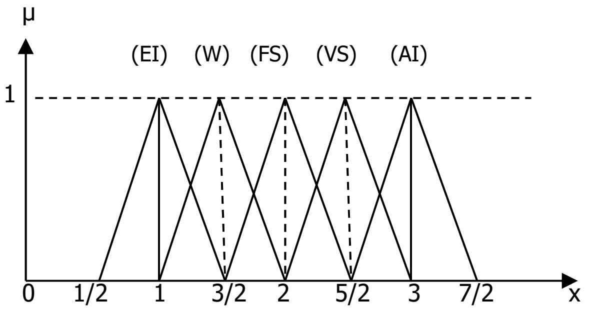

Fig. 1 Triangular fuzzy values representing the weight of each criterion. Source: Adopted from: Mahdavi & Niknejad, 2014

2.2 SUITABILITY EVALUATION

Following the development of final weights by AHP and fuzzy-AHP techniques, the suitability index was computed based on the sub-criteria considered in the analysis (Tab. 1). The suitability index was computed through weighted linear summation of different layers as shown in eq. (2).

$$S=\sum_{j=1}^{n} W_i R_{ji} \tag{2}$$

Where:

- S is the suitability score;
- n is the number of factors considered in the analysis;
- W_i is the weight of criterion i which was computed by using the AHP and fuzzy-AHP methods;
- R_{ji} is the value of pixel j in the map of sub-criterion i.

In our case, the value of the suitability score, S, ranges between 2 and 7 where a value close to 2 represents unsuitable land while 7 indicates extremely suitable. Arc GIS 10.4 model builder tool was used to develop a model of the green infrastructure suitability.

3 RESULTS

3.1 AHP AND FUZZY-AHP WEIGHTS

The weights of the sub-criteria obtained from the AHP and fuzzy-AHP methods are presented in Tab. 4. It can be noted that in AHP urban green infrastructure, current land use/cover and agricultural land suitability are the most effective criteria while physical attributes i.e. aspect, elevation and slope are the least effective ones. In fuzzy-AHP, urban green infrastructure, agricultural land suitability and land capability are associated with the highest weights; and similar to AHP, physical attributes are associated with the lowest weights. The ranks listed in Tab. 4 are relevant with the findings of the literature (Tab. 1).

CRITERIA	SUB-CRITERIA	AHP WEIGHTS	FUZZY AHP WEIGHTS
Geo-physical attributes	Aspect	0.021	0.016
	Elevation	0.02	0.011
	Slope	0.018	0.010
	Land capability	0.082	0.114
	Erosion risk	0.098	0.035
Accessibility	Distance from highways	0.03	0.029
	Distance from roads	0.028	0.023
	Distance from bus stops	0.044	0.056
	Distance from metro stops	0.039	0.052
Green and blue infrastructure	Distance from reservoirs	0.048	0.067
	Distance from coastline	0.047	0.064
	Distance from water bodies	0.048	0.067
	Distance from urban green areas	0.168	0.127
Urban land	Distance from industry/commerce	0.045	0.059
	Distance from high density residential areas	0.032	0.032
Vegetation	Current land use	0.12	0.113
	Agricultural land suitability	0.113	0.126

Tab. 4 Weights of sub-criteria for urban recreation land suitability evaluation

3.2 LAND SUITABILITY FOR GREEN INFRASTRUCTURE DEVELOPMENT

According to each criterion considered in the analysis, a map was prepared using the GIS software. Each GIS layer was classified following the classification of the related criterion provided in Tab. 1 and these are presented in Fig. 2. As described in Tab. 1, the highest suitability value is assigned for the most suitable class. For instance, in the case of slope, the slope lower than 5 is assigned with the highest suitability value. The maps in Fig. 2 were integrated using the corresponding weights with the application of weighted linear combination technique (eq. 2). Regarding final suitability, two different suitability maps were developed using the AHP and fuzzy-AHP methods. The suitability maps are provided in Fig. 3.

The results indicate that according to the AHP method, 2% of the area is highly suitable, around 15% is moderately suitable; 19% is marginally suitable and the rest has either low or very low suitability (Tab. 5; Fig. 3a). There is no high suitability class in the map produced from fuzzy-AHP method. Moderate suitability is 10% and marginal suitability is around 23% and the rest is lowly suitable for green infrastructure development (Tab. 5; Fig. 3b).

The results show that about 89% of pixels of the two maps were classified similarly. The results also indicate that more than half of the total area is classified as low suitability or very low suitability in both of the maps presented in Fig. 3. Around 35% of the total land is classified as suitable and these are mostly located in the southern part of the Pendik Region.

4 DISCUSSION AND CONCLUSION

In this study, land suitability for urban green infrastructure was assessed using AHP and fuzzy-AHP methods integrated with GIS. Seventeen factors including geo-physical characteristics, accessibility, blue and green infrastructure, urban land and vegetation were selected for the land suitability analysis. The weights of each sub-criterion were determined by using AHP and fuzzy-AHP methods separately. Two different land suitability indexes were calculated using the weighted additive combination model. Our findings from the suitability analysis are in line with the actual green infrastructure map in that main part of green infrastructure are located in highly and moderately suitable sites.

AHP is an example of multi-criteria decision making methodology that has been effectively used in multiple criteria problem solving and decision making. Decision making problems may contain socio-economic, physical and political factors requiring linguistic variables for multi-criteria decision assessment. In traditional AHP approach, numerical values of linguistic variables are used for the assessment of the subject criteria included in the analysis. The fuzziness and vagueness in the decision making process requires the use of fuzzy values.

Therefore, besides traditional AHP, we also used fuzzy-AHP approach for weighting the criteria that explain green infrastructure suitability in Pendik district. The study, in fact, evaluates and compares the results obtained from suitability analysis using AHP and fuzzy-AHP approaches. The AHP method had advantages and limitations: The method is flexible and can be integrated with different techniques such as linear programming, fuzzy logic etc. This makes it easier for the users to benefit from extensive options and achive the desired goals by more efficient means. However, there is a drawback of the methodology as it requires a questionnaire survey and expert opinions to conduct the measurement of the relative weights which makes the method more time consuming regarding the technical applications.

Further limitations of the method include insufficient knowledge for the area of interest, the reproducibility of the results and subjectivity of the weighting of the variables (Park et al., 2011). As described by Park et al. (2011) and Xu et al. (2011), there are alternative methods for the suitability assessment of land use development including frequency ratio (FR) model, logistic regression (LR), artificial neural network (ANN), and back-propagation neural network (BPNN) model. The FR model is simple as the calculation process and the inputs are easy to understand and the significance of factors explaining land use growth can be easily interpreted. The method is less time consuming in technical applications. The LR approach makes it possible to analyze the relationship between land use growth and its determinants quantitatively. To constract the underlying statistical relationship, the data in GIS environment needs to be converted to comply with the needs of the statistical program. The existence of big data may limit the performance of the statistical programme as it may not work well.

The ANN and BPNN models provide an improvement over the LR model as they make it possible to have more accurate analysis with a few training dataset. However, the models have some drawbacks such as difficulty in understanding the computation process, and the long calculation times and big volumes of calculation, which makes it less suitable for technical applications. Given this framework on the applications of alternative methodologies in UGI suitability assessment, we suggest the application of these methodologies using our structured data as a future research. This will allow us to compare the results of this work with those obtained from alternative approaches. From our findings we note that despite the differences in the methodology used for weighting the criteria, there is little difference in the weights obtained from AHP and fuzzy-AHP. Urban green infrastructure, agricultural suitability, current land use/cover and land capability were assigned with the highest weights whereas physical characteristics indicated the lowest weights. Overall, the weights of urban green infrastructure, agricultural land suitability, current land-use/cover and land capability accounted for almost half of the total weights assigned to sub-criteria. This has influenced the final suitability maps in that there is little difference in the suitability classifications obtained from AHP and fuzzy-AHP approaches. The results indicated that there is almost 90% coincidence regarding the suitability classes of the two maps of AHP and fuzzy-AHP. In the AHP, moderate and marginal suitability classes cover more than 40% of the area whereas using the fuzzy-AHP approach the study area results to be less suitable for green infrastructure development. According to the two maps produced, the southern part of the study area, along the existing urban green infrastructure corridor, is found suitable for future land development.

The site suitability maps obtained in this study are effective in assessing green infrastructure potential of the study area; and therefore can be utilised by local authorities and planners in their decision making and planning for the future site developments. Considering that there are small differences in the criteria weights obtained from AHP and fuzzy-AHP, for easiness of computation, we recommend using the AHP approach for the suitability assessment of green infrastructure development in Pendik district.

If the difference is higher concerning the AHP and fuzzy-AHP weights resulting in considerable differences in the suitability classifications in the maps, the use of fuzzy-AHP is recommended. Determination and assessment of the criteria for land suitability analysis can be affected from the differences observed between the evaluators e.g. experts, planners, policy makers and their characteristics. For instance, a pessimistic evaluator may not give any point more than five to assess a criterion; by contrast others may give more than five even though it is irrelevant. This implies that there is fuzziness in the decision making process and fuzzy-AHP method can be effectively used to deal with the issue of fuzziness. Therefore, the proposed methodology of fuzzy-AHP is promising for land suitability assessment not only for green land development but also for other land uses. Apart from the weightings we applied in the AHP process, there are different approaches for the application of weightings and overlaying of GIS layers for developing the suitability map and we suggest to use them in the future research to compare the findings from current study. These include: Boolean overlay, Weighted Linear Combination (WLC) and Ordered Weighted Avaraging (OWA). According to the Boolean method, all the criteria are combined by logical operators such as intersection (and) or union (or) to produce discreate Boolean maps. WLC is an aggregation method where the factors are standardised to a common numeric range and then combined by weighted averaging.

The OWA method involves two different sets of weights: criterion imporatance weights and order weights. Through changing the order weights, it provides flexibility to develop a complete range of decision support maps (including cases of Boolean approach and WLC) and large variety of decision strategies (Romano et al., 2015). The details of these three approaches are provided in Romano et al. (2015).

The application and implementation of suitability analysis for the UGI development is important for the preservation of ecosystems and their functions as well as the structure of the landscape. It is therefore vital to construct such a conceptual framework and to have analysis of quantitative research to be performed for each individual green space in our case study area. As argued by Hobbs and Saunders (1990), preserving individual green space is a temporary solution and without continuity and connectivity of green spaces through the creation of corridors and urban greenways, isolation and loss of genetic diversity is inevitable.

This has not been considered in the current plans and applications in our case study area which resulted in green spaces be more fragmented and isolated. This would lead to reduction in green spaces and the quality of ecosystem services where urban environmental issues will become more serious.

The combination of different green spaces to construct a green space network is therefore highly significant in the UGI planning considering that it is difficult to use one or few of the green spaces to maintain all the benefits of greening in urban areas (Uy & Nakagoshi, 2008). Such comprehensive green space framework can constract a theoratical basis for the practices and applications of organising UGI at different scales aiming at supporting a number of key landscape ecology requirements in our study area.

		SUITABLE AREAS (USING AHP)			SUITABLE AREAS (USING FUZZY-AHP)		
SUITABILITY	SUITABILITY SCORE	TOTAL PIXELS	AREA (sq. KM)	AREA (%)	TOTAL PIXELS	AREA (sq. KM)	AREA (%)
Very low	2	44309	39.88	22.41	38798	34.92	19.62
↓	3	87475	78.73	44.24	94532	85.08	47.81
	4	37066	33.36	18.75	44608	40.15	22.56
	5	28843	25.96	14.59	19775	17.80	10.00
High	6	20	0.02	0.01	0	0	0

Tab. 5 The area and percentage of different suitability classes developed from AHP and fuzzy-AHP methods

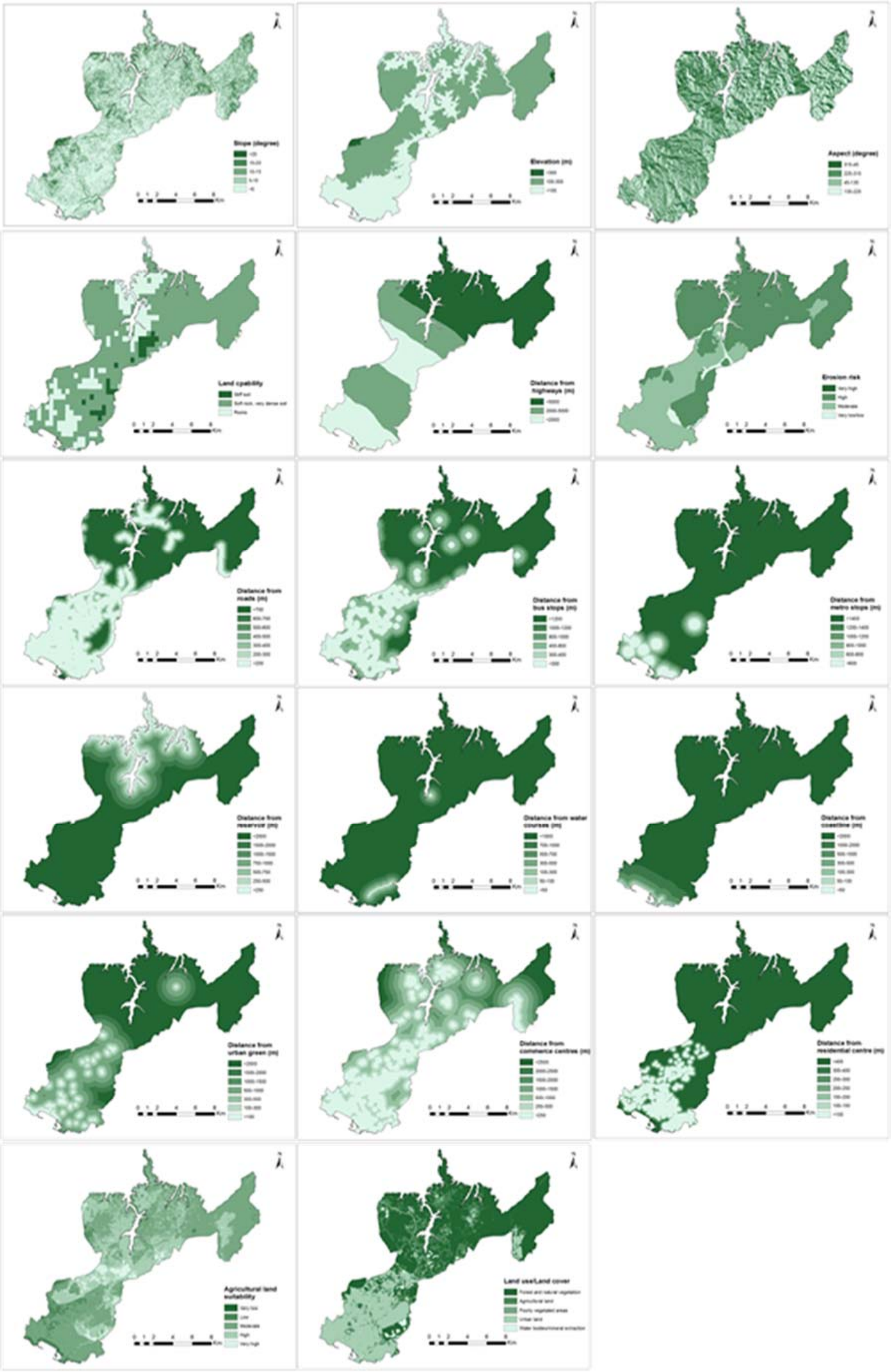

Fig. 2 Suitability value maps for each criterion

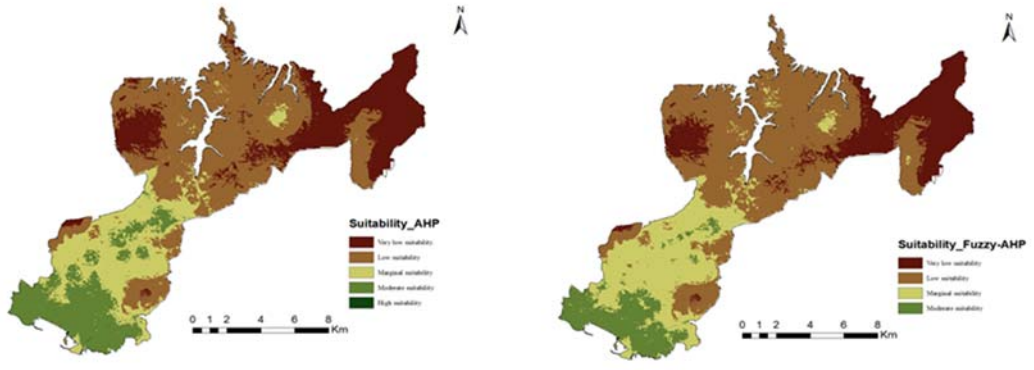

Fig. 3 Suitability maps AHP (a) left; Suitability maps Fuzzy-AHP (b) right

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