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An Assessment of Land Use/Cover Suitable for Peri-urban Green Space Development: an Example of an Integration of GIS with the Multi-Criteria Analysis (MCA) Approach

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Abstract

Land allocation priorities to urban green cover are usually neglected particularly in the countries of developing economies such as Turkey. Lack of urban green space can cause many social and physical problems among the residents. Therefore, urban planning and policy should incorporate suitable green land in the urban planning of cities to optimise the benefits obtained from urban green spaces. Land suitability analysis is a commonly used methodology which provides a framework for developing strategies in the planning of green land development. Two different approaches will be utilised for the assessment of suitability of land uses for urban agriculture, forest and natural vegetation in the Pendik district of Istanbul. Standardisation of values in criteria maps was done using the deterministic approach in the first case whereas fuzzy membership was utilised as an alternative in the second case. Analytical Hierarchical Process (AHP) was used for the weighting of sub-criteria and map layers were overlaid using the weighted linear combination using the GIS software. Geophysical factors, transport and services accessibility, land cover/use, blue and green amenities, soil properties, geology and erosion susceptibility are the main criteria selected for the assessment of urban green land suitability. The provision of suitable land for urban agriculture, forest and natural vegetation uses will provide a framework to the land use planning and decision support aimed at contributing to urban sustainable development.

Keywords: Land suitability analysis, Agricultural land, Natural Vegetation, Forest, AHP, GIS

1. Introduction

The unprecedented growth of population and rapid urbanisation observed in many cities and regions in the world have caused serious environmental problems including climatic and ecological changes in the ecosystems, loss of high value agriculture lands, adverse impacts on biodiversity, land degradation, soil erosion and others (Steinfeld et al., 2006; Hasnat et al., 2018). Urban green land contributes to environmental and social services to alleviate the environmental problems caused by urbanisation and sprawled patterns of development (Gavrilidis et al., 2019). In particular, agriculture and forest uses are important in supporting agricultural production and maintaining air and water quality, reducing greenhouse gas emissions, preserving ecosystems and ensuring food quality (Ennaji et al., 2018). The development of agricultural activities and management of forest resources are necessary for the protection and conservation of natural resources, which would enhance the socio-economic well-being of local villagers (Pramanik, 2016). Therefore, an effective assessment of urban green land suitability is a decisive approach in conservation and restoration of urban ecosystems and services to both sustain benefits from urban green spaces and ensure food security.

Land suitability analysis is conducted to encounter potential capabilities and suitability for different objectives (Pramanik, 2016). Multi-criteria analysis is the mostly applied methodology for the land suitability analysis. Multi-criteria assessment (MCA) of land suitability is based on different criteria such as geo-physical elements as well as economic and socio-cultural factors are included in the analysis to support the decision making process and to solve different land problems with multiple alternatives (Yu et al., 2011; Shakya et al., 2019). Geographic Information Systems (GIS) integrated with MCA allowed using information from different data to identify the most appropriate spatial pattern with precision and higher flexibility (Adham et al., 2016). This integrated approach allows solving highly complex problems of land management with best alternatives. It is therefore used extensively in the literature for identifying the suitable lands for urban development (Xu et al., 2011; Ustaoglu and Aydınoglu, 2020a), agriculture (Mendas and Delali, 2012; Tadesse et al., 2020), urban green land (Uy and Nakagoshi, 2008; Li et al., 2018), afforestation (Hanell and Magnusson, 2005;

Nurda et al., 2020), and watershed management (Reshmidevi et al., 2009; Kadam et al., 2021).

The analytic hierarchy process (AHP) is a multi-attribute technique that is incorporated into the GIS-based procedures for assessing land suitability. AHP is used to determine the weights of influence in a given land use based on pairwise comparisons of parameters according to their relative importance (Saaty, 2000). AHP was firstly developed by Saaty (1980) aiming to establish a hierarchical model in solving complex problems of land management. AHP has been widely used in a variety of problems where complex parameters exist across various levels interacting with each other. Pramanik (2016) used AHP in a GIS environment with the aim of choosing the most suitable locations for agricultural land use. Qiu et al. (2017) focused on AHP and GIS techniques that were integrated into the evaluation models to create land use suitability map for livestock development planning. In another study in which GIS, AHP and fuzzy-AHP were integrated, Ustaoglu and Aydınoglu (2020a) developed a model for evaluating land use suitability for urban development. Barakat et al. (2017) is another example that used Boolean and AHP based standardisation in GIS environment for the landfill site selection problem. Aydi et al. (2013), Zolekar and Bhagat (2015), Ramya and Devadas (2019), Tashayo et al. (2020), Orhan (2021) are the other examples that are based on the combination of AHP and GIS techniques. Also GIS (Uy and Nakagoshi, 2008; Mendas and Delali, 2012) and fuzzy set (Giardano and Riedel, 2008; Keshavarzi, 2010) have been explicitly applied in land suitability studies. However, in these studies GIS and fuzzy set were applied alone resulting in poorly calculated suitability values and imprecise judgements resulting from poor outcomes. Hence, an integrated method of AHP, fuzzy set and GIS techniques is an enhanced approach to improve the accuracy of land suitability evaluation for particular land uses. There are few studies in the literature which incorporated this integrated method in the assessment of suitability for urban green land development. Romano et al. (2015), Aliani et al. (2017), and Ustaoglu and Aydınoglu (2020b) are few exceptions.

The main aim of the study was to identify suitable locations for the peri-urban agriculture, natural vegetation and forest development in Pendik district that is located in eastern Istanbul, Turkey. This study complements the prior work undertaken by Ustaoglu and Aydınoglu (2020b) that focused on evaluation of suitable land for urban recreation development. The land uses covered in the current study are peri-urban agricultural landscapes that are mainly located in the northern Pendik district where there are small villages scattered in the region’s rural part. By contrast, the land evaluated in Ustaoglu and Aydınoglu (2020b) is the urban recreation uses that are located in the vicinity of urban land in the southern part of Pendik district. In the current study, the combination of GIS, fuzzy-set and AHP were used and an integrated model was developed which allowed analysing and ranking of land suitability in a hierarchical structure. The model with the fuzzy set is compared with the conventional method where land suitability classification is based on a traditional Boolean approach. In both models, ArcGIS was used to analyse the spatial data and AHP to determine criteria weights, which were aggregated using the linear weighting method. Based on the differences in criteria classification (i.e. conventional vs. fuzzy set methods), the study compared the spatial extent of the suitable areas for peri-urban green land development suggested by both methods. The main reason for selecting Pendik district as a study area is that the district is part of Istanbul Metropolitan Region, and unlike many other Istanbul districts; it contains abundance of greenfield land in the northern part whereas urban land is located in the southern part. Pendik district has been growing due to natural forces and migration given its labour market potential in commercial and industrial sectors as well as it houses a port and the second international airport of Istanbul.

2. Materials and methods

2.1. Study area and data

Pendik district is mainly a plain district located in the eastern part of Istanbul. The district is located between the north latitudes 40°52′38′′ and the east longitudes 29°15′27′′ (Figure 1). The study site covers an area of about 180 km^2 in which there are 36 neighbourhood areas. It is surrounded by Şile in the North, Kartal-Sultanbeyli in the West, Tuzla in the East, and Marmara Sea in the South. The Mediterranean climate is the dominant climate in the district with cool winters and warm to hot summers. Total population of Pendik district is around 726,000 as per 2020 census and population density is ranging from 34,207 to 17.2 inhabitants per square kilometre, the former represents the high density urban area while the latter is the low density rural area. Residential, industrial/commercial uses, port and airport are the main land uses observed in the southern part. In the northern part, there are five villages located in Göçbeyli, Ballıca, Kurna, Emirli and Kurtdogmuş neighbourhoods, and agriculture is considered as the main occupation of the inhabitants. The rural land uses include agriculture (770 Ha), natural vegetation (550 Ha) and residual and primary forests (5300 Ha). Wheat, barley, oat, fruits, vegetables and animal products are the main sources of income for the rural inhabitants.

The spatial analysis and map processing were performed using the ArcGIS 10.4 software. The land use data that was used as one of the factors effecting suitability was obtained from Copernicus Urban Atlas database for the year 2012 (EEA, 2018). The digital elevation model (DEM) dataset (30m resolution), transportation map, land capability and administrative boundary

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maps were obtained from the database of Municipality of Pendik. The spatial data for slope and elevation were developed from DEM dataset using the ArcGIS software.

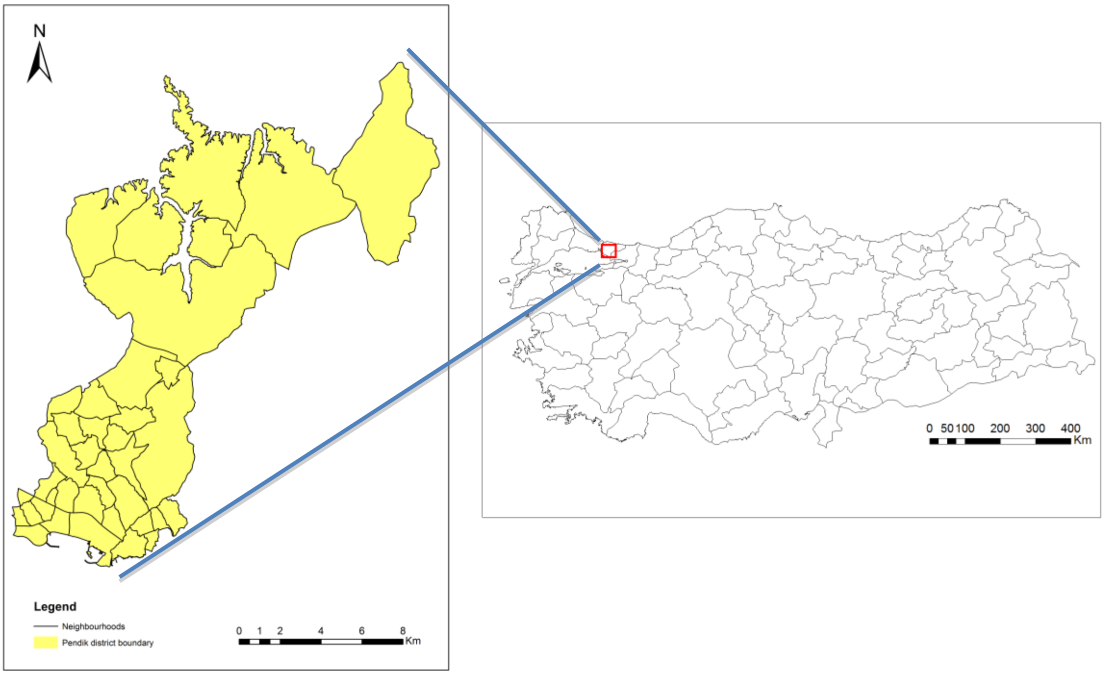

Fig. 1. The study area of Pendik district, Istanbul, Turkey

2.2. Methods

2.2.1. The selected criteria for suitability assessment

In this study, multi-criteria land suitability modelling was developed to find and evaluate potential locations for peri-urban green land development based on a group of constraints and criteria. Depending on their importance in the greenfield development, fifteen different criteria were selected (Table 1). Elevation, slope and aspect are considered as physical factors (Fig.1a, b, c). Elevation is a significant factor that causes temperature changes, particularly in highlands. Aspect indicates southern and eastern orientations that are exposed to sunlight and heat; and slope is an important landscape metric that influences the distribution of soil qualities. Thin soils are found on steep slopes with high level of erosion whereas deep soils are at gentle slopes located at the bottom of valleys and foothill zones. Land use/cover of the region can give an idea about the present status of land use (Fig.1d). Land use/cover indicates the spatial distribution and characteristics of land such as agricultural land, plantations, buildings, fallow land, bare land, mixed trees, forest, wetlands and water bodies. Thapa and Murayama (2008), Zolekar and Bhagat (2015), Pramanik (2016), Ustaoglu and Aydınoglu (2020a, b) are examples that used land use/cover classification for land suitability analysis.

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Water sources are essential for the development of agriculture, natural vegetation and forests; and hence these are included in many studies that focus on suitability analysis of agricultural landscape (Fig.1e, f). Distance to fast and slow roads is important criteria given that a good road network provides access to backward regions to trade and investment and contributes to economic growth (Fig.1g, h). Transport infrastructure is at the centre of food supply chains because a good transport infrastructure enables the small-scale producers to obtain essential inputs and get their products to the market. Physical proximity to the market zone and urban centers are also important factors that support agricultural development (Fig.1i, j). Therefore, both transport accessibility and physical distance to markets and population centers were included in the analysis. Soil layer is the main source of water and nutrients to plants (Fig.1l). Soil qualities, plant growth and agricultural productivity vary according to soil depth. For instance, the agricultural productivity is high in soils with an effective depth of around 100cm, which can be classified as deep soils (Li et al., 2017). Fallow lands and dense forest are classified into soil classes of moderate and marginal depth, respectively (Zolekar and Bhagat, 2015).

Soil erosion removes fertile topsoil, which is rich in physical, chemical and biological properties particularly in hilly zones. Higher elevation results in higher erosion due to steep slopes and high rainfall. Soil erosion is a risk factor for agricultural production; therefore it should be included in the agricultural land suitability analysis (Fig.1o). Soil drainage is related to the capability of soil to drain excess water which cause inadequate supply of oxygen for root respiration and retention of carbon dioxide produced from respiration. This may influence the growth of plants or even cause death of plants. For these reasons, soil drainage was also included in the land suitability analysis (Fig.1n). Finally, the correlation between lithology and agricultural uses was checked, and found that Polonezköy, Ömerli, and Kartal formations (see Table 1 notes) are the most suitable for agricultural land development. Therefore, lithological formations were considered as a relevant factor which may influence land use suitability (Fig.1k).

Table 1. Selected criteria for urban green space development analysis

Main criteria	Sub-criteria	Score	References
Slope	0-1	7	Zolekar and Bhagat (2015); Yalew et al. (2016); Pilevar et al. (2020)
	1-3	7	
	3-6	6	
	6-12	5	
	12-20	4	
	20-30	3	
	>30	2	
Elevation (m)	0-15	7	
	15-150	5	

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	150-250	3	Pramanik (2016); Yalew et al. (2016);
	250-350	2	Pilevar et al. (2020)
	>350	1	
Aspect	SW	7	Maleki et al. (2017);
	S, SE	6	Pramanik (2016);
	E, W	5	Akıncı et al. (2013)
	NW, NE	3	
	N	1	
Land-use/cover	Arable land (annual crops)	7	Zolekar and Bhagat (2015); Pramanik (2016); Thapa and Murayama (2008)
	Permanent crops	7	
	Pastures	6	
	Herbaceous vegetation	5	
	Isolated structures	4	
	Open spaces with little or no vegetation	3	
	Forests	2	
	Water bodies	1	
	Urban land	1	
Distance from water courses (km)	0-0.3	7	Pramanik (2016); Thapa and Murayama (2008)
	0.3-0.6	6	
	0.6-1.0	5	
	1.0-2.0	4	
	2.0-3.0	3	
	>3.0	1	
Distance from reservoir (km)	0-0.5	7	Thapa and Murayama (2008)
	0.5-1.0	6	
	1.0-2.0	5	
	2.0-3.0	4	
	>3.0	3	
Distance from fast roads (km)	0-1.0	7	Pramanik (2016)
	1.0-2.0	6	
	2.0-4.0	5	
	4.0-8.0	3	
	>8.0	1	
Distance from slow roads (km)	0-0.3	7	Romano et al. (2015)
	0.3-0.6	6	
	0.6-1.0	5	
	1.0-2.0	4	
	2.0-3.0	3	
	>3.0	1	
Distance from market zone (km)	0-5	7	Thapa and Murayama (2008); Yalew et al. (2016)
	5-10	6	
	10-20	5	
	20-30	3	

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	>30	1	
Distance from urban dwellings (km)	0-5	7	Maddahi et al. (2014); Romano et al. (2015)
	5-10	6	
	10-20	5	
	20-30	3	
	>30	1	
Geology	Opk, Tö	7	Özgül (2012)
	Dk	6	
	Qal, Qyd	5	
	Osys,Osyg	4	
	SDp, DCd, Oa	3	
	Ct	2	
	Others	1	
	>30	1	

Table 1 (cont.)

Main criteria	Sub-criteria	Score	References
Soil depth (cm)	>90	7	Yalew et al. (2016); Nguyen et al. (2015)
	90-50	6	
	50-20	5	
	<20	4	
Agricultural land use capability	I-II-III-IV (suitable for arable land)	7	Yalew et al. (2016)
	V-VI-VII (unsuitable for arable land)	4	
	VIII (unsuitable for agriculture)	1	
Other soil properties	Low stoniness-good drainage	7	Maleki et al. (2017); Yalew et al. (2016); Akıncı et al. (2013)
	Surface stoniness	3	
	Poor drainage	2	
	Very poor drainage	1	
Erosion susceptibility	Very low or low	7	Nguyen et al. (2015); Akıncı et al. (2013)
	Moderate	5	
	High	3	
	Very High	1	

Note: Description of geology: Opk (Polonezköy formation): siltstone, sandstone, conglomerate; Tö (Ömerli formation): post-tectonic deposits; Dpk (Kartal formation): micaceous shale, siltstone, limestone and shaley limestone; Qal, Qyd, OSys: superficial deposits; (Yayalar formation): feldspathic quartz-arenite, quartz-wacke; OSyg (Yayalar formation): sandstone and siltstone; SDp (Pelitli formation): limestone, limestone with shale, reefal limestone, marn, sandstone; DCd (Denizli formation): limestone and shaley limestone, lydite-shale, nodular limestone, iydite, radiolarian; OSa (Aydos formation): quartzite, conglomerate, mudstone and shale; Ct (Trakya formation): sandstone, siltstone, shale, limestone

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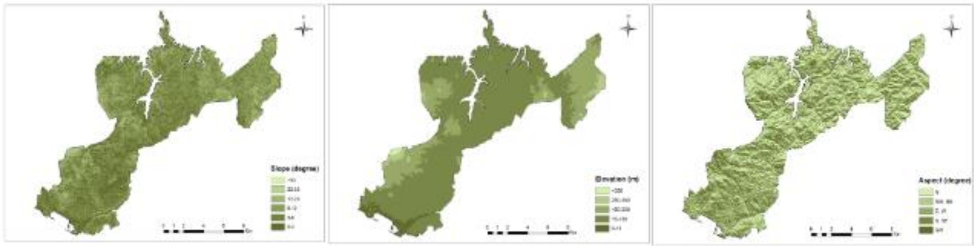
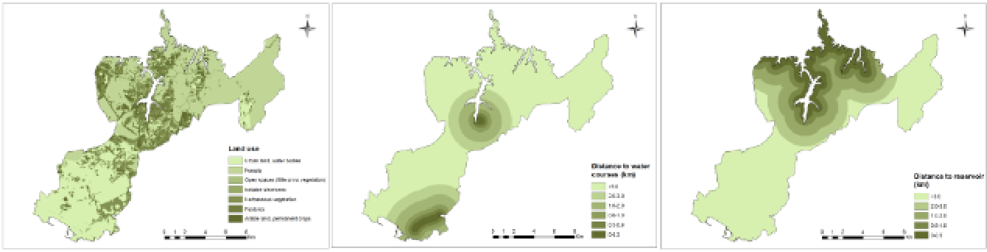
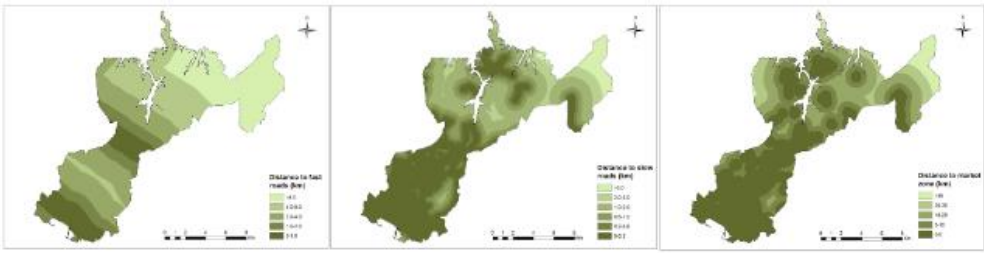


(a) Slope (degree) (b) Elevation (m) (c) Aspect (degree)

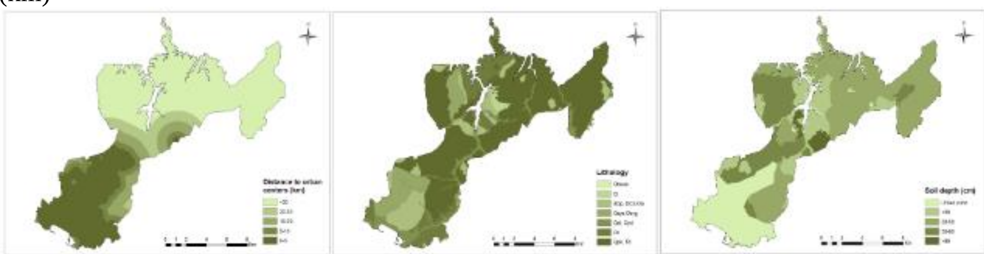


(d) Land use (e) Distance to water courses (km) (f) Distance to reservoir (km)

Fig.1. Standardised maps used for the urban green space suitability analysis for Pendik, Istanbul



(g) Distance to fast roads (km) (h) Distance to slow roads (km) (i) Distance to market zone (km)



(j) Distance to urban centers (km) (k) Lithology (l) Soil depth (cm)

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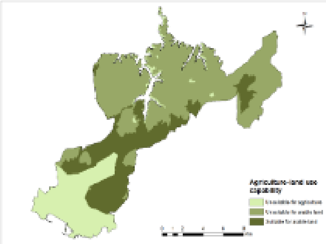
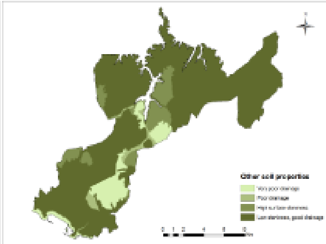
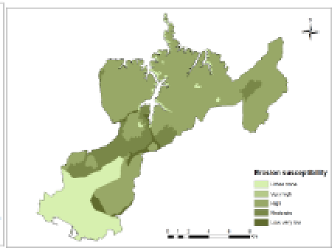

(m) Agricultural capability


(n) Other soil properties


(o) Erosion susceptibility

2.2.2. Suitability classification of criteria

Spatial modelling of land suitability was carried out in a GIS environment. The analysis was initiated by locating the suitable and unsuitable zones for the location of urban green space in each of the thematic maps by assigning the highest suitability value of 7 if the condition set for the corresponding criterion was satisfied and a value between 6 and 1, the latter representing the lowest suitability value, if the opposite applied. As an example, the land having a slope of 0 to 3 degrees was assigned with a value of 7 and the other slope intervals were given a value between 6 and 1. Since there is no single standard for rating the criteria, review of literature was considered for the standardisation of the selected criteria (see the last two columns of Table 1). The result of this process is a series of numeric maps that the Boolean logic was applied to. The Boolean logic model gives equal weight to the same numeric terms in the maps, for instance, the attributes that are assigned with 7 are considered as being equally relevant in determining land suitability for green space development. The criteria maps described in Table 1 were combined using the Boolean Operator OR, which maps overlapping information of the suitability scales.

Table 2. The evaluation criteria for urban green land with fuzzy membership function

Main criteria	Sub-criteria	Lower limit	Upper limit	Agriculture	Natural vegetation	Forest	Type of fuzzy membership function
Physical attributes	Slope	0	39.5	√	√	√	Monotonically decreasing linear
	Elevation	0	536	√			Monotonically decreasing linear
	Aspect	-1	359.5	√			Symmetric Gaussian
	Fast roads	0	17,166	√			Inverted sigmoid
Accessibility	Slow roads	0	6833.9	√			Inverted sigmoid
	Reservoirs	0	14,639	√	√	√	Inverted sigmoid
Water resources	Water bodies	0	14,844	√			Inverted sigmoid
Urban land and vegetation	Market zone	0	6595.9	√			Inverted sigmoid
	Residential dwellings	0	13,853	√			Inverted sigmoid
	Land use/cover	-	-	√	√	√	Inverted sigmoid
Geology	Erosion risk	1	7	√	√	√	Monotonically decreasing linear
	Geology	1	7	√			Monotonically decreasing linear
	Soil depth	1	7	√		√	Monotonically decreasing linear
	Soil limiting factors	1	7	√	√		Monotonically decreasing linear
	Land capability	4	6	√	√	√	Monotonically decreasing linear

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Fuzzy logic is different from the Boolean model given that it allows objects or elements to belong partially to multiple sets and have intermediate values. Fuzzy logic was first introduced by Zadeh (1965), which claimed that the objects do not have a rigid boundary and thus there is a gradual transition from zero to unity membership. These sets are named as fuzzy sets and the elements of these sets have membership values between 0 (non-membership) and 1 (full membership). A fuzzy set can be defined as:

$$A = \left\{ x, \mu_A(x) \right\} \quad for \quad each \quad x \in X \tag{1}$$

where $\mu_A(x)$ is the membership function that defines the grade of membership of x in A. The value of $\mu_A(x)$ ranges between 0 and 1 for all A. If $X=\{x_1, x_2,\ldots,x_n\}$, A can be defined as

$$A = \left\{ \left[x_1, \mu_A(x_1) \right] + \left[x_2, \mu_A(x_2) \right] + \ldots + \left[x_n, \mu_A(x_n) \right] \right\} \tag{2}$$

The membership function μ_A is defined as $x \rightarrow [0,1]$ with each element x belonging to X with a grade of membership $\mu_A(x) \in [0,1]$. This implies that when $\mu_A=0$, the value of x does not belong to A and when $\mu_A=1$, it completely belongs to A. Alternatively, $0<\mu_A(x)<1$ implies that x belongs to a certain degree to A.

Fuzzy membership values reflect both the relative importance of each criterion map, as well as the relative importance of each class in a single map. There are no practical constraints on the choice of the fuzzy membership values; therefore membership functions can take any shape and can be non-continuous or non-linear, symmetrical or asymmetrical. In practical applications, triangular, Gaussian, sigmoid, inverted sigmoid and linear functions are generally used. In the present study, Gaussian function was used when suitability value increases with the increasing value of the criterion, and after reaching the maximum value, suitability decreases with the increasing value of the criterion. Inverted sigmoid and monotonically decreasing linear functions were considered when suitability decreases with increasing value of a criterion. Table 2 presents the criteria, sub-criteria, control points, and fuzzy membership functions used for the corresponding criteria. The details of the fuzzy membership functions can be seen in Ustaoglu and Aydınoglu (2020b).

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2.2.3. Analytical hierarchy process

The AHP is one of the most widely used multi-criteria methods for quantifying the comparison of the decision criteria in a pairwise technique. The pairwise comparison matrix is based on forming judgements between two criteria and aim to prioritise entire list of parameters (Saaty, 1997). The pairwise comparison analysis assists decision makers to assign different levels of importance to the factors involved in the land suitability model. In the AHP method, the first step is to construct a hierarchical model consisting of objectives, criteria, sub-criteria, and alternatives (Saaty, 1990). The second step is to assign the relative importance of factors based on Saaty's scale (Saaty, 1980) and construct the pairwise comparison matrix. The scale ranges from 1 to 9 where 9 indicates the extreme importance and 1 indicates equal importance between two criteria in the pairwise comparison matrix (Table 3). The pairwise comparison matrix in the current study was developed using the relevant literature provided in the last column of Table 1 and also taking into account the expert views who expressed their opinions on the subject criteria, using the continuous rating scale given in Table 3. Next, the degree of consistency of pairwise comparisons should be checked, which is based on a consistency ratio (CR) index indicating the probability that the matrix ratings are randomly generated. The CR index is given as in eq. (3)

$$CR = \frac{\lambda_{\max} - n}{(n-1)RI} \tag{3}$$

where λ_{max} is the largest or principal eigenvalue of the pairwise comparison matrix, n is the order of the matrix, and RI is the average of resulting consistency index depending on the order n. A standard threshold value of 0.10 was adopted in the literature regarding the AHP applications. Accordingly, the CR index equal to or less than 0.10 indicates a significant level of consistency (Saaty, 1980). The CR index greater than 0.10 is deemed to lack of consistency; and therefore the matrix needs to be re-adjusted. In this study, the consistency ratio regarding agricultural land use was 0.093, natural vegetation was 0.061 and forest use was 0.072, which indicated that pairwise comparison matrices were consistent.

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Table 3. The rating scale for pairwise comparison matrix

Relative importance	Degree of preferences
1	Equal
3	Moderate
5	Strong
7	Very strong
9	Extreme
2, 4, 6, 8	Intermediate
Reciprocals	Less importance

1/9 1/7 1/5 1/3 1 3 5 7 9

← →

less importance more

2.2.4. Weighted linear combination

The land suitability indices for agricultural, natural vegetation and forest uses were calculated through weighted linear summation of the layers using eq. (4).

$$SI_j = \sum_{i=1}^{n} W_{ij} \mu_{ij}(x) \tag{4}$$

where SI is the suitability index of land evaluation unit j where j=agricultural land, natural vegetation, forest; W_i is the weight value of factor i, and $\mu_i(x)$ is the membership grade for factor i. Regarding fuzzy set model, SI ranges between 0 and 1 where the value 0 indicates totally unsuitable and 1 is the highest suitability.

3. Results

3.1. The weights obtained from AHP

The results of criteria weights obtained from AHP method for each of the agriculture, natural vegetation and forest uses can be seen in Table 4. Regarding agricultural land use, elevation, land use capability, limiting soil factors and land use/cover are the factors assigned with the highest weights, which is followed by soil depth, erosion susceptibility and distance from market zone. As for natural vegetation and forest, land use capability and slope have the highest weights, which is followed by land use/cover. Limiting soil factors are assigned with the lowest weight in case of natural vegetation and it is the soil depth that has the lowest weight in case of forest use.

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Table 4. AHP weights for the evaluation criteria

Land use	Sub-criteria	Weight
Agriculture	Slope	0.044
	Elevation	0.145
	Aspect	0.028
	Distance from water courses	0.035
	Distance from reservoir	0.035
	Distance from fast roads	0.021
	Distance from slow roads	0.021
	Distance from market zone	0.052
	Distance from urban dwellings	0.034
	Land use/cover	0.131
	Geology	0.031
	Soil depth	0.088
	Land use capability	0.143
	Limiting soil factors	0.133
	Erosion susceptibility	0.06
Natural vegetation	Slope	0.211
	Distance from reservoir	0.06
	Land use/cover	0.048
	Land use capability	0.51
	Limiting soil factors	0.033
	Erosion susceptibility	0.138
Forest	Slope	0.246
	Distance from reservoir	0.1
	Land use/cover	0.15
	Land use capability	0.31
	Erosion susceptibility	0.13
	Soil depth	0.064

3.2. Land suitability for peri-urban green space development

The results of the application of two suitability models on the peri-urban green space development are presented in Table 5. The land suitability map for agricultural uses were initially generated using the deterministic method and classified into seven categories i.e. the values range between 7 and 1 where 7 points to very high suitability and 1 is the very low suitability (see Table 5). The deterministic method estimated 37% of the surface of the study area as being highly suitable for agricultural development. Regarding the fuzzy method, suitable land is classified into seven categories where the values range between 0 and 1; the values lower than 0.3 indicate the lowest suitability whereas the values greater than 0.8 are the highest suitability (Table 5). From the fuzzy method, 62% is suitable for agricultural land use. Of these areas, 5.68% were defined as very highly suitable, 21.71% as highly suitable,

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and 34.89% as moderately suitable. Also the results showed that the largest part of Pendik district were characterised as moderately suitable for agricultural production and only 8%

Table 5. Comparison of suitability differences in deterministic and fuzzy models

	Deterministic model Suitability Classes	Land Area (Ha)	Land Area (%)	**Fuzzy model** Suitability Classes	Land Area (Ha)	Land Area (%)
	Agricultural Land					
Very low suitability ↓	0-1	-	-	<0.3	13.5	0.08
	1-2	0	0	0.3-0.4	49.86	0.28
	2-3	16.83	0.09	0.4-0.5	1362.15	7.67
	3-4	895.59	5.04	0.5-0.6	5275.35	29.69
	4-5	10148.04	57.12	0.6-0.7	6199.02	34.89
	5-6	5891.04	33.16	0.7-0.8	3857.85	21.71
Very high suitability	6-7	814.59	4.59	>0.8	1008.36	5.68
	Natural Vegetation					
Very low suitability ↓	0-1	-	-	<0.3	1676.43	9.38
	1-2	2651.4	14.83	0.3-0.4	2708.82	15.15
	2-3	1080.27	6.04	0.4-0.5	642.69	3.60
	3-4	8693.28	48.63	0.5-0.6	1170.18	6.55
	4-5	1443.06	8.07	0.6-0.7	6735.15	37.68
	5-6	3906.99	21.86	0.7-0.8	1781.55	9.97
Very high suitability	6-7	100.98	0.56	>0.8	3161.16	17.68
	Forest					
Very low suitability ↓	0-1	-	-	<0.3	1472.76	8.23
	1-2	3086.91	17.26	0.3-0.4	2738.52	15.31
	2-3	1841.58	10.30	0.4-0.5	490.95	2.74
	3-4	2729.34	15.26	0.5-0.6	727.47	4.07
	4-5	8393.94	46.93	0.6-0.7	4557.51	25.48
	5-6	1811.52	10.13	0.7-0.8	5467.5	30.57
Very high suitability	6-7	21.96	0.12	>0.8	2430.54	13.59

were identified as unsuitable land. Most of the highly suitable areas are located at the central part while others are scattered in the northern and south-eastern parts of the Pendik district (see Fig. 2a, b). Suitable lands are mostly located on flat terrain and covered mainly by agricultural land, forest and natural vegetation areas.

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In Table 5, findings from deterministic model indicated that a relatively smaller portion of the area is classified as highly suitable for natural vegetation and forest development. The share of highly suitable area in total is about 0.56% and 0.12% for natural vegetation and forest uses, respectively. Moderate suitability class has a high share of more than 50% whereas low suitable land ranges between 14% and 17% for both natural vegetation and forest uses. According to fuzzy model findings, natural vegetation is associated with a smaller percentage of moderate suitability and forest with a smaller percentage of low suitability. The moderate suitability class is around 10% of the total land of the study area in case of natural vegetation and low suitability class is less than 3% of the total area for the forest use. Regarding natural vegetation, around 65% of land was classified as suitable and it was 68% for the forest land use. Of these areas, 17,68% and 13.59% were defined as very highly suitable, 9.97% and 30.57% were highly suitable, and 37.68% and 25.48% were moderately suitable for natural vegetation and forest land, respectively.

The findings from both models demonstrated that highly suitable land is located in the central part and north-eastern part of the study area and there is only a small portion located in south-eastern part (Fig. 2c, d, e, f). These are the locations in the vicinity of existing agriculture, forest and natural vegetation uses mainly located in the central and northern part of the study area while there are also locations in the south but these are small and more scattered. Most of the suitable area was located at a closer distance to the main road and had a good transport connection with fast and slow roads. Suitability increased far away from areas with high population density and closer to the areas of market zone and existing village centers. These results were in agreement with the findings of other studies that focused on land suitability analysis of agricultural landscapes internationally (Zolekar and Bhagat, 2015; Romano et al., 2015; Pramanik, 2016; Qiu et al., 2017).

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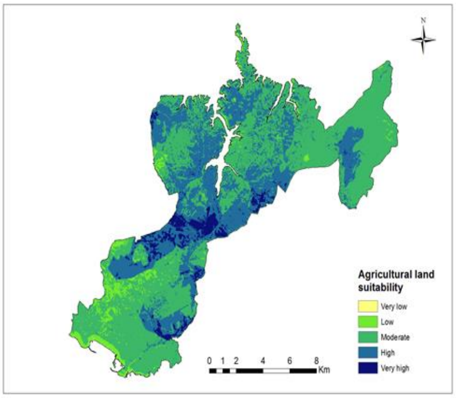
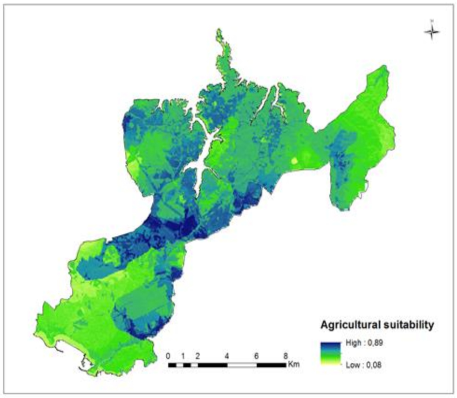
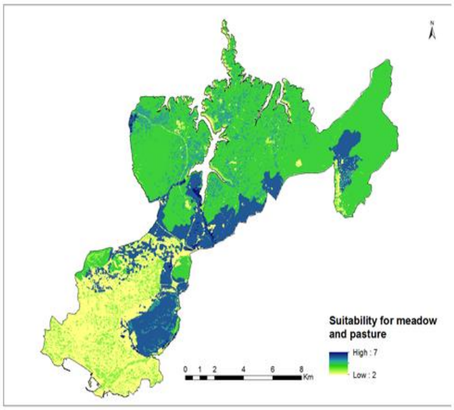


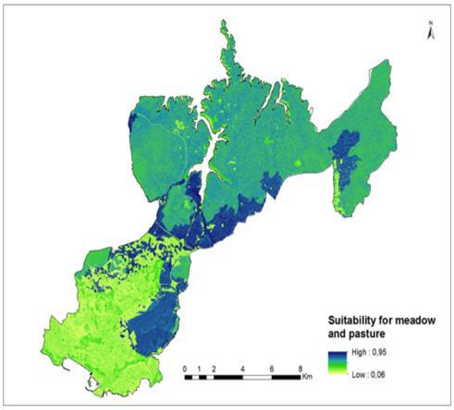
(a) Agricultural land (deterministic model)



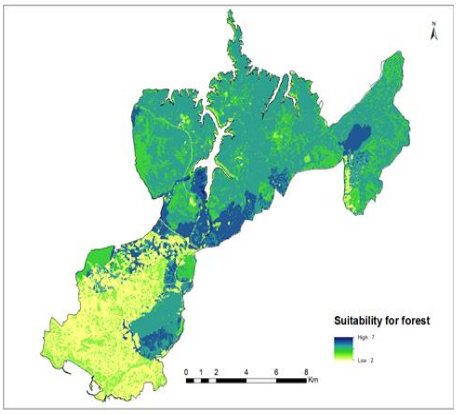
(b) Agricultural land (fuzzy model)



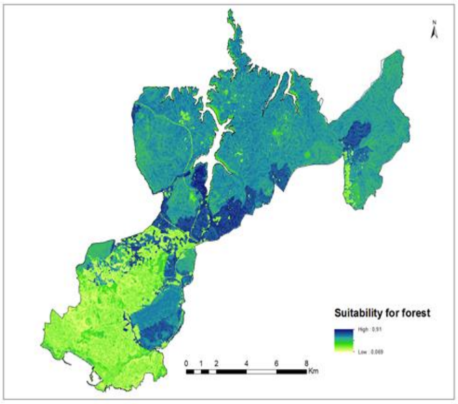
(c) Natural vegetation (deterministic model)



(d) Natural vegetation (fuzzy model)



(e) Forest (deterministic model)



(f) Forest (fuzzy model)

Fig. 2. Potential suitability for agriculture, natural vegetation and forest uses based on deterministic and fuzzy models for Pendik district

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4. Discussion

The aim of the study was to determine suitable locations for agricultural, natural vegetation and forest developments in Pendik district, Istanbul. The integrated model of GIS, fuzzy set and AHP provides a useful tool for evaluating the suitable locations of peri-urban green space development. This fuzzy model was compared with the traditional deterministic approach which integrated GIS, Boolean model and AHP for the land suitability assessment in the case study area. Implementation of different methods has provided a comparative analysis of criteria classification, ranking and options priority order, which would contribute to site selection problem for the peri-urban green land in Pendik district.

In the first model, the Boolean logic was used to classify the suitability for peri-urban green land use. This model is easy to understand and apply; and its performance depends on the adopted constraints and the quality of the input maps. This model has been widely used in the literature for the site suitability assessment of waste disposal (Baiocchi et al., 2014), solar power plant (Ibrahim, 2020), wind farm (Flora et al., 2021), water aquaculture and livestock development (Hadipour et al., 2014; Qiu et al., 2017), agricultural land (Romeijn et al., 2016), and urban and industrial development (Ramya and Devedas, 2019). Different from Boolean logic, fuzzy set theory allows partial membership of suitability; therefore it is a more realistic measure of continuous factors. This is confirmed by Barreto-Neto and de Souza-Filho (2008) which showed that modeled runoff from fuzzy method is closer to the measured runoff in the tropical watershed covered by Atlantic forest and pasture in their study area. A further study by Zhang et al. (2015) demonstrated that fuzzy set provides a more flexible assessment in the site selection of tobacco production given that there are no certain boundaries between suitable and unsuitable classes. Their results were in agreement with the actual production situation and high production regions comply with the highly suitable zones. Similar results were reported by Aydi et al. (2016), Bagherzadeh et al. (2018), Bikdeli (2019), and Ustaoglu and Aydınoglu (2020b). Therefore, it can be concluded that fuzzy set is an advanced approach given that the findings from the fuzzy model are effective and promising; therefore fuzzy set approach can be utilised in land suitability assessment not only for agricultural, natural vegetation, and forest land but also for other land uses.

Regarding land suitability assessment, one of the key challenges is to identify relative importance of the factors in the multi-criteria analysis framework. Several factors need to be considered simultaneously but these impact land suitability unequally. There are different methods in the literature adopted for the calculation of weights of the different factors such as Ordered Weighted Average (OWR) (Jamshidi-Zanjani and Rezaei, 2017), fuzzy

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membership approach (Ahamed et al., 2000), grey relational analysis (Ahmadi et al., 2016), overlay in GIS maps (Falasca et al., 2012), AHP/ANP (Seyedmohammadi et al., 2019), PROMETHEE (Vavatsikos et al., 2020), ELECTRE (Sanchez-Lozano et al., 2016), TOPSIS (Ramya and Devedas, 2019), regression analysis (Park et al., 2011), principal component analysis (Mistri and Sengupta, 2019) and machine learning methods (Ahmadi and Layegh, 2014). The current study utilised AHP method for the weighting of parameters based on the review of literature and expert views were also considered. AHP provides capability of integration of heterogeneous data since it enables experts to assign weights in a systematic and logical way. AHP is an effective method in the construction of weights and it is superior to its alternatives given that its inconsistency can be measured and controlled in the presence of conflicting criteria. Due to explained reasons, AHP has been successfully applied in many land suitability assessment studies (Elaalem et al., 2011; Akıncı et al., 2013; Zolekar and Bhagat, 2015; Pramanik, 2016; Qiu et al., 2017; Ennaji et al., 2018; Ramya and Devedas, 2019; Ustaoglu and Aydınoglu, 2020a, b; Han et al., 2021). Despite the advantages, AHP method is criticised due to existence of ignored interdependencies of the various factors in the AHP applications that are based on subjective assignment of relative weights of the two criteria. ANP that is an extension of AHP can be suggested as a remedy to this problem because ANP considers interaction of different levels of criteria relative to each other as well as dependencies of criteria within a level. An alternative methodology to deal with factor interdependence is the principal component analysis, which transform a number of correlated variables into a small number of uncorrelated factors. Through a few factors, the interrelationship among original factors is minimised; therefore these new factors can be used as assessment factors (Zhang et al., 2015). These alternative weighting methods can be considered in a future work to be compared with the findings from the current study.

From socio-economic and environmental perspectives, there is growing evidence that (peri)-urban agriculture and forestry has an important role in poverty alleviation (Zezza and Tasciotti, 2010), environmental quality improvement (Lwasa, 2014; Wei et al., 2018), contribution to food security (Lee-Smith, 2010; Chagomoka et al., 2018) and providing outdoor spaces for recreation (Ives and Kendal, 2013). These foreseen benefits are important particularly for Istanbul, which has been characterised by strong urbanisation. The urban area has expanded rapidly in many districts particularly in the last decades, and Pendik is among the highly developed areas in Istanbul where there are both high density and low-density population residing in the area. In Pendik district, urban growth has been extended to peri-urban areas with declining population density in many cases. This situation has caused conversion of agricultural and forest land, and increased farmland

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fragmentation. Supporting peri-urban agriculture and forest activities in Pendik is therefore important to support ecosystem services, improve environmental quality, provide income to the rural residents and other benefits are expected resulting from connection and networking of urban green spaces. Peri-urban agriculture and forestry needs to be integrated into the planning and management of the urban system. In order to connect agricultural/forest uses with the urban system, land suitability analysis can provide as an input for such an analysis through providing spatial information on the suitable sites. Therefore, the findings from the current study can be used for the planning and management of peri-urban agriculture and forestry activities in the Pendik district.

Conclusion

The present study was conducted to assess the suitability of rural land particularly located in the northern area of Pendik district for agriculture, natural vegetation and forest uses using GIS and multi-criteria assessment approaches. A total of fifteen indicators, namely physical factors, land use/cover, water sources, accessibility, market zones, geology and soil properties, and erosion susceptibility were used for the agricultural suitability assessment. A more limited number of factors such as slope, water resources, land use/cover, soil properties and erosion susceptibility were used for assessing suitability for natural vegetation and forest land development. In the first model, Boolean approach was used for the classification of suitability whereas the second model applied fuzzy set for the same purpose. AHP was applied to estimate the weights of indicators to take into account their influences in selecting suitable land for peri-urban agriculture and forest development. The calculator function and overlay analysis of GIS were used to produce the final suitability maps. The resultant land suitability map from Boolean approach was classified into seven levels of land use suitability where 1 indicating unsuitable and 7 is the highest suitable land. The map from fuzzy set approach was also examined under seven land suitability classes where the values close to 0 represent unsuitable land and the values close to 1 are the highest suitable land.

From the first model, a total area of 814 Ha, 100 Ha and 21 Ha were found highly suitable for agriculture, natural vegetation and forest uses, respectively. By contrast, findings from the second model indicated that 1,008 Ha, 3,161 Ha and 2,430 Ha of land are highly suitable for agriculture, natural vegetation and forest uses. More significant portions of land were assigned with moderate suitability class for all land uses in both models. In case of agriculture, natural vegetation and forest land, around 10,000 Ha of land are moderately suitable according to model 1 findings; and according to model 2, 11,000 Ha of agricultural land, 7,000 Ha of natural vegetation, and 5,000 Ha

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of forest land correspond to moderate suitability classes. Regarding very low suitability classes, agricultural land has the lowest share in both models, and from fuzzy model, natural vegetation has 9% and forest has 8% shares of the total land area. From deterministic model, there is no very low suitability class for any of the agriculture, natural vegetation and forest uses. Both models used for prioritising agricultural and forest developments in the current study provide as an effective tool for practitioners, planners and policy makers. The results indicated diverging maps of land suitability based on Boolean model and fuzzy model findings. This will provide planners and policy makers a varying range of possibilities in the assessment of land suitability and site selection for the agricultural, natural vegetation and forest uses. Therefore, the findings from the study can guide the planning processes of the rural area of the Pendik district as part of planning and management of green landscape developments.

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