EVALUATING SUITABILITY OF A GIS–AHP COMBINED METHOD FOR SUSTAINABLE URBAN AND ENVIRONMENTAL PLANNING IN BEYKOZ DISTRICT, ISTANBUL

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ABSTRACT

Many metropolitan areas in the world currently face challenges of rapid urbanisation. At the urban peripheries, the balance between 'urban areas' designated for new settlements for city inhabitants and 'green areas,' which provide ecosystem functions, has come under heavy pressure because of this rapid urbanisation. Spatial planning research provides methods for a thorough evaluation of urban development strategies. In this paper, a method is proposed that provides a systematic Suitability Assessment for the metropolitan territory, from the perspective of both urban planning basic principles and environmental sustainability. This approach, which combines Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) techniques, is applied to a case study in Istanbul, Turkey, to evaluate current urbanisation patterns. Beykoz District spans an area of more than 30,000 ha at the Anatolian side of Istanbul, along the Bosphorus. Currently 79% of the total area is forested, 15% is agricultural land and 6% is urbanised. These characteristics make it a unique and financially precious area. It is thus particularly important to ensure that urban planning and development in this district are sustainable. In the Suitability Assessment, six main parameters are included, namely slope, streambed, Natural conservation status priority, forested areas, agricultural areas and watershed areas. Twenty-four sub-parameters are weighted by the AHP technique and integrated levels of suitability are determined by weighted overlay using GIS. The final map produced using this combined technique shows how urban constructions are spreading on the urban fridge of the Beykoz District. The resulting suitability map provides for a better comprehension of alternative settlement locations for preserving nature and sustainable development. The systematic and fact-based characteristics of the described methodology add to the legitimacy of its outcomes. The proposed method can serve as a suitability assessment instrument to analyse future urbanisation plans on their wider implications in terms of sustainability.

Keywords: Analytic Hierarchy Process (AHP), Beykoz, Environmental Sustainability, Geographical Information Systems (GIS), Istanbul, Suitability.

1 INTRODUCTION

Many metropolitan areas in the world currently face challenges of rapid urbanisation. At the urban peripheries, nature reserves, watersheds, floodplain areas and forests are being transformed in new built-up urban areas with modern housing and business districts and accompanying transport infrastructures. The balance between areas newly designated for built-up urban land uses, and areas reserved for 'environmental or green land use functions' is under stress in many urban peripheries because of this rapid urbanisation. Good urban planning, which is sustainable on the long term, needs to take into account the multiple facets and dilemmas around this balance between various land use functions, regarding both short-term and long-term environmental and safety implications. Expanding the territory for urban settlements located on the outskirts of the city, in areas previously occupied by forests and vegetation with various water and nature-based environmental services, increases the risk for future damage in case of extreme weather events, and reduces the level of resilience of the territory in the future. In combination with climate change with expected increase of extreme

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weather events, this implies an increased risk and exposure of urban settlements for floods, droughts, forest fires, landslides and related natural disasters.

The term 'environmental sustainability' was first used by the World Bank in 1992 in relation to conducting environmentally responsible development and it involves finding a balance between the pressure of population growth and the conservation of natural land cover [1]. One of its premises is that of intergenerational equity, and it also examines the relationship between resources and urbanisation [2]. According to Baynes and Wiedmann [3], 'environmental sustainability assessment has two general purposes, monitoring and measuring the past or current environmental pressures, states, or impacts of urban areas and simulating possible future scenarios of change'. In this context, when making a basic environmental sustainability assessment it is necessary to use a suitability analysis to make sustainable decisions about urban planning in built-up areas or areas with natural land cover.

A suitability analysis in a Geographic Information Systems (GIS) context enables decisions on whether a particular area is suitable for a certain use [4]. The basic premise of a GIS suitability analysis is that each aspect of the urban area has characteristics that are, to some degree, either suitable or unsuitable for settlements, according to certain criteria. Suitability is determined through systematic, multi-factor analysis of different aspects of the terrain [5], [6]. In addition, the AHP technique is used to assist in weighting these multi factors objectively, mathematically and correctly during this process [7]. Analytical Hierarchy Process (AHP) and GIS-based suitability analysis have been applied to a wide range of suitability evaluation issues in the last few decades [7–15]. Therefore, in this study, AHP results work together with GIS to produce an optimum land suitability map as the output.

The Environmental Performance Index (EPI) [16] uses objective statistical weightings and urban development suitability criteria (in accordance with Act. No: 3194 of Turkish Law [17]; it is used as the basic principle set for the study. Therefore, legal requirements are taken into consideration, based on both international and local standards, when analysing the suitability of development in the Beykoz District of Istanbul.

In this context, the aim of this study is to determine the extent of risk that current urbanisation presents to environmental sustainability. This is achieved by creating a suitability analysis that defines natural thresholds and is then compared to a map of existing settlements in the Beykoz District in Istanbul, Turkey. AHP–GIS combined technique and basic data set is designed for being available and applicable for all settlements in Turkey to help decision makers of urban planning.

2 CASE INTRODUCTION AND METHOD DESCRIPTION

Criteria used in suitability analyses vary widely according to the subject and aim of the study concerned [18]. This study analyses natural land cover elements that directly affect environmental sustainability in relation to Beykoz's characteristic structure.

The Beykoz District in Istanbul is chosen as the case study area for evaluating whether it is suitable for being developed in an environmentally sustainable manner. Basic principles are set using six criteria according to the EPI [16] and Act. No: 3194 of Turkish Law [17]. The AHP and GIS are used as a combined technique, and Super Decisions V2.0 and ArcGIS V.10.4.1 are used as tools.

2.1 General Case study information: Beykoz district in Istanbul

Istanbul has a population of approximately 20 million [19] and since the beginning of the 1950s, it has experienced rapid urbanisation. In addition, migration from other cities to

Istanbul and sizeable investments made by both the government and private sectors have accelerated urbanisation of the city. In this respect, the urban periphery has been one of the most affected areas. The centre and fringe of the Beykoz District are a good example of such an area; situated at a valuable location at the junction of the Bosphorus and the Black Sea, the area attracts the attention of investors and real estate developers more than other areas. In addition, the district has plentiful natural resources (forested areas, agricultural areas, lake, river, unique flora and fauna), making it even more desirable for real estate development. However, uncontrolled urbanisation growth is directly affecting and aggravating environmental problems [20].

The Beykoz District spreads over an area measuring 31,279 ha on the northern side of Istanbul and is situated at the meeting point of the Bosphorus and the Black Sea (see Fig. 1). It is a naturally rich and historically valuable area (particularly the area on the Bosphorus coast).

In 2015, the population of Beykoz was 249,727 [19]. The district currently has 45 neighbourhoods (after 20 villages were given neighbourhood status) [21], and forested areas and agricultural areas comprise 79% and 15% of Beykoz, respectively.

Istanbul has three bridges for connecting Europe and Asia. Beykoz District hosts two of them on the Anatolian side. The area is attracting increasing public and private investment because of ease of transportation and the associated increase in both the working and permanent population is beginning to threaten the natural areas.

Currently, the forests in the Beykoz District are seen as 'green lungs' of Istanbul Metropolitan Area. The green landscapes provide for recreational spaced for Istanbul citizens, its forests and natural vegetation protect the area for landslides and floods, and its agricultural areas produce food close to urban food markets. These are long-term ecosystem services that serve the wider metropolis in the long term. However, these long-term ecosystem services come under pressure due to gradually ongoing spatial development and plans for urbanisation, which are taken in a piecemeal sequence of vision-building and decision-making by multiple levels of government, at the district level and metropolitan level.

2.2 Parameters used in evaluating suitability

Evaluation and determination of sub-parameters are prepared according to THE EPI [16] developed by Yale University (Yale Center for Environmental Law and Policy) and Columbia University (Center for International Earth Science Information Network) in collaboration with the World Economic Forum and the Joint Research Centre of the European

Figure 1: Location and some photographs of Beykoz in Istanbul.

Commission. In addition, several laws relate to Act. No: 3194 of Turkish Law, which is used as a basic guideline.

Natural and artificial thresholds used in planning need to be specific to a local area [22]. Therefore, the main and sub-parameter indexes are created by integrating global and local values for Beykoz and are shown in the following table. Six parameters are used in the analyses conducted in this study: slope, streambed, Natural conservation status (NCS) priority, watershed areas, forested areas and agricultural areas, respectively. In addition to the six main parameters, 24 sub-parameters are prioritised using a hierarchical process, and these are generated and input to the suitability analysis (see Table1).

2.2.1 Slope

Slope is one of the most important criteria used in suitability analysis in relation to possible construction. It is included as a criterion in suitability analysis due to the strain in physical construction conditions, the increase in construction costs and the increase in the intervention

Table 1: Areal and percentile distributions of main and sub-parameters in study area.

Main parameters	Sub-parameters	Area (ha)	Area (%)
Slope	60+	2815	9%
	40–-59	625	2%
	25–39	8758	28%
	15–24	6569	21%
	5–14	10635	34%
	0–4	5005	16%
Streambed	Within 10 m buffer zone of streambed	12472,5	40%
	Outside of 10 m buffer zone (others) of streambed	18806,5	60%
Natural conservation status (NCS) Priority	1st	22096,62	70%
	2nd	2178,54	7%
	3rd	3423,42	11%
	Not degreed	3423,42	11%
	Others	157	1%
Forested areas	Within forested land	24699	79%
	Outside of forested land	6580	21%
Agricultural areas	Strict agricultural area	2100,58	7%
	Pasture area	80,04	1%
	Marginal agricultural area	2664,69	9%
	Others	26433,69	83%
Watershed areas	Strict nature reserve	1315,33	4%
	Short-range	1629,87	5%
	Medium-range	1839,03	6%
	Long-range	2502,32	8%
	Others	24084,83	77%

between the original topographical nature and the risk of landslide due to inclination of the water flow area. This suitability is also graded, and sloping areas are classified according to percentage changes. In this respect, areas where the slope is less than 24% are classified as being ideal settlement areas at different grades (0–4% is the most suitable, 5–14% is fairly suitable, 15–24% is poorly suitable) (see Fig. 2a). For areas with slope up to 40%, it is possible to undertake construction if necessary precautions are adhered to, but it is not considered appropriate in relation to planning principles. Where the slope is 60% or more, areas are not considered suitable for construction [22]. The results of analysis show that 39% of the Beykoz district is not suitable for use as a residential area.

2.2.2 Streambed

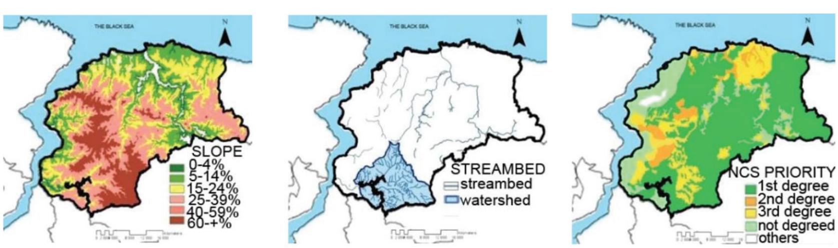
Beykoz is located within the Elmalı Basin, which is one of Istanbul's most important water resources. It also has a dam lake, which is fed by many small-scale rivers and the Riva Stream [23]. Due to the risk of adversely affecting the water cycle in ecological systems, or flooding and liquefaction in the ground, streambeds (and a 10 m buffer zone) are areas not suitable for settlement [22]. The potential risks that could occur as a result of construction are determined and controlled by relevant regulations of the General Directorate of State Hydraulic Works (DSI) of Turkey. Our analyses determine that 40% of the area is unsuitable for construction with respect to these risks (see Fig. 2b). In the data obtained from the IMM [21], dried streambeds are included in the analyses as having the same risk potential.

2.2.3 Natural conservation status (NCS)

As previously mentioned, Beykoz is a particularly historical and culturally significant area, and 99% of the district consists of protected areas [21], [23]. According to the analysis results (see Fig. 2c), 70% of the area consists of 1st degree natural protected areas, which can only be used for scientific studies, and 7% of the district consists of 2nd degree natural protected areas, which can be settled on by public institutions in relation to principles for public interest. The remaining district consists of 3rd degree natural protected areas, which are not categorised as natural and historical protected areas, and conservation-based approaches can be used with respect to construction thereon.

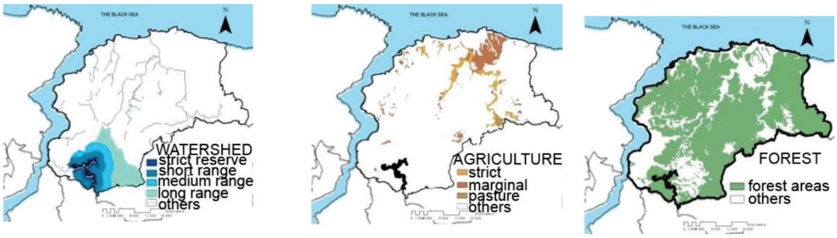
2.2.4 Forested areas

Beykoz District is one of the richest districts in Istanbul in terms of its forested area (79% of the district), (see Fig. 3a), and these forests are home to many endemic fauna and flora [23].



(a) (b) (c)

Figure 2: (a) Slope analysis map, (b) Streambed analysis map, (c) NCS analysis map.



(a) (b) (c)

Figure 3: (a) Forest areas analysis map, (b) Agricultural areas analysis, (c) Watershed areas analysis map.

2.2.5 Agricultural areas

There are 45 neighbourhoods in Beykoz. However, 20 settlements still maintain their rural character. For this reason, agricultural activities continue, although they are locally limited [24],[25]. Strict agricultural areas, marginal agricultural areas and pasture areas constitute 17% of the province (see Fig. 3b).

2.2.6 Watershed areas

The Elmalı Basin is located within the boundaries of Beykoz and constitutes 23% of its total area. Analysis of watershed areas is made for short-range, medium-range and long-range areas of protection, in accordance with directives determined by the Regulation on Drinking Water Basins of ISKI [26] for protected areas that are strict nature reserves. The results of analysis are as follows: 23% of the area is categorised as being a basin; 4% is a strict nature reserve, 5% is a short-range protection area, 6% is a medium-range protection area and 8% is a long-range protection area (see Fig. 3c).

2.3 AHP approach

The AHP is a strong and easy to understand methodology that provides the possibility of combining qualitative and quantitative factors to enable decision making processes of groups and individuals [27], [28]. It is a general multi-criteria decision-making approach used for complex, incomprehensible, or unstructured problems [28]. The AHP approach has been used in urban planning since 1984 [29].

The model is generally based on the following principles [30]:

- The problem is set on a hierarchical structure and weighing the criteria forms the general structure of priorities.
- The AHP obtains priorities from pairwise comparisons according to elements of the decision at a higher level.
- Pairwise comparison judgements are placed in a matrix.
- Priorities are found by calculating the maximum Eigen value of the matrix.
- Inconsistencies in judgements are also calculated.

To evaluate the criteria included in a level compared with other criteria included in the next hierarchy level, scoring is made using a fundamental scale for a pairwise comparison matrix produced by Saaty [31]. According to Saaty [31] for the intensity of importance '1' represents 'equal importance', '2' represents 'weak importance of one over another', '5' represents 'essential or strong importance', '7' represents 'demonstrated importance', '9' represents 'absolute importance', '2, 4, 6, 8' represent 'intermediate values between the two adjacent judgements'. The pairwise comparison matrix consists of n(n−1)/2 comparisons for n number of elements [32].

2.4 Data sets and methodology

At the first step, raw geographic and statistical data from relevant institutions are obtained. These data are then evaluated. After obtaining and organising raw data, three main steps are taken as follows. The first step defines the natural threshold parameters and prepares layers of these for analysis; the second step uses a point scoring system of thresholds for weighted overlay analysis and the third step involves weighting the parameters. The pairwise comparison matrix shows the significance of criteria (see Table 2).

After making the comparison, it is necessary to test the consistency ratio (CR) to determine whether the AHP is consistent or not. The CR calculation is a three-step process: (i) λ calculation, (ii) consistency index (CI) calculation and (iii) determination of random index (RI), as follows,

$$\lambda = \frac{\sum_{i=1}^{n} (A \times W) i}{n} \tag{1}$$

$$CI = \frac{\lambda - n}{n - 1} \tag{2}$$

$$CR = \frac{CI}{RI} < 0.1 \tag{3}$$

After mathematical processes, the results of the three steps are: Max. Eigen value (Λ Max) = 6,2; N = 6, CI (Λ Max -N)/(N−1) = 0,04; RI = 1,24; CR = CI/RI = 0,03. The CR value of 0.03 proves that the comparison is formed consistently, as the ratio is lower than 0.1; according to Saaty [33], a CR value higher than 0.1 indicates an error in calculations or inconsistencies made during the pairwise comparison.

Table 2: Weights of main parameters and sub-parameter scores.

Criteria	Slope	Streambed	NCS	FA	AA	WA	Weights
Slope	1	1/5	1/7	1/9	1/7	1/9	0,025
Streambed	5	1	1/3	1/5	1/3	1/5	0,067
NCS	7	3	1	1/3	1	1/3	0,137
FA	9	5	3	1	3	1	0,317
AA	7	3	1	1/3	1	1/3	0,137
WA	9	5	3	1	3	1	0,317

2.5 Parameter weights and sub-parameter scores

Sub-parameters are also scored using this process (see Table 3). When scoring, conserving natural land cover, ecosystems and mitigating disasters from the perspective of urban environmental sustainability are taken into consideration. High points are given to the sub-parameters that positively affect suitability, and classifications are differentiated to evaluate each parameter.

After appointing parameter weights and sub-parameter scores to related layers in the ArcGIS V.10.4.1 program, raster maps of six parameters are overlaid using the weighted sum overlay analysis, and a map of 'suitability analysis from the perspective of environmental conservation for Beykoz' is generated. The analysis layer is divided into four classes of equal ranges: highly suitable, fair, poor and unsuitable, respectively.

Table 3: Weights of main parameters and sub-parameter scores.

Main parameters	Weight	Sub-parameters	Score
Slope	0,025	40–+	1
		25–39	3
		15–24	5
		5–14	7
		0–4	9
Streambed	0,067	Within 10 m buffer zone	1
		Outside of 10 m buffer zone (others)	9
Natural conservation status (NCS)	0,137	1st	1
		2nd	1
		3rd	4
		Not degreed	6
		Others	9
Forest areas (FA)	0,317	Within forested land	1
		Outside of forested land	9
Agricultural areas (AA)	0,137	Strict agricultural area	1
		Pasture area	2
		Marginal agricultural area	5
		Others	9
Watershed areas (WA)	0,317	Strict nature reserve	1
		Short-range	1
		Medium-range	4
		Long-range	7
		Others	9

3 CASE RESULTS AND DISCUSSION

According to the 'suitability map from the perspective of environmental conservation for Beykoz', a significant part of the area (86% and 29181 ha) is determined to be unsuitable for urbanisation; 4% (1354,9 ha) of the study area is considered to be poor, 7% (2409,8 ha) is fair and 3% (994,3 ha) is highly suitable for urbanisation (see Fig. 4).

This study focuses on the environmental dimension of sustainable urban development, and the method involved here can be used to help decision makers determine priorities objectively by using a mathematical model in planning. In the next step, the suitability analysis is superposed on the area that is already built (see Fig. 5a and b). Current and complete data of buildings were obtained from the district and metropolitan municipality to make this analysis.

After superimposing the maps, results show that 21% of buildings already in Beykoz (11,800 buildings) are located on areas that are considered unsuitable for construction. The other buildings are located as follows: 16% (8.922 buildings) in poor areas, 26% (14,262 buildings) in fair areas and 37% (20,225 buildings) in highly suitable areas.

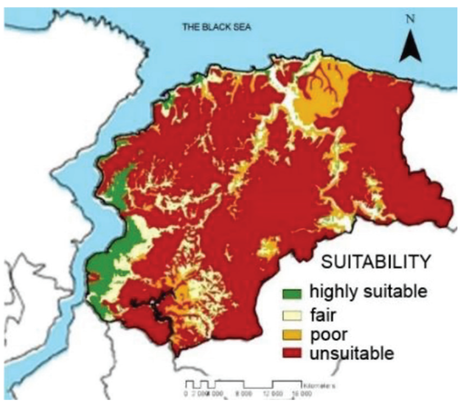


Figure 4: Suitability analysis from perspective of environmental conservation for Beykoz District.

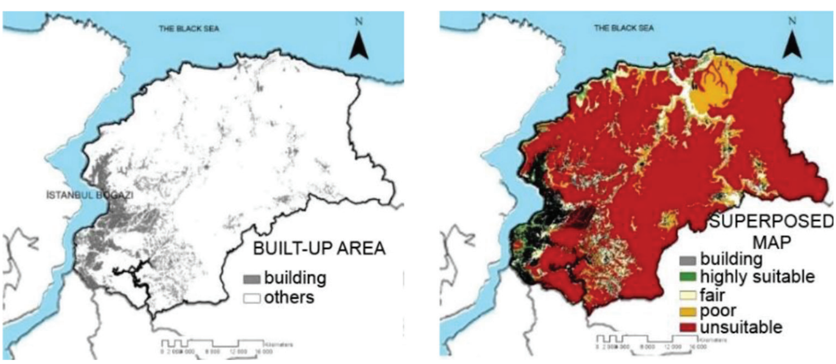


Figure 5: (a) Map of built-up area, (b) Superposed map of current settlements according to suitability analysis.

4 CONCLUSIONS

Sustainable urban development is a multidimensional concept and discussions pertaining to the components and general objectives of this concept are ongoing [34].

However, the natural environment underpins sustainability policies and remains the most important concept in this respect. In this context, urban planning has direct impacts on environmental sustainability, and appropriate tools are required to steer urban growth.

This research intends to provide an advanced, objective and easily applicable tool for achieving sustainable development at settlements that have naturally rich areas. In this context, this study was conducted in the Beykoz District, which includes the most intensive settlements in Istanbul because of its natural assets and large investment projects and is related to both local and core values. The AHP–GIS combined technique, which bases the decision mechanism on evidence and is objective, is used for the first time in a suitability analysis for urban planning.

Results show that the areas that can be settled without threatening the sustainability of the natural environment are limited (3% of total area) in Beykoz. Currently only 37% of all the buildings in the district are located in this area. Areas that are deemed unsuitable for construction comprise a significant part (86%) of the district, and 21% of all buildings in the district are located in these areas.

The maps created in this study show that sprawling construction is moving towards naturally rich areas at the urban fringe; therefore, nature is being exploited by urban ecosystems. In addition, as environmental sustainability is being damaged, social and economic threats are created within the sustainability system.

For example, there are direct consequences from building on the streambed or in very highly sloped areas, such as flooding, landslide or high construction cost, etc. According to the suitability map, it is evident that the most unsuitable areas are those lying within watershed areas, yet these are most at risk of being built-up.

Legal regulations should not allow the spread of urban development to natural areas. This study uses AHP to prioritise criteria, with the aim of the local municipality's urban development and planning department making use of the results and prioritising public policies. When making development decisions, instead of destroying natural values it is suggested that urban gaps are filled in and old buildings are renovated.

Consequently, the resultant environmental suitability map simplifies better comprehension of alternative settlement location suitability patterns for preserving nature and future sustainable development. Therefore, it can be used at decision-making process about urban growth. The final suitability map also determines the areas that have the least environmental disaster risk for the citizens, thus this refers increasing quality of life.

The method can be replicated in other areas. It can serve as a suitability evaluation framework to assess future urbanisation plans on its wider implications in terms of ecosystem services and sustainability functions. The method makes long-term sustainability implications of urban planning processes visible. By including information on watersheds, slopes, forests etc in its suitability assessment, it includes considerations on the dimensions of (loss of) ecosystem services. By taking these dimensions into account, the implications of eroding ecosystem services, like increased risk of landslides, flooding, and loss of biodiversity, become visible and tangible for decision-makers. The systematic, independent and fact-based characteristics of the methodology that is described in this paper, add to the evidence-based legitimacy of its outcomes.

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