Chapter 5

Evaluation of Settlement Suitability with Regards to Natural Environmental Ingredients Using GIS and AHP

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Abstract

In recent years, rapid population growth worldwide has led to the unplanned expansion of settlements. This situation has resulted in various problems in the natural environment. To address these issues, it is necessary to conduct studies that consider natural environmental ingredients in the selection of suitable locations for settlements. In this study, it is aimed to evaluate the suitability for settlement in terms of natural environmental ingredients by using a GIS-supported analysis and Analytical Hierarchy Process (AHP) method of 5000 Evler district, which is located in the central district of Karabük and consists of 3 neighborhoods. For this, areas suitable for settlement have been identified using factors of geology, hydrogeology, land use, elevation, slope, aspect, distance to fault lines, landslide risk, distance to rivers, ground acceleration, distance to roads, temperature and precipitation. With the obtained weights, a weighted overlay analysis is performed using GIS software, where all layers are overlaid, resulting in the production of a suitability map for the study area. The produced settlement suitability map generated is divided into two different classes: moderate and low sensitivity. According to the obtained results, in terms of suitability for settlement in the study area, it is observed that areas with moderate sensitivity cover 301.42 hectares, while areas with low sensitivity cover 20.82 hectares. The results obtained from this study are expected to assist decision-makers in future land management efforts in the study area and its surroundings. This study also emphasizes that GIS-based MCDA and AHP methods are very powerful methods in producing settlement suitability maps.

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1. Introduction

Natural environmental ingredients affect both the establishment and development processes of settlements (Aliağaoğlu and Uğur 2021). As in the world, population and urbanization have increased in Türkiye in recent years, resulting in the expansion of existing settlements and the formation of new settlements. For the solution of the problems that arise in the settlement areas, it is of great importance to carry out appropriate site selection studies that take in to account the natural environmental ingredients (Bayar 2005). In this way, it will both contribute to the construction of solid construction and make efficient use of the areas to be opened for settlement. At this stage, it is important to use Geographic Information Systems (GIS) techniques (Özşahin and Kaymaz 2015). GIS, which is an effective tool for accurate planning (Karabulut et al. 2022), provides decision makers with ease, quickness and flexibility in making decisions in the planning of residential areas (Özşahin 2016).

Spatial decision problems typically encompass multiple, conflicting, and incomparable evaluation criteria. In the process of making such decisions, there are various groups involved, such as decision-makers, stakeholders, managers, and interest groups, among others (Malczewski 2004, Malczewski 2006). Assigning relative weights to different criteria used in suitability analyses becomes more complex. The Geographic Information System (GIS)-based multi-criteria decision-making technique has become highly prevalent in spatial planning and management (Joerin et al. 2001, Mendoza and Martins 2006, Makropoulos and Butler 2006, Karnatak et al. 2007, Greene et al. 2011). ELECTRE (ELimination and Choice Expressing REality), SMART (Simple Multi-Attribute Rating Technique), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), Delphi, and AHP (Analytical Hierarchy Process) are among the decision-making methods used in MCDA (multi-criteria decision analysis) (Yaralıoğlu 2004). Various studies have applied these methods. Joerin et al. (2001) used ELECTRETRI in conjunction with GIS, which is an essential tool for utilizing spatial data, in the process of creating a land-use suitability map for settlement. Er (2006) introduced a different perspective into urban planning in Istanbul, where he combined the Delphi technique with SWOT Analysis and mapped the results using GIS. Baysal and Tecim (2006) conducted a suitability analysis for solid waste disposal sites by integrating the TOPSIS and ELECTRE methods with GIS. Arca et al. (2023) used the Fuzzy Analytic Hierarchy Process (FAHP) in conjunction with Geographic Information Systems (GIS) to identify suitable areas for the installation of solar energy plants in the Safranbolu District.

In this study, it is aimed to evaluate the suitability for settlement in terms of natural environmental ingredients by using a GIS-supported analysis and Analytical Hierarchy Process (AHP) method of 5000 Evler district, which is located in the central district of Karabük and consists of 3 neighborhoods. In addition, with this study, it is aimed to contribute to the sustainable planning of the region of 5000 Evler, where the construction has started with cooperative constructions, especially in the central district of Karabük, which has seen a population increase compared to previous years (TÜİK 2023), according to the address-based population registration system (ADNKS) data of the Turkish Statistical Institute (TÜİK).

2. Material and Method

2.1. Study Area

The study area includes 5000 Evler 75. Yıl, 5000 Evler Bahçelievler and 5000 Evler Cumhuriyet Districts located in the city center of Karabük province in the Western Black Sea region. The study area, which covers an area of 322.24 ha, includes 0.29% of the central district's surface area. Karabük province is surrounded by districts of Yenice in the west, Eskipazar in the south, Ovacık in the east and Safranbolu in the north, and the study area covering 3 neighborhoods is located in the north-east of Karabük city center and between the city center and Safranbolu.

Unlike the part that emerged in the first development period of Karabük and constitutes the city center, the 5000 Evler region is the region that was formed as a result of cooperatives and where regular construction is seen (Karabük Governorship 2023). The population of Karabük Province is 248,458 and more than half of this population lives in the central district. The population of the central district is 137,428 people. The total population in 5000 Evler, which covers 3 neighborhoods, is 27,488 people and approximately 20% of the central district population lives in these 3 neighborhoods (TÜİK 2023). Karabük is located on the North Anatolian Fault (NAF) line; The NAF line starts from Gerede, which is approximately 40 km away from Karabük city center, which is the study area, and continues from Eskipazar and İsmetpaşa locations, that is, from the Karabük border (Ersöz et al. 2016).

2.2. Parameters

In order to achieve the highest level of results and conduct an accurate analysis in studies aimed at determining suitable areas for settlement, it is essential to appropriately acquire the most fundamental data while considering the ingredients of the natural environment. Following a literature review, commonly used and suitable layers have been selected for the study area. In spatial analyses, data related to the location are collected, and criteria are developed based on the researcher's observations, expert opinions, and references. Therefore, although similar parameters are used in each study, different results are obtained depending on the characteristics of the location. In this study, areas suitable for settlement have been identified using factors such as geology, hydrogeology, land use, elevation, slope, aspect, distance to fault lines, landslide risk, distance to rivers, ground acceleration, distance to roads, temperature and precipitation.

The lithological units cropping out in 5000 Evler 75. Yıl, 5000 Evler Bahçelievler and 5000 Evler Cumhuriyet Districts are listed as Safranbolu formation (Tes), Karabük formation (Teka) and Örencik formation (Tplö). Safranbolu formation (Tes), which features a medium-thick layer, exhibits a thin sandstone-conglomerate layer, and then transitions to sandy limestone, carbonated sandstone and limestone levels. The Karabük formation (Teka), another formation with medium-thick layer characteristics, presents marl, claystone and sandstone intercalations and thin coal levels towards the top. The Örencik formation (Tplö), which consists of an alternation of terrestrial conglomerate, sandstone and mudstone, presents a medium-thick layer feature (Timur and Aksay 2002). The lithological map of the study area (Timur and Aksay 2002) can be seen in Figure 1a.

Among the lithological units in the study area, the Safranbolu formation constitutes a hydrogeological semi-permeable unit due to its sandy levels along with carbonate rocks. Örencik formation, which presents layered features with medium grain size clay, silt size impermeable grains, is slightly permeable. The Karabük formation, which contains fine-grained levels and volcanic rocks, constitutes a hydrogeologically impermeable unit (Figure 1b).

Land use plays a significant role in suitability for settlement (Özşahin 2012). Unplanned and uncontrolled urban growth in current residential areas results from the indiscriminate alteration of land cover (Çetin 2012, Özşahin and Kaymaz 2015). In this study, land use was examined in four categories: dry farming, horticulture, pasture, and forest (Figure 1c).

Elevation is considered a determining factor in terms of suitability for settlement among natural environmental ingredients (Yalçınlar 1967, Özdemir 1996, Erkal and Taş 2013). When selecting appropriate locations for settlements, it is advisable to consider higher elevations above sea level to mitigate potential risks of tsunamis and floods, even though areas with high elevations may not be the preferred choice. To effectively incorporate elevation data into the analyses, it is recommended to use continuous data that represent elevation values as surfaces rather than discrete data that may contain discontinuities (Demir 2018). The elevation data for the study area has a resolution of 12.5 meters. The study area was divided into three classes using the natural break method for elevation analysis (Figure 1d).

The slope characteristics of the lands where settlements are established and developed are also crucial in terms of suitability for settlement (Değerliyurt 2014). The most suitable areas for construction are those with slopes below 10%. Indeed, as the slope increases, the costs associated with road construction, canal development, and maintenance also rise (Aliağaoğlu and Uğur 2010). However, steep terrain, if otherwise suitable, can provide favorable conditions for the occurrence of various types of natural disasters (Beer 1996). Slope data for the study area were generated from the digital elevation model of the region (URL-1 2023) and categorized into five classes: 0-2 degrees, 2-8 degrees, 8-16 degrees, 16-24 degrees, and over 24 degrees (Figure 1e).

Another important consideration within the scope of suitability for settlement is the aspect. When choosing settlement locations, north-facing directions are less preferred compared to flat and south-facing ones (Aliağaoğlu and Uğur 2010). In the context of Turkey's conditions, slopes facing east are more favored in site selection as they are less exposed to the effects of wind and precipitation compared to west-facing slopes (Yalçınlar 1977). Therefore, in the study area, the weight values of aspect classes are higher in the south and east directions compared to the north and west directions. Flat areas, which are the most problematic in terms of natural disaster risk (such as flooding or liquefaction), have the lowest weight values compared to all other directions (Figure 1f).

Another parameter that controls suitability for settlement in the study area is the distance from fault lines. As the distance from fault lines increases, the impact of the fault decreases, leading to larger weight values and increased suitability for settlement. Faults within the study area have been transferred to the Geographic Information System (GIS) environment from the General Directorate of Mineral Research and Exploration (MTA) Geological Sciences Map Viewer and Drawing Editor (MTA 2023, AFAD 2023) and four different buffer zones have been created at 500-meter intervals for use in GIS-based analyses (Figure 1g).

Landslides are natural disasters that can lead to serious loss of life and property, making the landslide risk factor essential in suitability for settlement analyses. Selecting suitable locations is necessary to minimize both the material and immaterial damages caused by landslides (Çellek et al. 2015). Appropriate site selection assists in the purposeful organization of urban land use, including residential, agricultural, industrial, and park areas (Bathrellos et al. 2012). Furthermore, for urban development, it is essential to identify landslide-prone areas and ensure that areas where the city will expand in the future have a healthy and sustainable structure. Otherwise, urban development areas may be exposed to natural disasters (Bathrellos et al. 2017). When examining the natural environmental characteristics of the research area, it is observed that areas prone to landslide risk are widespread in the 5000 Evler Bahçelievler and 5000 Evler 75. Yıl neighborhoods. In other words, these areas have a high risk of landslide occurrence. As the distance from landslide-prone areas increases, the levels of suitability for settlement show a positive correlation. The landslide risk map of the study area is given in Figure 1h.

The factor of distance from river networks holds a determining priority in suitability for settlement (Özşahin 2012). Although there is no specific distance established in the literature regarding proximity to river networks, it has been recommended that residential uses should not be permitted within 100 meters on either side of rivers and within 36 meters (Özşahin and Kaymaz 2015). This is due to the potential for rivers to cause environmental damage when they surpass their capacity and overflow their banks (Hoşgören 2000). As one moves farther away from rivers, the risk of flooding and inundation decreases, thus increasing suitability for settlement (Figure 1i).

Ground acceleration is a measure of how much and how quickly the ground shakes during an earthquake. It is recorded as centimeters per second squared (cm/s^2 or gal), and it represents a fraction of the gravitational acceleration (g=981 cm/s^2) during the earthquake (Aydöner and Maktav 2006). Ground acceleration is a parameter that should be considered in suitability for settlement analyses because it is a crucial value for ensuring the balance between the load transferred to structures and the soil-structure interaction. For the study area, the peak ground acceleration coefficient was obtained as 0.4 using the AFAD Turkey Acceleration Data and Analysis System (AFAD 2023) (Figure 1j).

Transportation is a vital necessity for everyone, which is why the proximity to roads is another important parameter to consider in suitability for settlement analyses. The suitability of a settlement area is closely related to its distance from roads. The proximity to roads is a significant criterion in determining the socioeconomic characteristics of urban and rural areas (Bathrellos et al. 2012). Additionally, because road construction can be costly, settlements should ideally be located in close proximity to roads (Garad et al. 2020). In areas near roads, the factor weights are high, whereas as one moves farther away from roads, the factor weights decrease (Figure 1k).

The temperature and precipitation conditions are fundamental factors that should be considered when selecting a settlement location (Özşahin and Kaymaz 2015). This is because temperature and precipitation conditions play a critical role in determining many essential factors for settlements, such as agriculture, water resource management, climate suitability, natural disaster risk, energy consumption, and access to water resources, and in planning them sustainably. To obtain more accurate results while creating temperature and precipitation maps for the study area, the annual average temperature and precipitation data from five observation stations near the study area were collected (URL-2 2023). The Inverse Distance Weighted (IDW) spatial interpolation method was used in the analysis of temperature and precipitation distribution (Figure 1l, Figure 1m). Since suitability for settlement decreases as precipitation increases, the weights of alternative criteria for this factor were scored based on changes in precipitation quantity.

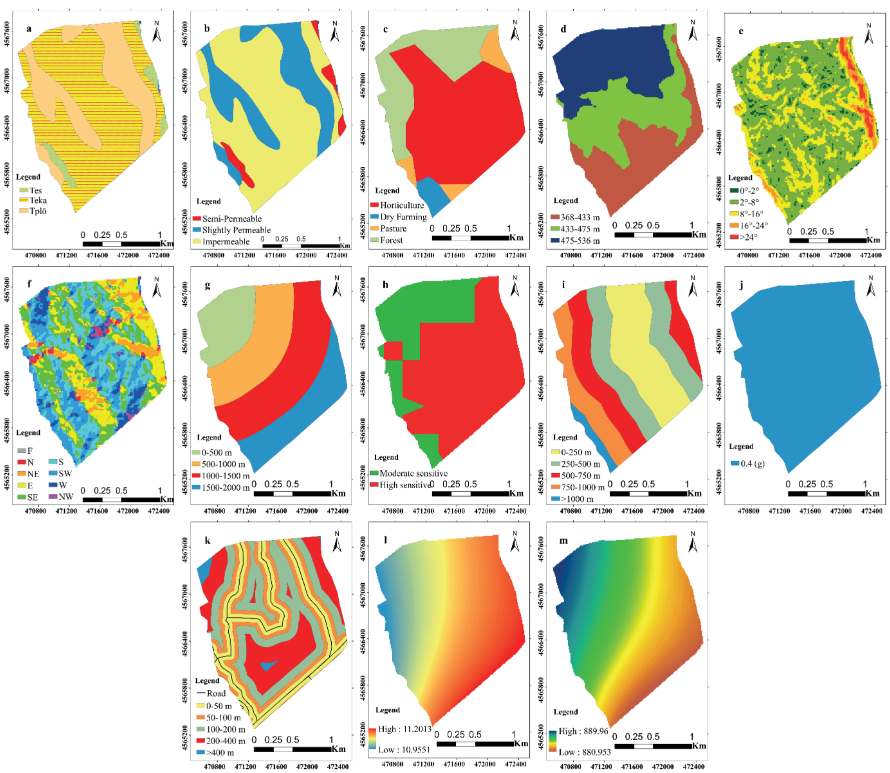

Figure 1. Parameters. (a geology, b hydrogeology, c land use, d elevation, e slope, f aspect, g distance to fault lines, h landslide risk, i distance to rivers, j ground acceleration, k distance to roads, l temperature, m precipitation).

2.3. Method

In this study, the suitability analysis conducted for a specific purpose encompasses the determination of impact values, the establishment of weighting coefficients, and the combination of these factors to create suitability maps. In this process, the main and sub-factors to be used in the assessment were initially identified. The determination of assessment factors was influenced by the land characteristics of the research area, on-site land observations, literature review, current land use, and expert opinions. Impact values to be assigned to sub-factors were done on a scale ranging from 1 to 5. Here, 1 indicates unsuitability for settlement, while 5 signifies suitability for settlement. The choice of this scale was influenced by both the literature review (Esen 2019, Eminağaoğlu et al. 2016, Özşahin 2016) and the belief that a more suitable statistical evaluation would be provided.

The weighting coefficients were determined using the Analytic Hierarchy Process (AHP), which is one of the multi-criteria decision-making methods employed in Geographic Information System (GIS)-based applications. The AHP method, developed by Thomas L. Saaty in 1977, serves as a suitable model for solving multi-criteria decision-making problems (Saaty 1977). The AHP method enables users to determine the weights of criteria in solving problems that depend on multiple criteria. The reason for the preference of AHP by decision-makers is its ability to consider subjective criteria in multi-criteria decision-making, as well as its ease of use and comprehensibility (Ömürbek et al. 2013, Soba and Bildik 2013). The fundamental challenge in multi-criteria decision-making problems is to determine weights, importance, or superiority in order to make choices among various alternatives while considering multiple criteria. To address this issue, AHP is an effective method frequently utilized in Multi-Criteria Decision Analysis (MCDA). One of the most significant features of the AHP method is its ability to incorporate both objective and subjective thoughts of decision-makers into the decision-making process (Kuruüzüm and Atsan 2001). Therefore, AHP is a mathematical method that considers the priorities of both groups and individuals, evaluating qualitative and quantitative variables together. This makes AHP more robust compared to other decision-making methods (Gülenç and Aydın Bilgin 2010). In the AHP method, a hierarchical model is established for each problem, consisting of objectives, criteria, sub-criteria, and alternatives (Kavas 2009). In this method, the problem is structured into a hierarchical framework, and the weights of the criteria that make up the hierarchy are calculated (Öztürk and Batuk 2010). At a given level, a scoring is conducted using Saaty's proposed preference scale (Table 1) for the evaluation of criteria in relation to the criteria at the immediately higher level, and a pairwise comparison matrix is generated (Saaty 1980). The pairwise comparison matrix consists of n(n-1)/2 comparisons for n elements (Öztürk and Batuk 2010, Malczewski 1999).

Table 1. AHP assessment scale (Saaty 1977, Saaty 2008).

Significance Degree	Definition
1	Equally significant
3	First criterion slightly more significant than the second
5	First criterion more significant than the second
7	First criterion remarkably more significant than the second
9	First criterion has the absolute significance over the second or preferred.
2,4,6,8	Intermediate values are used in cases requiring reconciliation.

The resolution of a problem using the Analytic Hierarchy Process (AHP) involves determining the priorities or weights of criteria based on pairwise comparisons made. The determination of priorities or weights is achieved by normalizing the pairwise comparison matrix. For this purpose, the column elements of the matrix are divided by the sum of each column to create a "normalized pairwise comparison matrix." The row elements in the generated matrix are then summed, and the total value is divided by the number of elements in the row. This process yields the weight vector (Kavas 2009). While making pairwise comparisons of criteria, a certain degree of inconsistency may arise. Therefore, after creating the matrices, consistency ratios should also be calculated. In the Analytic Hierarchy Process (AHP), the Consistency Index (CI) is computed as the ratio of the Random Index (RI) to the Consistency Index. The CI is calculated using the following equation (Equlation 1). If the consistency ratio exceeds 0.1, the matrix should be reevaluated (Saaty 1980).

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad \text{Eq. (1)}$$

In this context, λmax stands for the sum of each column in the pairwise comparison matrix and the sum of the products of relative weights, whereas n denotes the order of the matrix. RI, on the other hand, refers to the Random Index, which measures the consistency of a randomly generated pairwise comparison matrix. The RI values for a randomly generated pairwise comparison matrix are presented in Table 2 (Saaty 1980).

Table 2. Random inconsistency values for parameter n=1…16 (Saaty 1980).

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41
n	9	10	11	12	13	14	15	16
RI	1.45	1.49	1.51	1.54	1.56	1.57	1.59	1.60

After calculating the weights of the factors, within the framework of Multi-Criteria Decision Analysis (MCDA) approaches, a suitability sensitivity map is created by combining all criteria using the most commonly used Weighted Linear Combination (WLC) analysis. WLC is based on the theory of a utility function that defines the real benefits associated with the possible solution set a decision-maker wants to evaluate (Fishburn 1967, Triantaphyllou and Mann 1989). In the WLC method, all attribute values of an option are considered, and regular arithmetic operations such as addition and multiplication are employed. It is essential in this method that attribute values and weights are numerical and comparable (Triantaphyllou and Mann 1989).

3. Findings

The components of the dataset used for creating a suitability map using AHP include geology, hydrogeology, land use, elevation, slope, aspect, distance to fault lines, landslide risk, distance to rivers, ground acceleration, distance to roads, temperature and precipitation. First, using the AHP algorithm and mathematical formulas as described by Saaty (1980) and later by Dang et al. (2011), weights for all the factors were calculated, and the results are presented in Table 3.

The AHP application indicates that in determining suitable settlement areas, the most important parameter is geology, with a weight of 0.21 assigned to it. The second most important parameters are land use and distance to fault lines, each with a weight of 0.15. The less important parameters, in decreasing order, are slope (weight: 0.12), landslide risk (weight: 0.10), proximity to rivers (weight: 0.07), elevation (weight: 0.05), hydrogeology and ground acceleration (weight: 0.04), distance to roads, temperature, and precipitation (weight: 0.02), and aspect (weight: 0.01). Additionally, the calculated Consistency Ratio (CR) was found to be 0.04 to assess the consistency between the values in the pairwise comparison matrix and the weight values. Since this value is below the recommended threshold of 0.10, as suggested by Saaty (2000), the values obtained from the pairwise comparison matrix are consistent.

Table 3. Comparison matrix and weight values (a geology, b hydrogeology, c land use, d elevation, e slope, f aspect, g distance to fault lines, h landslide risk, i distance to rivers, j ground acceleration, k distance to roads, l temperature, m precipitation).

	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**weight**
a	1	4	2	4	3	9	2	3	5	3	7	8	8	21
b	1/4	1	1/5	1/2	1/4	3	1/5	1/3	1/2	2	3	3	3	4
c	1/2	5	1	4	2	7	1	2	3	3	5	6	6	15
d	1/4	2	1/4	1	1/3	4	1/4	1/4	1/2	3	4	4	4	5
e	1/3	4	1/2	3	1	7	1/2	2	3	3	5	6	6	12
f	1/9	1/3	1/7	1/4	1/7	1	1/8	1/7	1/6	1/3	1/2	1	1	1
g	1/2	5	1	4	2	8	1	2	3	4	6	7	7	15
h	1/3	3	1/2	4	1/2	7	1/2	1	3	3	4	5	5	10
i	1/5	2	1/3	2	1/3	6	1/3	1/3	1	3	4	5	5	7
j	1/3	1/2	1/3	1/3	1/3	3	1/4	1/3	1/3	1	2	3	3	4
k	1/7	1/3	1/5	1/4	1/5	2	1/6	1/4	1/4	1/2	1	2	2	2
l	1/8	1/3	1/6	1/4	1/6	1	1/7	1/5	1/5	1/3	1/2	1	1	2
m	1/8	1/3	1/6	1/4	1/6	1	1/7	1/5	1/5	1/3	1/2	1	1	2

With the obtained weights, a weighted overlay analysis is performed using GIS software, where all layers are overlaid, resulting in the production of a suitability map for the study area (Figure 2). The produced settlement suitability map generated is divided into two different classes: moderate and low sensitivity. As a result of the conducted analyses, it was determined that there is a moderate sensitivity of 93.54% and a low sensitivity of 6.46%. According to the obtained results, in terms of suitability for settlement in the study area, it is observed that areas with moderate sensitivity cover 301.42 hectares, while areas with low sensitivity cover 20.82 hectares.

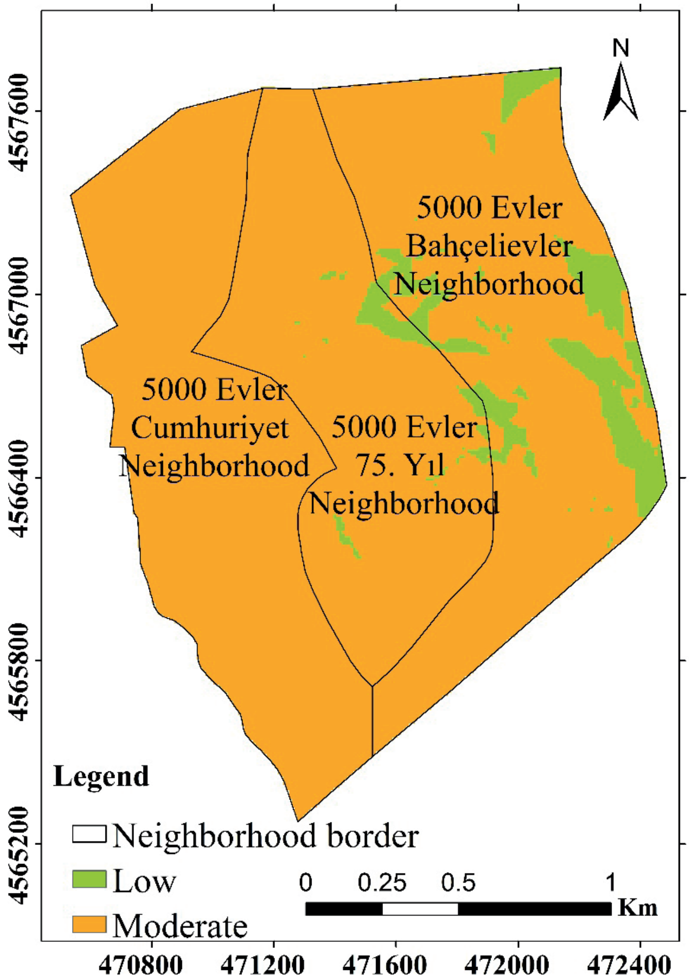

Figure 2. Settlement suitability map

4. Conclusions

GIS and MCDA methods are tools that allow for the selection of the best choice among various alternatives in site selection studies. Among the MCDA methods, one of the most commonly used and preferred methods is the Analytic Hierarchy Process (AHP), which enables decision-makers preferences to be expressed in adaptable ways. Based on 13 factors, this study, conducted using the GIS-based MCDA-AHP method, determined that the study area has moderate and low sensitivity levels for suitability for settlement. According to the obtained results, it was determined that there is a moderate sensitivity of 93.54% and a low sensitivity of 6.46%. According to these results, the entire Cumhuriyet neighborhood in the 5000 Evler region, which is the study area, offers moderate sensitivity of suitability for settlement in terms of natural environmental ingredients. 75. Yıl neighborhood, on the other hand, offers moderate sensitivity, except for very small local areas on the eastern edge and south. Bahçelievler neighborhood has more areas that are low sensitive to settlement than the other 2 neighborhoods. This study highlights that the GIS-based MCDA and AHP methods are powerful tools for generating suitability maps. The results obtained from this study are expected to assist decision-makers in future land management efforts in the study area and its surroundings.

The combination of various methods in suitability analysis for settlement and the study scale employed highlight the uniqueness of the research. Furthermore, significant analytical insights have been obtained concerning the geographical factors considered and the approach used. The results obtained from the research are considered a crucial step in the context of suitability analysis for settlement and the site selection process. Additionally, it is believed that the obtained results will provide ease for planners and decision-makers. However, in suitability analyses for settlement areas, it would be more beneficial to consider not only natural environmental ingredients but also social and technical factors (Duc 2006, Sedigheh et al. 2009, Yang et al. 2008).

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