



Site selection by using the multi-criteria technique—a case study of Bafra, Turkey

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Received: 3 April 2020 / Accepted: 20 August 2020 / Published online: 31 August 2020
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Abstract Population growth, which is the main source of the biggest problems of the world today, combined with migration from rural areas to urban centers, causes the urban centers to be even more concentrated. This necessitates the opening of new residential areas in many city centers, but new residential areas are mostly determined by the decisions of local authorities, who may not base their decisions on scientific data. With the wrong area selection, ordinary natural events can be potentially catastrophic. Such events can result in large numbers of casualties and material damage every year. In this study, an example of applying a method for location selection using various parameters has been realized. The study focuses on Bafra, Turkey (the study area). Risk maps were created in terms of floods and

overflows; maps of regions and high-voltage power transmission lines that enjoy a protected area status; and maps of regions in terms of biocomfort suitability. As a result of the evaluation made according to these criteria, it is calculated that only 1.96% of the total working area is suitable for use as a residential area. In relevant literature studies, it was observed that the studies related to the selection of residential areas were carried out only depending on a single standard or criterion. Some suggested biocomfort, and others used vulnerability to risks such as landslide, flood, and earthquakes as their main principle. Studies based on multi-criteria were generally used for purposes such as solid waste site selection and determination of the road routes. The study aims to shed light on the multi-criteria method in an attempt to standardize it in regional planning studies and to inspire similar studies in which different criteria can be used to achieve the maximum efficiency.

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Keywords Bafra · Biocomfort · Flood · Overflow · Site selection

Introduction

Today, the most important problems in the world are population growth-related problems. The world total population, which was around 717 million in 1750, exceeded 1.5 billion in 1900, reached 6 billion in 2000, and it is estimated to reach 8.5 billion by 2030 (Gültekin 2020). Increasing population produced many problems such as environmental pollution, global

climate change, unplanned urbanization, and unhealthy living conditions (Sevik et al. 2019).

One of the biggest side effects of the increasing population is unplanned urbanization. Unplanned urbanization is often exacerbated by migration from rural to urban areas. While only 9% of the total population lived in urban areas in the 1900s worldwide, this rate increased to 47% in 2000, and it is estimated that 60–90% of the world's population will be living in urban areas by 2030 (Şen et al. 2018; Cetin et al. 2017a, b). In Turkey, this rate is even higher as 92.5% of the total population lives in urban areas currently (TUIK 2020).

Both the increasing population and migration from rural to urban areas lead to inevitably opening new areas for settlement in urban centers. In order to meet the increasing demand for residential areas, local governments make decisions according to criteria that are not entirely based on scientific data, and this can cause major problems that result in loss of lives and properties. However, determining the areas to be settled in a region is an extremely serious issue that needs to be strictly and properly planned, which means involving many criteria.

These criteria that need to be taken into consideration in determining new residential areas are emphasized in this study. An example of site selection in this subject is examined in the case of Bafra, which is one of the increasingly populated areas in our country. Within the scope of the study, it was aimed to determine the most suitable areas in terms of settlement by using flood, overflow, protected areas, energy transmission lines, and biocomfort data.

Materials and method

Study area

The study was conducted in the scale of Bafra (41° 33' 45.72 N, 35° 54' 21.24 E), which is one of the largest districts of Samsun, which in turn is one of the largest cities of Turkey. Bafra is located in an area that is highly preferred as a residential area due to its location, edaphic and climatic conditions, and therefore, attracts an increasing population every year, deeming it obligatory to continuously open up new residential areas. The geographical location of the study area is given in Fig. 1.

Method

Firstly, data of the study area were collected, and risk classes maps were created in terms of floods and avalanches. At this stage, some data was obtained from official institutions, and sub-variables were produced using these data. Landslide inventory is the basic data for landslide susceptibility analysis. In order to estimate the landslides that may occur in the future, the first thing to do is to determine the main features of the sites in the inventory map (Erener et al. 2016). Between 1983 and 2016, landslide inventory map was used in 458 of 565 studies in statistical-based landslide susceptibility studies (Reichenbach et al. 2018). In this study, 271 landslides existing in the 1/25,000 scale landslide inventory map of MTA in 2007 were used as the lithology basic data. Seventy percent of 271 landslides were analyzed to test the landslide susceptibility map, and the remaining 30% were not included in the calculations for control purposes.

Lithology is the main parameter used in almost all landslide susceptibility studies. In some studies, while lithology was explained by stratigraphic age and lithologies of rocks (Lee and Min 2001; Ilia et al. 2015), in others, formation names were also included (Akıncı et al. 2010; Akıncı et al. 2014; Pourghasemi et al. 2014).

1/25,000 scale digital geology map used in this study was obtained from MTA. The digital map has been converted to the ESRI GRID format, and subsequently, susceptibility maps have been produced. The digital map has been correlated according to the 1/100,000 scale geology study (E36–F36, E35) by MTA Turkey, and 16 different lithologies have been surfaced in the study area (Uguz and Sevin 2009; Keskin 2011).

In the production of landslide susceptibility maps, the frequency-rate method is used to find the relationship between the locations of each factor affecting the landslides that occurred in the past and the landslides that may occur in the future (Lee and Min 2001; Clerici et al. 2002; Vijith and Madhu 2008; Erener and Düzgün 2010; Termeh et al. 2018). FR is defined as the ratio of the probability of occurrence of an event to the probability of its non-occurrence (Akıncı et al. 2010; Rasyid et al. 2016; Fayez et al. 2018). In calculating the frequency ratio method, the information of past landslides (inventory) has—due to their location—been divided into factors. Pixel numbers are generated by classifying each factor and using GIS functions. The following formula is used for frequency ratio calculation.

Fig. 1 The showing of geographical location of Bafra



$$FR = \frac{PLO}{PIF}$$

PLO refers to the percentage of landslide presence in each sub-category of a landslide factor, while PIF represents the percentage of each category of a factor that affects the landslide. In the frequency table, PLO in percentage is calculated as A/B and PIF in percentage as C/D . In these relations, A refers to the number of landslide cells of each subclass in the study area, B refers to the total number of landslide cells in the study area, C refers to the number of cells in each category of the study area, and D refers to the total number of cells in the study area (Huang et al. 2018). Numbers greater than 1 represent high correlation, and numbers less than 1 represent low correlation. The frequency ratio calculated for each category is shown on the dependent layer using ArcGIS 10.5. In the continuation of the process, all layers were overlapped, and the landslide susceptibility

index (HDI) was found. Thematic maps showing five risk classes for the study area were produced by applying the produced FR to all data sets.

In the production of overflow fields, thematic maps showing five risk classes for the study area were produced by applying a 5000 mt of buffer to the streams produced from drainage networks. The Kızılırmak Delta Bird Sanctuary in the study area is an area that is listed in the UNESCO World Heritage List and cannot be opened for settlement due to it being under protection. Along with this area under protection, high-voltage power transmission lines, which are inconvenient for establishing a residential area, are also represented on digital maps.

Later, biocomfort maps were created by using the long-term climate parameters of the region. Interpolation techniques were applied to temperature, and relative humidity data were obtained from the meteorological stations in the study area. The spatial

interpolation technique coordinates are algorithms that produce values between certain points. There are many interpolation techniques in GIS. Co-Kriging, Kriging, inverse distance weighted (IDW), radial basis functions, kernel, and natural neighbor are the most important of these algorithms (Cetin et al. 2010, 2018a; Cetin 2015, 2016, 2019, 2020; Adiguzel et al. 2019; Kaya et al. 2018). Inverse distance weighted and Co-Kriging techniques were used for this study.

The most commonly used IDW technique among the interpolation methods is

$$F(x, y) = \sum_{i=1}^n W_i f_i$$

where n is the number of abutments at the surface, f_i shows known data values at the fulcrum, and W_i weights;

$$W_i = \frac{\frac{1}{D^{p_{ij}}}}{\sum_{i=1}^n \frac{1}{d^{p_{ij}}}}$$

Here, p is known as “power parameters,” and p is between 0 and 5. In the Shepard method, the p value is generally chosen as 2. If the p value is 2 according to Shepard method, it is called inverse square distance. (Cetin 2015; Cetin 2016; Tunçay et al. 2016; Cetin et al. 2019; Cetin 2019).

Another technique used is Co-Kriging technique:

$$Z_1(S) = \mu_1 + \varepsilon_1(S)$$

$Z_2(S) = \mu_2 + \varepsilon_2(S)$ is calculated with the formula

where μ_1 and μ_2 including unknown constants $\varepsilon_1(S)$ and $\varepsilon_2(S)$ show two random errors. Co-Kriging $Z_1(S_0)_1$ tries to guess, but in doing so it also deals with covariance information (Cetin 2015; 2016, 2019, 2020; Cetin et al. 2019; Zeren Cetin and Sevik 2020; Zeren Cetin et al. 2020).

New Summer Index has been preferred for the determination of bioclimatic comfort conditions for summer in Samsun. The fact that this index has a classification for coastal area and has been used in similar bioclimatic comfort studies has been decisive in its preference in this study.

Introduced for the first time in 2000, the New Summer Index (SSI) was presented at the American Society of Heating, Refrigeration and Air

Conditioning Engineers (ASHRAE) meeting in California and validated by tests conducted by Kansas State University (Güçlü 2009; Tzenkova et al. 2007).

New Summer Index; $SSI = 1.98 [Ta - (0.55 - 0.0055Ur)(Ta - 58)] - 56.83$ calculated using the formula. Ta in the formula, the air temperature ($^{\circ}F$), Ur represents relative humidity (Güçlü 2009; Pepi 1987; Tzenkova et al. 2007).

In the last stage of the study, all the maps created were overlapped, and the areas with low risk of flood and overflow, which are not in the area under protection and on the energy transmission lines route and suitable for biocomfort conditions, were determined, and thus, the most suitable areas to set up a settlement area on were determined according to the aforementioned multi-criteria.

Results

The map of risk groups created in terms of flood within the scope of the study is given in Fig. 2.

According to the map of risk groups in terms of floods created as a result of the study, approximately 27.24% of the total study area were determined to be class 1, 14.59% class 2, 24.34% class 3, 16.49% class 4, and 17.34% class 5 lands. Considering that the 1st and 2nd class lands have low flood risk and 3rd class lands are medium risk lands, approximately 66.17% of the total area can be accepted as suitable for settlement. The map of risk groups created in terms of overflow is given in Fig. 3.

According to the risk groups' map in terms of the overflow created as a result of the study, approximately 11.92% of the total study area was determined to be class 1, 19.05% class 2, 29.67% class 3, 19.86% class 4, and 19.5% class 5 lands. Considering that the 1st and 2nd class lands have low overflow risk and 3rd class lands are medium risk lands, approximately 60.64% of the total area can be considered suitable for settlement. Energy transmission high-voltage lines, which are not suitable for establishment in protected areas and settlements in the study area, are given in Fig. 4.

Areas in which settlement is not legally possible and power transmission lines where settlement is extremely risky in the study area cover approximately 4.29% of the study area. Using the climate data and topographic data of the study area, the areas suitable for biocomfort are given in Fig. 5.

When the regions of the study area that are classified as comfortable and uncomfortable are examined, it is determined that the southern part of Bafra is largely uncomfortable, and the uncomfortable areas other than this are centered upon the eastern part of the district, and a very small area in the west of the district is uncomfortable. It has been determined that approximately 69.34% of the study area is comfortable, and 30.66% is not comfortable.

On the maps of flood and overflow risk groups created within the scope of the study, 1st, 2nd, and 3rd class lands are classified as lands with low or moderate flood and overflow risk, and these lands are accepted as suitable areas to establish a residential area. Establishing a residential area in protected lands is prohibited by law; it is inconvenient to establish residential areas in areas where energy transmission lines pass. Establishing a residential area in areas not suitable for biocomfort is not considered suitable for human health, psychology, and energy efficiency. Therefore, by considering all these criteria, the most suitable areas for establishing a

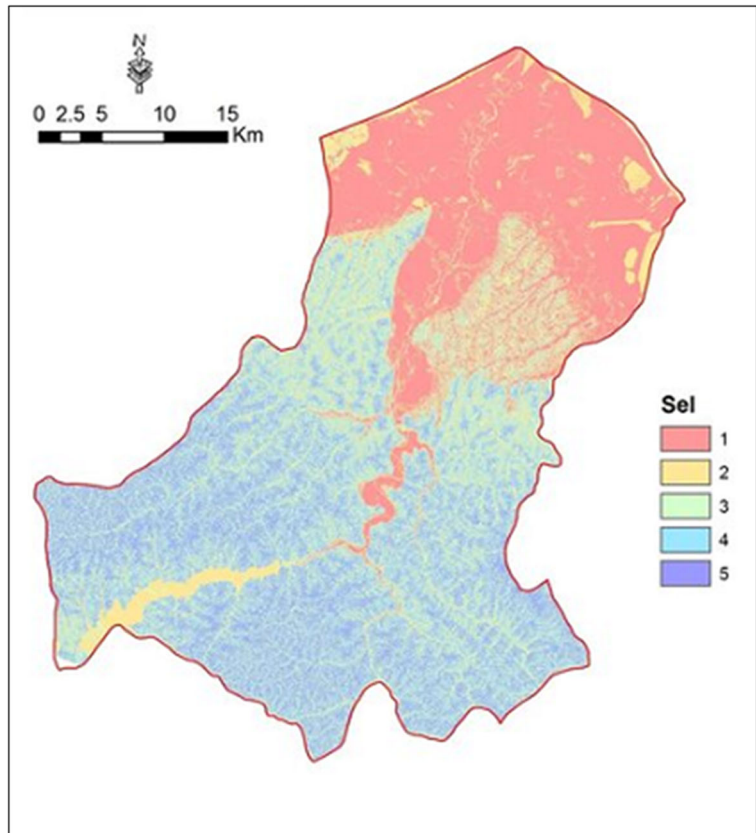
residential area were determined, and these areas are shown in Fig. 6.

When the areas suitable for establishing a residential area in terms of the criteria subject to the study are analyzed, it is seen that these areas are centered more in the central parts of Bafra. In general, the northern part of Bafra is the section where the slope is very low and the southern section is with the highest slope. The ratio of the areas determined as suitable for the establishment of a residential area to the total study area is calculated as only 1.96%. Therefore, approximately 98.04% of the study area is evaluated not suitable for settlement in terms of at least one of the criteria subject to the study.

Discussions

Increasing population and village-to-city migration in many parts of the world makes it mandatory expanding residential areas in city centers; however, the opening of new residential areas is generally carried out in line with

Fig. 2 Map of risk groups in terms of flood



the opinions of local administrators without any criteria. However, selection of the wrong site has consequences that may cause the loss of lives of people and huge amounts of material loss every year.

It is stated that 2238 overflow events occurred in the world between 1900 and 2008, about 2 billion people were affected and about 3 million people lost their lives. As a result of these overflows, \$200 billion of material damage occurred. In the last 20 years, 49% of 560 thousand people who died as a result of floods, earthquakes, fires, storms, and volcano eruptions have lost their lives due to floods and overflows, and natural disasters where the most casualties were experienced were floods and overflows (Dölek 2013).

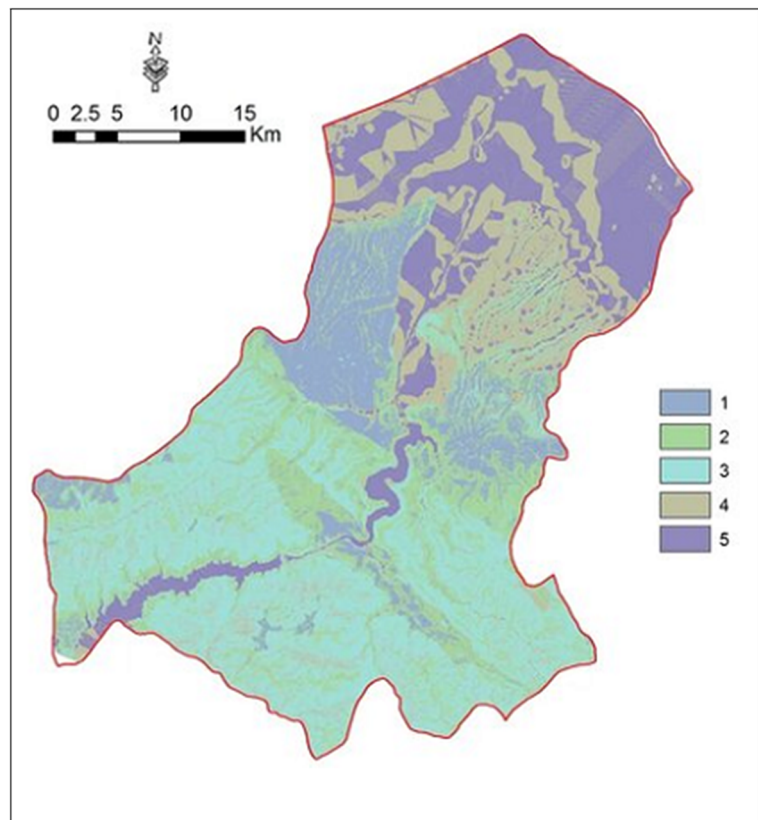
Floods and overflowing can lead to the death of large numbers of people in a short time and cause a great extent of damage. For example, in the flood that occurred on 27–30 July 2010 in Eastern Hindu Kush region in Pakistan, approximately 1800 people died, tens of billions of US dollars of economic losses occurred, and more than 20% of the land and more than 14 million people were affected (Mahmood et al. 2019).

Harvey hurricane and flood disaster in America damaged more than 204,000 buildings and caused about \$125 billion of damage (Mukherjee and Singh 2019).

Flood and overflow disasters are also common in our country and cause significant material damage besides loss of life. For example, 17 people died in the flood disaster that took place in the Western Black Sea between 20 and 21 May 1998, one of the floods that occurred in our country; and in Turhal floods in 2–3 March 2005, besides many houses, asphalt roads, municipal facilities, and abattoir buildings underwent great damage (Zeybek 2009). In the flood/overflow disaster that took place in Batman on 31 October–1 November 2006, heavy damage occurred in 1154 residences, 176 barns, and workplaces (Tonbul and Sunkar 2011).

Between 8 and 12 September 2009, in the flood disaster in Thrace and especially in Istanbul and its surroundings, the Thrace region was severely affected by the flood, and the disaster resulted in 32 loss of lives and caused damage in 3816 residences and 490 workplaces. Apart from structures such as factories, highways, and bridges near the stream beds, settlements

Fig. 3 Risk groups' map in terms of overflow



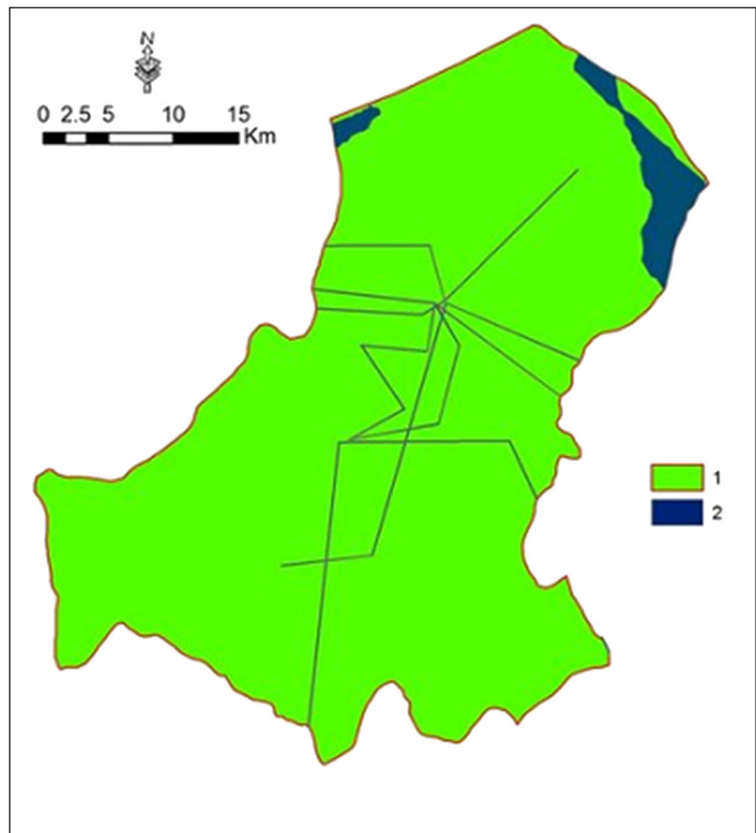
established near the stream beds were damaged by the flood. The heavy rains that affected the Aegean coast on 3–4 November 1995 caused sudden overflows in and around İzmir, and as a result, 61 people died and hundreds of buildings and settlements were damaged (Kömüscü et al. 2011). In our country, 695 overflow events occurred between 1975 and 2010; as a result, 634 people died, 810,000 hectares of land were flooded, and approximately 3.7 billion dollars of material damage occurred (Dölek 2013).

Moreover, it is stated that the incidence of these disasters on a global scale has increased in recent years. For example, the Houston region alone has witnessed the three strongest floods that have occurred over the past 4 years, over a 500-year period (Mukherjee and Singh 2019). As it is seen, although floods and overflows are one of the major problems for our country and the whole world, the risks of floods and overflows are not sufficiently taken into account in the establishment of residential areas, and this causes large damages and losses of lives as a result of floods and overflows.

One of the criteria that is not given sufficient importance in the selection of the residential area is suitable areas in terms of biocomfort. Human life is greatly affected by the climate. In order for people to feel comfortable, the environment must be within a certain temperature, humidity, and wind range. The situation where the temperature, wind speed, and humidity values in the environment are within the appropriate ranges for people is called as “bioclimatic comfort” or, shortly, “biocomfort.” When the biocomfort values are not within the proper range for people, people are disturbed in those areas and want to get away from them (Cetin 2016).

While the temperature below or above these values that are deemed comfortable can cause nervousness and weakness, it can also cause various problems in the circulatory and respiratory system, burns in the eyes, and dry throat. Therefore, people try to bring the ambient conditions to suitable ranges for them with the help of clothes, heating or cooling systems, etc. However, bringing the external climate conditions to the value ranges that people want requires a significant amount

Fig. 4 Protected areas and power transmission lines



of energy consumption and therefore costs. It is calculated that the energy consumption in 2030 will be 60% more than today, and the energy consumption in 2030 will be around twice as much in our country. When it is predicted that the population will increase only 1% in the same period, it can be understood how big the increase in energy consumption will be. The amount spent for heating and cooling in this energy consumption has a very important share (Cetin et al. 2018a, b, c; Elhadar 2020; Cetin 2019; 2020; Zeren Cetin and Sevik 2020; Zeren Cetin et al. 2020).

Considering the energy to be spent in order to bring both human satisfaction and the thermal conditions of the people in their environment to comfortable value ranges and the cost of this energy, it can be understood how important it is to determine suitable areas in terms of biocomfort especially in the selection of new settlements (Elhadar 2020).

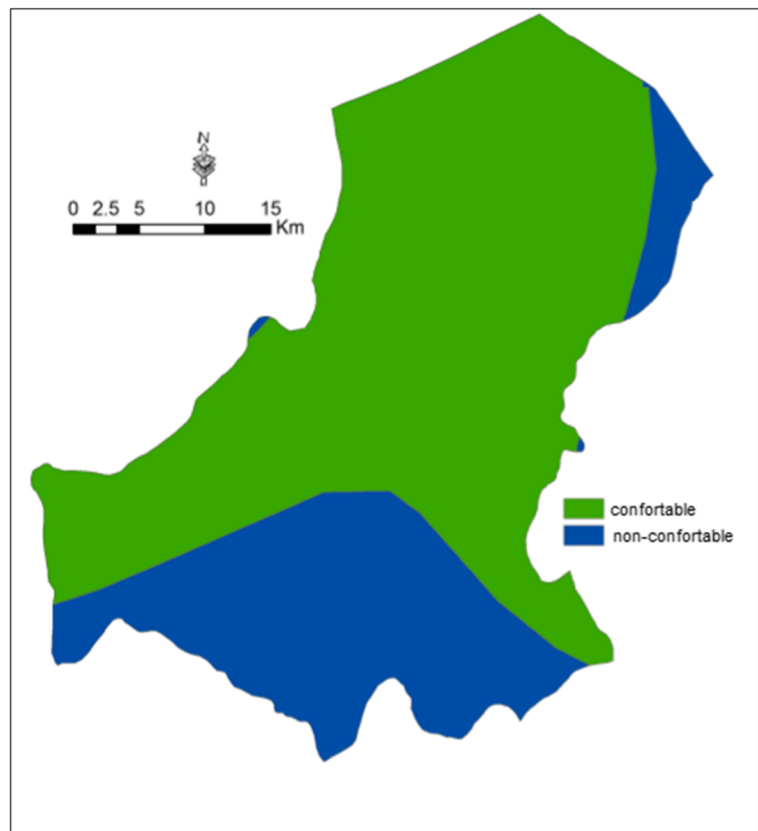
After recognizing the effects of biocomfort on human health, many studies, mostly compilations, have been conducted on issues such as the economic dimension of biocomfort, thermal comfort, and modeling

(Zomorodian et al. 2016; Lodi et al. 2017; Potchter et al. 2018). However, the number of studies on the determination of suitable areas in terms of biocomfort is still very limited.

In Turkey, which is one of the countries with the highest assessment of biocomfort, numerous studies have been carried out to determine suitable areas in terms of biocomfort in different cities. In these studies, suitable areas in Ankara (Çalışkan and Türkoğlu 2014); Erzurum (Bulgan and Yılmaz 2017), Kastamonu and its districts (Cetin 2016; Cetin and Zeren 2016; Cetin et al. 2017a, b), Aydın and its districts (Cetin et al. 2018a; Cetin et al. 2018c), Karabük (Cetin 2018), Elazığ (Cetin et al. 2018b), Bursa (Cetin 2019), Burdur (Cetin et al. 2019), Trabzon (Zeren Çetin 2019; Zeren Cetin and Sevik 2020), Kahramanmaraş (Cetin 2020), Bartın (Zeren Cetin et al. 2020), and Şanlıurfa (Kolbüken and Aytaç 2020) in terms of comfort were tried to be determined.

It is very important that the choice of residential area, which is of great importance in terms of both safety and comfort in people's lives, is not based on a single

Fig. 5 Areas suitable in terms of biocomfort



criterion but according to multi-criteria, in order to significantly reduce the loss of life and property in possible disasters. In addition, evaluation of criteria such as bioconformance can also provide significant advantages in terms of comfort and energy efficiency, in addition to safety. Remote sensing techniques, which allow the evaluation of large areas with minimum cost, are very useful when choosing a residential area. These techniques are used today in determining the risky areas in terms of natural disasters such as erosion (Arabameri et al. 2019), earthquake (Yariyan et al. 2020), and flood (Felsoni et al. 2020). GIS techniques based on multi-criteria are used in the selection of locations for areas such as garbage storage areas, road routes, and power plants, with the evaluation of different factors, especially natural disasters (Mohamed et al. 2019; Danesh et al. 2019; Kaya et al. 2020; Şakar et al. 2020).

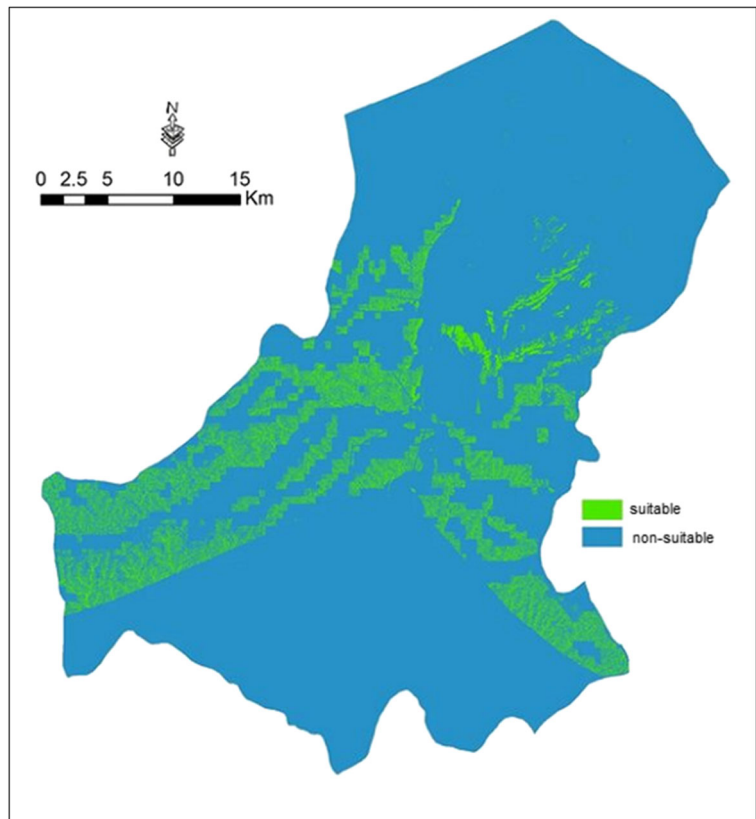
Decision making according to multi-criteria is used in different areas, but the number of studies related to its use in residential area is quite insufficient. When studies on the selection of residential area until today are examined. However, when the studies conducted to date are

analyzed, most of the studies focus only on a certain factor, and the number of studies evaluating more than one risk factor on the same area remains quite limited. When considered from this point of view, it is thought that this study will contribute significantly to the literature and give a new perspective to the subject.

Conclusions

Increasing population and migration to urban areas require new residential areas in some regions. However, the selection of these areas, namely, the determination of new settlement areas, is made today as a result of the personal decisions of the directors, far from scientific data. However, wrong site selection and establishment of residential areas in these areas may cause loss of life and property as a result of various natural disasters in the following years. However, before the establishment of new settlements, risk analysis for possible disasters such as floods and overflows and the establishment of

Fig. 6 Areas suitable for establishment of a residential area



settlements in low-risk areas can prevent major disasters from the very beginning.

One of the proposed criteria to be considered in the selection of residential areas is the areas suitable in terms of biocomfort. Settlements to be set up in comfortable areas will both enable people to live in areas where they will feel more comfortable, thereby affecting the peace, health, and happiness of the people, as well as significantly saving energy.

The criteria evaluated within the scope of the study can be a guide in the planning in the region subject to the study. However, diversifying and increasing similar studies, including factors such as fire, avalanches, earthquakes, as well as factors affecting peoples' health and happiness such as air quality and vegetation, and using a method that will be created with the participation of scientists from different fields with a multidisciplinary approach to the country's economy in site selection can make a big contribution to people's peace, health, happiness, and comfort. Although these studies are perceived as costly studies at the initial stage, considering the long-term benefits, it is hoped that the planning cost is very low. Therefore, it is of great importance in many respects to carry out such studies and to use them as a guide in urban planning studies.

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