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GIS-Based Land Suitability Analysis for Sustainable Urban Development: A Case Study in Eskisehir, Turkey

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Abstract

Suitable site selection for sustainable urban development is one of the critical and complex issues in urban planning. Since in the selection of land for urban development, many criteria must be considered and analyzed, it is required to use the most effective techniques to identify the best location for urban expansion. In order to consider the environmental sustainability in site suitability analysis, using Geographic Information System (GIS) can help for successful analysis and decision making. This study aims to find the most suitable location for sustainable urban development in Eskisehir province based on six main planning criteria, including ten sub-criteria. Safety, connectivity, socio-economic, compactness, topography, and eco-environmental conservation were considered as the main planning goals. Geophysical, cultural, and socio-economic data were used to assess land suitability for future urban growth by integrating the Analytical Hierarchy Process (AHP) and GIS. The findings of this research based on multi-criteria decision analysis revealed that the most extensive area has low suitability (44%) for sustainable development, while unsuitable areas represent 42% of the total area of the city. Areas with the highest suitability were rarely found (0.01%). Very low suitable lands were found as 7% of the total area. Moderately suitable regions constitute 7% of the entire area, which is composed of well-connected regions and can be used as second-degree suitable land for future sustainable urban development in the study area. The study presents an insight into sustainable urban development using GIS techniques and highlights the significant constraints that the city is facing.

Keywords
GIS-based multi-criteria evaluation; Land suitability analysis; Land-use planning; Sustainable urban development; AHP; MLC

Sürdürülebilir Kentsel Gelişme için CBS Tabanlı Arazi Uygunluk Analizi: Eskişehir Örneği

Öz

Kentsel gelişim için uygun alanların seçimi kentsel planlamada kritik ve karmaşık konulardan biridir. Kentsel büyüme için yer seçiminde pek çok kriter göz önünde bulundurulmalı, karşılaştırılmalı ve uygun yöntemler kullanmalıdır. Çevresel sürdürülebilirliği sağlayabilmek adına kentsel gelişim için yer seçimi analizinde, coğrafi bilgi teknolojilerinin kullanılması, doğru analiz ve doğru karar vermede yardımcı olabilecek güçlü yöntemlerden biridir. Çalışmanın amacı, Eskişehir il genelinde 6 ana planlama kriterine bağlı, toplamda 10 alt kritere dayanarak sürdürülebilir kentsel gelişim için uygun yer bulmaktır. Çalışmada kullanılan 6 ana planlama kriteri doğrultusunda, güvenli (risk ve afet), kolay ulaşılır (ulaşım), bütünleşik (mevcut kentsel alanlara bitişik), sosyo-ekonomik açıdan eşit (eğitim ve sağlık hizmetleri açısından eşitlik), ekolojik (çevreye duyarlı) ve kentsel gelişime uygun az eğimli yerler seçilmeye çalışılmıştır. Eskişehir il genelinde kentsel büyümeye uygun yerleri belirlemek amacıyla fiziki, kültürel, sosyal ve ekonomik veriler kullanılmıştır. Çalışmada belirlenen kriterlere göre il sınırları içerisinde kalan alanın % 44'ü kentsel büyüme için düşük uygunluğa sahip iken, % 42'si uygun olmayan alan olarak hesaplanmıştır. Kentsel gelişime en uygun yerler ise % 0,01 oranında bulunmuştur. Ayrıca il sınırları

Anahtar Kelimeler
CBS tabanlı çok kriterli değerlendirme; Arazi uygunluk analizi; Arazi kullanım planlaması; Sürdürülebilir kentsel gelişme; AHP; MLC

içerisinde kalan toplam alanın % 7'si kentsel büyüme için çok düşük uygunluğa sahipken, %7'si de orta derecede uygun alan olarak bulunmuştur. Diğer bir deyişle, %7 oranında orta derecede uygunluk derecesine sahip alanlar, gelecekte kentsel büyüme için ikinci derece uygun alanlar olarak kullanılabilir. Çalışma, CBS tekniklerini kullanarak sürdürülebilir kentsel kalkınma hakkında bir fikir vermekte ve kentin karşı karşıya olduğu önemli kısıtlamaları vurgulamaktadır.

1. Introduction

Today, more than half of the world's population resides in urban areas, and this is due to socio-economic reasons which lead people to move from rural areas to urban areas (Desa 2014). Therefore, the trend towards urbanization is increasing, which results in the growth of the urban population and the extent of urban areas (Desa 2014). In recent decades, due to concerns over clean air and water, climate change, and land-use, sustainability has attracted attention, especially sustainable urban planning (Wheeler and Beatley 2014). Since changes in urban population result land-use change, effective land-use planning is needed to evaluate the best land areas for urban growth. According to the FAO definition, the term "land-use" is related to human activities on land, such as agriculture, buildings, roads, etc. While the term "land cover" describes both the natural and the artificial features present on the surface of the earth. Land-use planning is defined by the Food and Agriculture Organization of the United Nations (UNFAO) as "the systematic assessment of land and water potential, alternatives for land-use and economic and social conditions in order to select and adopt the best land-use options" (FAO 1993, p. 1). In the land-use planning process, the ecological, environmental, and socio-economic aspects, including the sustainability of land-use, are needed to be taken into consideration (FAO 1993, 2007). Protection of the environment and cultural heritage plays an important role in urban planning. Preservation of cultural heritage assets means maintaining the history of a nation (Doğan and Yakar 2018). Thus, evaluation of land suitability and effective land-use planning is vital for sustainable urban development (Nguyen et al. 2015, Scholten and Stillwell 2013).

Planning includes a variety of activities and exists in many variations undertaken at different spatial scales that differ with respect to many distinctions (Scholten and Stillwell 2013, Van Assche et al. 2013). Spatial planning is a coordinated set of policies, practices, and scientific discipline, which is concerned in shaping and governing spaces considering socio-economic and eco-environmental issues (Van Assche et al. 2013).

Information has an important role in planning, and it is vital in achieving the objectives of planning (Scholten and Stillwell 2013). Scholten and Stillwell (2013) define planning as information processing activity; therefore, all of the information which is used in the planning process must be organized, managed, and presented in an appropriate form. Since large amounts of spatial data with their attributes are involved in multi-criteria environmental planning, which can be in different types and extensive in quantity and quality, thus only a system like Geographic Information System (GIS) can provide the framework to undertake these activities. Accordingly, numerous spatial decision-making issues lead to the GIS-based Multi-Criteria Decision Analysis (MCDA); therefore, the integration of these two areas of research gives best results in suitability modeling (Malczewski 2006). In modern urban planning, remotely sensed datasets are the fundamental information, providing accurate and reliable information for planning and management that can be further integrated with many other spatial attributes. The integration of Remote Sensing (RS) and GIS enabled with multi-criteria evaluation methods, facilitates a better understanding of real planning problems and provides extremely useful decision support to the analyst (Akanbi et al. 2013, Chen 2016, Scholten and Stillwell 2013, Taranto 2007, Yeh 1999). Considering the increasing scientific applications of GIS, it has been recently referred to geographic information science or GIScience. Blaschke et al. (2014) define GIScience as a multidisciplinary and multi-paradigmatic rapidly developing field with fuzzy boundaries, which cannot be demarcated to a particular field.

Sustainable urban planning requires the involvement of various disciplines, including architecture, engineering, ecology, environmental science, economic development, law, and politics, among others. Hence experts' opinion from various fields is strongly required in the planning process (Aburas et al. 2017, Chen 2016).

According to the year 2017, the population growth rate of Eskisehir city is 1.85 %. Therefore, it is required to pre-determine the new location for future sustainable urban development in this city. This study aims to integrate the GIS-based Weighted Linear Combination (WLC) technique with the Analytical Hierarchy Process (AHP) to analyze and find the most suitable areas for sustainable urban development in Eskisehir city. The study shows the significance of GIS and remote sensing application in spatial decision making in a case study of sustainable city development.

2. Methodology

Site selection for sustainable urban development was the purpose of this research. To achieve the aim of the study, the following processes were performed. First, the study area and planning criteria were defined. The main urban planning goals were defined as follows (Chen 2016): safe city, ecological city, connected and compact city, and city of equality. Then the required data were collected and pre-processed accordingly. Subsequently, GIS-based multi-criteria decision analysis was performed. Finally, by conduction spatial data analysis, the suitability map was created, and the results were presented.

2.1. Study area

Eskisehir province was selected as the study area. Eskisehir is located in the north-western of Central Anatolia Region of Turkey between latitudes 39-40°N and longitudes 29-30°E. The city is 78 km to the northeast of Kutahya, 233 km to the west of Ankara, and 324 km to the southeast of Istanbul. It is located on the banks of the Porsuk river with an elevation of 782 m. The province has 14 districts and covers an area of 2,678 km^2. Based on 2017 statistics, the urban population of the city is 784,036, with a metropolitan population of 860,620 and an annual growth rate of 1.85% (HTTP. 1). Eskisehir is one of the leading cities with a modern, regular, and high rate of urbanization. The city is known as a university town. In terms of socio-economic development, it is one of the most important cities in Turkey. The economy of the city is based on services (60%), industry (30%), and agriculture (10%) (HTTP. 2). Eskisehir has a humid continental climate with a warm summer and cold and snowy winter. The average minimum and maximum temperature reach -3.5 °C and 29.1 °C, respectively. The average amount of annual precipitation is about 400 mm. The urban settlement and commercial areas are mostly flat.

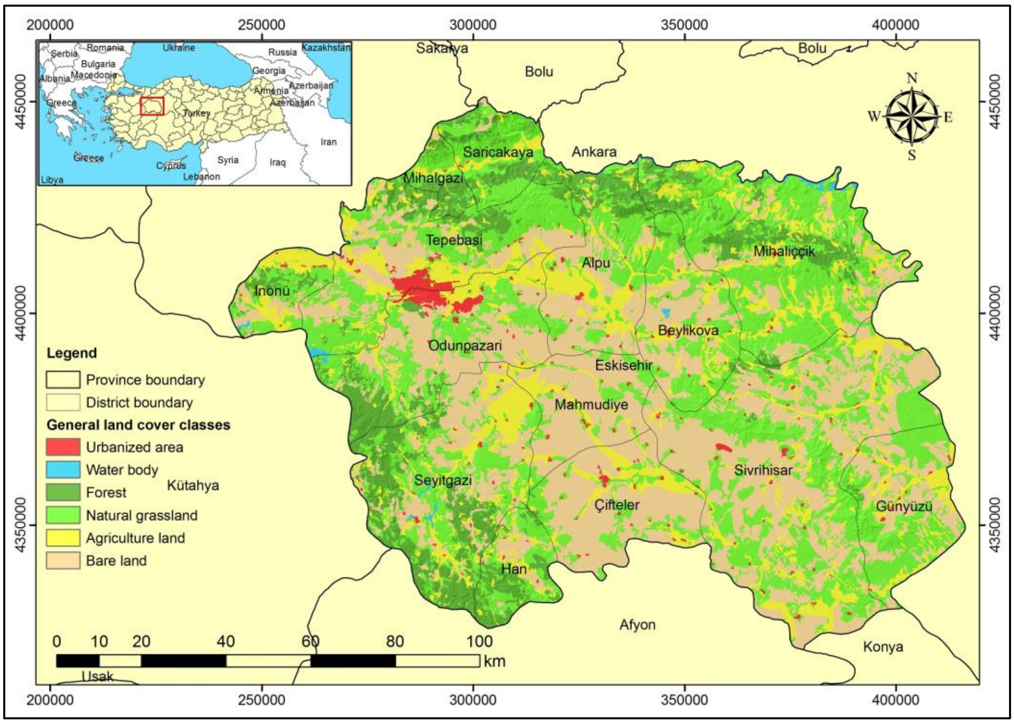

Figure 1. Study area

2.2. Materials

To achieve the study goals, the criteria table was prepared, and related socio-economic and physical environment data were collected from different sources such as remotely sensed satellite data and thematic maps. Preprocessing such as mosaicking, coordinate transformation (projection), resampling, and subsetting was performed on each raster and vector data to prepare the data for analysis. Table 1 shows the collected data used in spatial analysis.

Table 1. Data used in spatial analysis.

Data	Data type	Data source
Digital Elevation Model (spatial resolution, 30 m)	Raster	United States Geological Survey (USGS)
Land cover (resolution, 100m)	Raster	European Environment Agency, CORINE 2012
Geological data	Vector	Hydrogeological Map of Eskişehir and Inonü Plains (DSI). Eskisehir Geological Map made by MTA.
Fault lines	Vector	Hydrogeological Map of Eskişehir and İnönü Plains (DSI). Eskisehir Geological Map made by MTA.
Protected areas	Vector	Eskisehir Regional Directorate of Forestry, Department of Water Affairs. Data collection and preparation: (Ağaçsapan and Çabuk 2016)
Hydrological data (Streams)	Vector	European Environment Agency
Roads	Vector	OpenStreetMap
Built-up	Raster	European Environment Agency
Educational centers	Vector	Google Maps
Health centers	Vector	Google Maps

2.3. Methods

The flowchart of the overall methodology adopted in this study is shown in Figure 2. For the purpose of land suitability analysis for sustainable urban development, GIS techniques and Analytical Hierarchy Process (AHP), introduced by Saaty (1987) were used. AHP is one of the useful multi-criteria decision analysis methods, which is widely used in GIS-based decision analysis (Aburas et al. 2017, Bozdağ et al. 2016, Saaty 2008)

Along with the AHP, weighted overlay analysis was performed in the ArcGIS environment. Weighted overlay analysis is a group of methodologies and one of the most commonly used approaches for solving multi-criteria problems, especially in optimal site selection or suitability modeling. The analysis was performed according to the following steps: firstly, the problem was divided into sub-models, then the significant layers were determined, and geoprocessing operations were performed on each input layer.

Then, the layers were reclassified and standardized to make the data comparable and combinable with each other. In this stage, the common scale of 1 to 5 was selected, in which higher values indicate more suitable locations for urban growth.

Subsequently, using the AHP method, factor weights were determined by pairwise comparison matrix. The criteria influence weights were defined based on the literature review (Akbulut et al. 2018, Aburas et al. 2017, Aburas et al. 2015, Chen 2016, Kumar and Shaikh 2013) and experts' opinion.

After transforming the data within a layer and determining criteria weights, the input thematic maps were superimposed using the weighted overlay method. Finally, after computations and analysis, suitable and unsuitable areas were identified in the final suitability map. A Detailed description of the methodology is presented in the following sections.

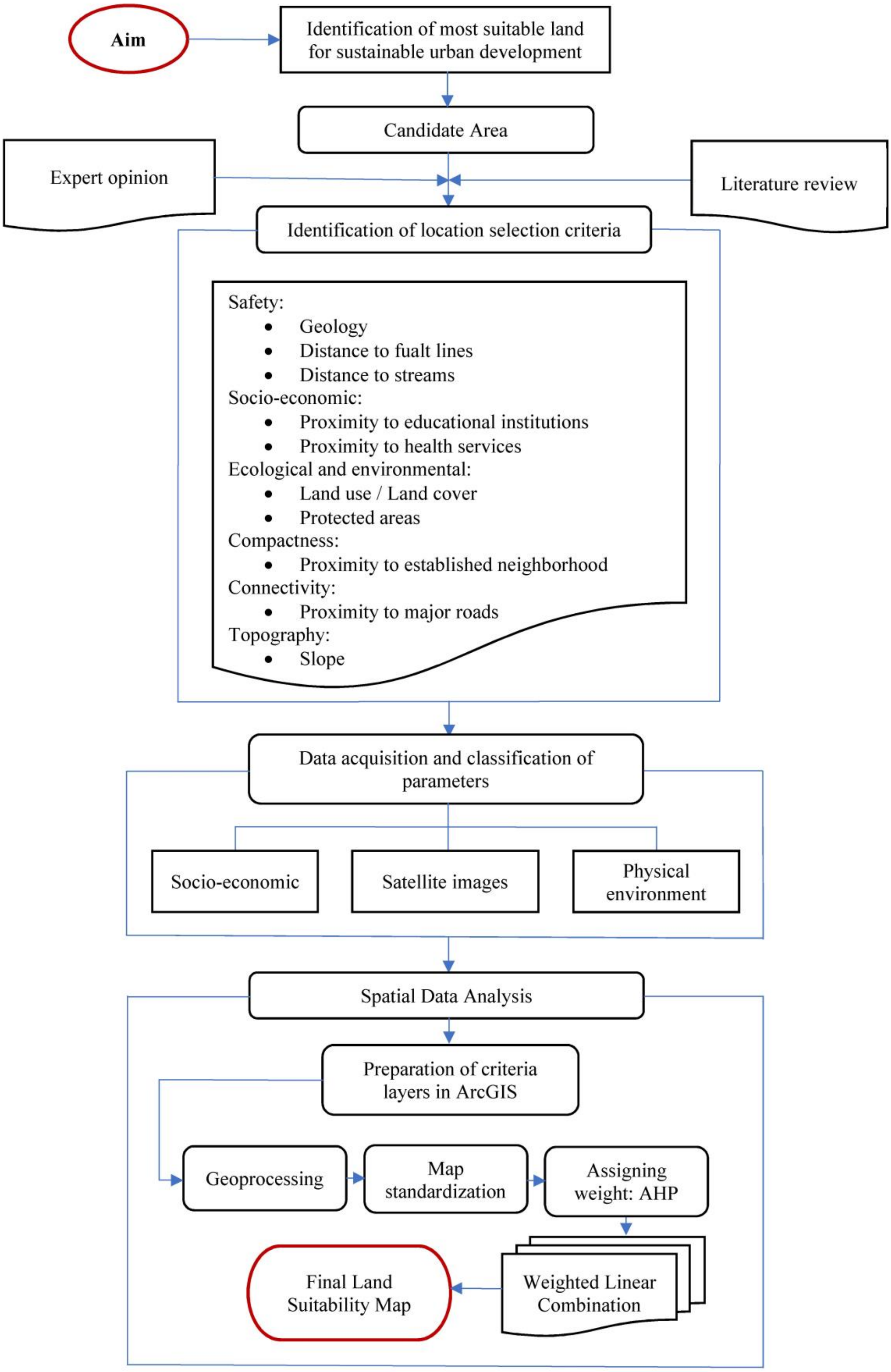

Figure 2. Overall flowchart of the research methodology

2.3.1. Defining and creating planning criteria layers

In order to identify the most suitable areas for future urban development, socio-economic and environmental factors must be considered to ensure sustainability (Aburas et al. 2017, Chen 2016)). Eskisehir has experienced a remarkable development in recent years; education, health, professional services, and commerce represent a notable contribution to the community. This development has become an essential source of employment. Education, health, and transport infrastructure are the anchors of growth. The presence of major roads and infrastructure contributes to the connectivity between neighboring cities providing opportunities for growth in Eskisehir. By completing and improving what has already been built, the benefits of past investment will increase. Furthermore, it will settle people in proximity to one another and lead to job creation. Additionally, geographical characteristics and natural resources provide extra value to the city.

In this study, ten criteria were selected for evaluating land suitability. The six main planning criteria considered as the primary planning objectives of the study are:

1) Safety: The new development area must be safe from natural hazards and disasters; therefore, areas with a certain vulnerability should be avoided in future development. Thus, to avoid geohazards, the following three factors were defined as sub-criteria for the safety factor of the land suitability analysis:

<u>Geological stability:</u> Any engineering structure requires detailed knowledge of engineering geological properties of the foundation as well as the material used for construction (Tudes 2012, Culshaw and Price 2011). To prevent related hazards, the new urban area should be placed on the most stable geological formation. Eskisehir city is characterized by widely distributed alluvium soil deposited by different processes, conglomerate, siltstone, claystone, limestone, shale, marl, and other hard rocks (basalt, granite, andesite, etc.). For this purpose, the geological map was reclassified into five categories, and scores were given based on the material type (Figure 3a). The lowest grade was given to areas covered by loose and unstable materials (e.g., alluvial) because these materials are very susceptible to volume changes due to variations in moisture content, which can cause cracking and stability problems in structures built upon such materials (Tudes 2012, Culshaw and Price 2011).

<u>Distance from fault lines:</u> The urban area must be selected at a safe distance from geological fault lines. Eskisehir fault system is generally NW and EW trending zone of active deformation, which predominantly characterized as strike-slip faults (Tudes 2012, Culshaw and Price 2011). The farther a structure to the existing fault line or seismic generator, the lower its magnitude and intensity. To mitigate the risk of earthquake, buffer zones were created using fault lines in the vector map; areas with less than 250 m distance from fault lines were defined as unsafe, and for greater than that, higher scores were gradually given, which the highest grade assigned to distances >1500 m (Figure 3b).

<u>Distance from flood zones:</u> The future development area should be located at a safe distance from flood zones. To avoid flood hazards, buffer zones were created using stream map, and after converting from vector to raster, the map was reclassified and rated based on buffer distances. Areas <500 m away from streams were considered vulnerable and unsuitable, and areas with a distance of 500-750 m were ranked with very low suitability. The ranking score was increased with the increase of distances, where the highest score was given to the areas >1250 m away from flood zones (Figure 3c).

2) Slope: The urban area should be located on relatively flat land because areas with steep and high slope are prone to landslides (Tudes 2012, Culshaw and Price 2011, Akbulut 2018). Due to issues such as flooding, erosion, as well as the cost of construction, steep slopes should be avoided. To analyze the topography of the city, we need the elevation model. For this purpose, eight scenes of the SRTM digital elevation model (DEM) with 30 m resolution were gathered and mosaicked. Subsequently, the slope map was generated in percent increments using the DEM data and reclassified (Figure 3d). After reclassifying the slope map, scores were given based on the slope percentage. Areas with a slope of <5% were considered as potentially suitable, and the suitability was reduced with the increase of slope, where sites with a slope >25% were ranked as unsuitable.

3) Ecology and environment: Since sustainable development is our main objective, conservation of ecosystems and natural resources is of paramount importance. The future urban area should not affect the environment, especially ecologically sensitive areas; flora and fauna must be considered in the establishment of the new urban areas. To develop the city with less damage and negative effects on nature and the environment, forests, green areas, agriculture, and restricted areas should be preserved and protected (Chen 2016, Bozdağ et al. 2016). Today, using science and technology and forward-looking approaches, decision making is quite easy to create a resilient, livable, ecological, and sustainable city. To achieve this goal, the land cover map of the study area was reclassified and ranked as per their suitability (Figure 3e).

The map of protected areas was used as a sub-criterion of the ecological and environmental factor. The land cover and protected area maps were reclassified, in which classes such as natural resources and protected areas were restricted. Buffer zones were created around protected areas (archaeological sites, lakes, natural sites, etc.), and areas with distances greater than 500 m were ranked as suitable sites. (Figure 3f). Keeping sustainability in mind, instead of using soil map as another criterion, agriculture and green areas were given lower scores, and higher scores were assigned to barren and other available areas in the land cover map.

4) Compact city: To take advantage of existing sources, such as infrastructure and facilities, and to reduce the costs of housing development, the future urban area should be in reasonable proximity to the existing built-up areas to consolidate the urban zone and reduce the impacts of urban sprawl (Chen 2016). To achieve this goal, and have a more compact urban form, buffer zones were created around established urban areas on the residential map, and the map was rated based on proximity to buffer zones, where the highest score was assigned to the nearest sites (Figure 3g).

5) Socio-economic (city of equality): Undoubtedly, education and health are the basic requirements of each person; thus, areas for future growth should be reasonably close to existing educational institutions and health services (Chen 2016). This goal is of great importance for urban development. To this end, maps of schools and health services were prepared, and buffer zones were created. Areas with the closest distance were considered highly suitable (Figures 3h & 3i).

6) Connectivity (transport): Eskisehir city is served by well-developed urban transport and roads. Access to existing infrastructure prevents extra costs and provides an opportunity for urban growth and densification. To retain the sustainable connectivity between existing and future built-up areas in the city, the map of major roads was prepared, and buffer zones were created. Regions closest to the main roads (<500 m) were considered to be highly suitable, and the ratings were gradually reduced depending on the distance to the buffers, where areas with distances >2 km were rated with lower suitability scores (Figure 3j).

2.3.2. Determining criteria weights using analytical hierarchy process (AHP)

The AHP method was used to evaluate each criterion and determine the weights of the main and sub-factors. Since multiple important objectives are difficult to prioritize, AHP can serve as a powerful MCDA tool to consider complicated problems that involve several interrelated objectives (Saaty 1987, 2008, Ouma and Tateishi 2014). AHP has the ability to allow a hierarchical structure of the criteria, when allocating the weights, it gives users a better focus on specific criteria and sub-criteria. This provides the active participation of decision-makers in examining all possible options.

The AHP process consists of four principal steps (Saaty 1987, Saaty 2008). The first step is to breakdown the problem into a hierarchical structure. For this purpose, the abovementioned criteria were created and divided into sub-criteria. The second step is to create decision matrices at each level. A pairwise comparison matrix was developed, where each factor was compared with the other factors relative to its importance based on a scale of 1 to 9, where 1 indicates equal preference between two factors, and 9 shows a particular factor which is extremely preferred over the other (1= equal, 3= slightly favors, 5= strongly favors, 7= very strongly favors, 9= extremely favors; 2, 4, 6 & 8 are intermediate values). This pair comparison makes it possible to independently assess the contribution of each factor, thus simplifying the decision-making process.

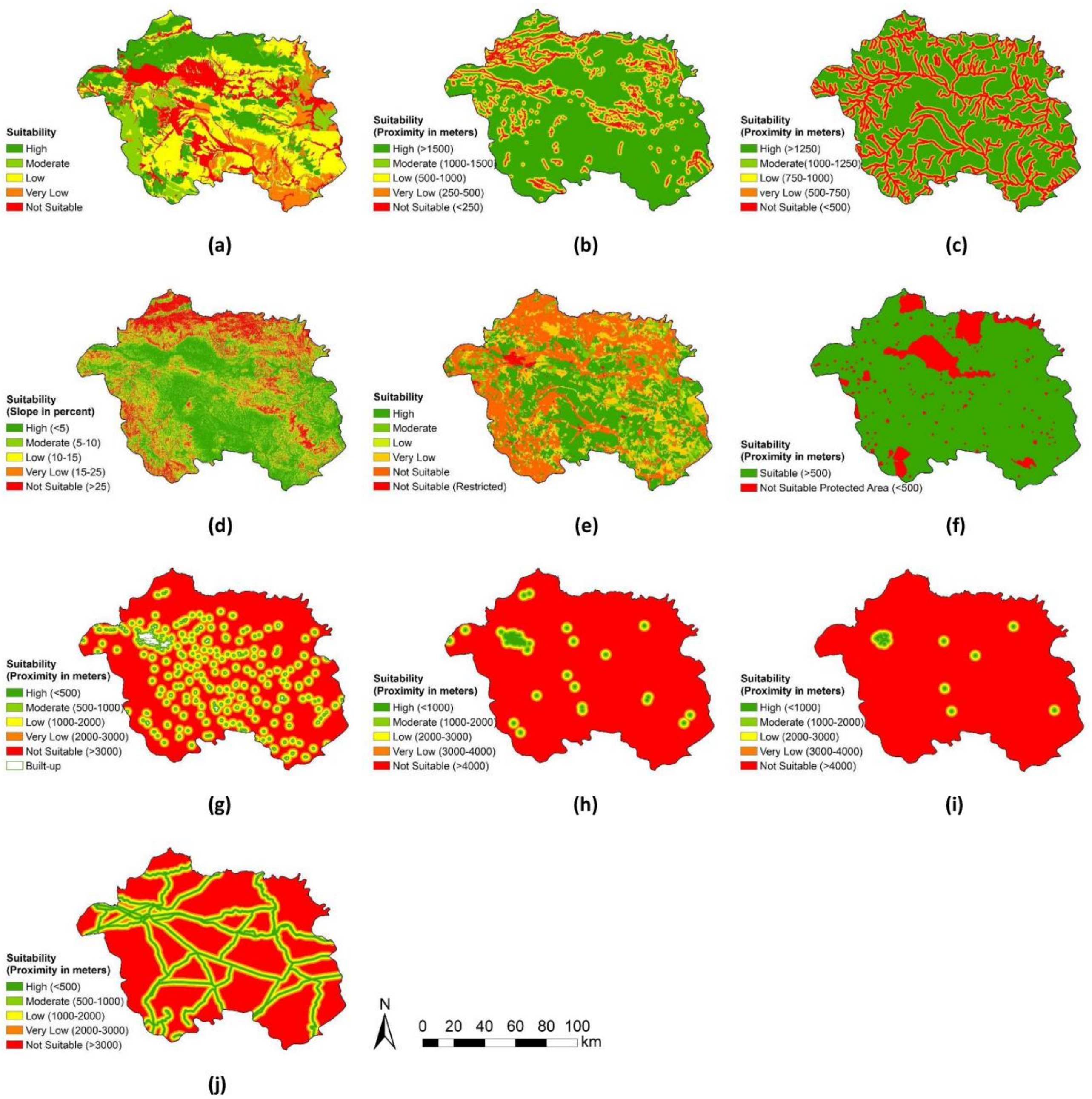

Figure 3. Geo-processed and reclassified thematic layers used in GIS-based multi-criteria land suitability analysis: (a) geological map; (b) distance to fault lines; (c) distance to streams; (d) slope; (e) land cover; (f) protected areas; (g) distance to existing built-up areas (compact city); (h) distance to educational institutions; (i) distance to health services; and (j) distance to major roads.

In the third step, after the development of the ratio matrix, each main and sub-factor in the matrix was normalized by dividing each factor value in every column by the sum of that column. Then, the relative weights (which is also called normalized principal Eigenvector) were calculated for each factor by determining the mean value of the rows using the pairwise comparison method (Table 3). In order to verify the consistency of the calculated weights, the consistency ratio (CR) should be calculated, and it must be less than 0.10 otherwise, it is not considered consistent (Saaty 1987, 2008). CR value was calculated using equation (1):

$$CR = \frac{\mathrm{CI}}{\mathrm{RI}} \quad (1)$$

where RI is the Random Consistency Index, in which the value is given as 1.24 depending on the number of factors in Saaty's RI table (Table 2); and CI is the Consistency Index, which is calculated using equation (2).

$$CI = \frac{(\lambda_{max} - \mathrm{n})}{\mathrm{n} - 1} \quad (2)$$

$$CI = \frac{(6.3 - 6)}{6 - 1} = 0.06$$

where λ_{max} is the Principal Eigen Value, and n is the number of factors.

The value of λ_{max} was calculated using the sum of the products between each element of the priority vector and column totals. The value of λ_{max} in this study is 6.30, which according to the conditions of the AHP method, it should be equal to or greater than the number of factors. Since the number of main factors in this study is 6, it satisfies the condition. According to the equation (2), the consistency ratio (CR) value in this study is 0.05, which 0.05 < 0.10, so it is consistent, and there is no contradiction in the calculation of weights. The consistency ratio values for sub-factors were also calculated, and all values complied with the condition CR <0.10 indicating that a consistent matrix was formed. Accordingly, the determined factor weights were accepted to use in the fourth step, which is synthesis using weighted linear combination.

Table 2. Random consistency index (Saaty 1987)

n	1	2	3	4	5	6	7	8	9	10
R. I	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

2.3.3. Weighted linear combination (WLC)

WLC is the most prevalently used multi-criteria evaluation analysis method in GIS (Siefi et al. 2017, Malczewski 2000). Land-use suitability analysis using weighted overlay method leads to more rational urban planning decision-making. Weighted overlay analysis includes different data layers with various aspects. In this method, manipulation of the overlay process is allowed by assigning different weights for each input layers, so the factors that play a more critical role will have a more significant impact on shaping the outcome of the overlay analysis. This is the advantage of weighted overlay over other methods such as fuzzy overlay, binary overlay, or ranking overlay (Malczewski 2006). However, this method is highly dependent on the determination of factor weights, where highly favored factors will result in higher values in the final output raster. This issue is critical, so experts' opinion is crucial in the defining scales applied to input layers and weights given to factors in the AHP process.

To be able to combine the attribute of layers and perform calculations on them, before executing the weighted overlay, all vector criteria layers were converted to raster format. Since the WLC method requires all values which are included in different attribute layers to be transformed to a comparable unit, all the criteria layers had already been normalized in the scale of 1 to 5 (see Figure 3). Table 3 shows the influence weight of factors which were determined based on the literature review, experts' opinion, and

AHP method. Safety issues are extremely important in urban planning; thus, the safety factor was given primary weight (25%) in the analysis. Secondary weighting (20%) was given to the slope factor due to the significance of topography in urban planning. The remaining weights are 15% and 10%, where the sum of the criteria weights must be equal to 100.

In the fourth step, weighted overlay analysis was performed on sub-criteria layers using their defined weights to produce the main criteria maps. Finally, the overall weighted linear combination was performed using equation (3), and as a result, the final suitability map was produced.

$$S = \sum_{i=1}^{n} W_i \; X_i * \prod C_j \qquad (3)$$

where S is the composite suitability score, W_i is weights assigned to each factor, X_i is factor scores (normalized cell values), C_j is constraints (built-up areas, wetlands, risky regions, and protected areas), and Π is the product of constraints.

Table 3. Influence weight of factors (contributed in weighted overlay analysis) determined using AHP method.

Planning criteria	Sub-criteria	Sub-criteria weight	Criteria weight
Safe city	Geology	30	25
	Fault line	35	
	Streams	35	
Socio-economic/ City of equality	Proximity to educational institutions	50	15
	Proximity to health services	50	
Ecological and environmental	Land cover	60	15
	Protected area	40	
Topography	Slope	100	20
Connected city	Proximity to roads	100	10
Compact city	Proximity to established neighborhood (built-up)	100	15

The Model Builder tool was used in the ArcGIS environment for producing the suitability model (see Appendix A). Model Builder is also known as a visual programming language that automates the GIS workflow; it facilitates constructing and executing simple workflows to develop and run reusable and complex geoprocessing models (HTTP. 3). The model builder expedites model sharing and allows to integrate ArcGIS with other applications. The tool not only makes the analyzing process dynamic but also enables the user to change the input criteria, values, weights, and quickly test multiple alternative scenarios.

1. Results and Discussion

In order to determine the most suitable land for sustainable urban development, a GIS-based multi-criteria decision evaluation method by integrating AHP and WLC was used to analyze and evaluate the selected criteria scores. Each criteria map was preprocessed and prepared for geospatial analysis using ArcGIS spatial analyst tools. Using the normalized score values, the maps were converted into grid format. The suitability maps were derived using the wight values obtained from AHP and the weighted overlay function of ArcGIS software. The results of the weighted overlay based on similar groups are given in Figure 4. The suitability maps were classified into five categories, i.e., high suitability, moderate, low, very low, and not suitable.

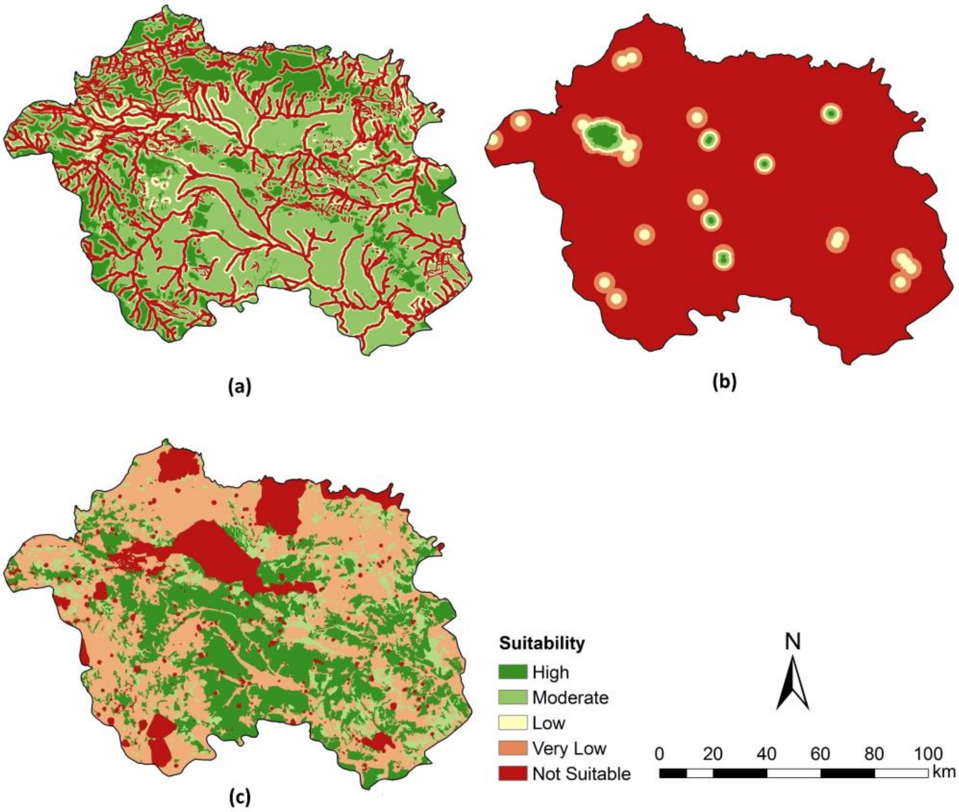

Figure 4. Suitability map based on similar factors: (a) weighted safe city map; (b) weighted socio-economic map; and (c) weighted ecological & environmental map.

The final land suitability map was calculated and produced by aggregating all factor maps and their computed weights using the weighted linear combination approach. Figure 5 shows the final suitability map of sustainable urban development in Eskisehir city.

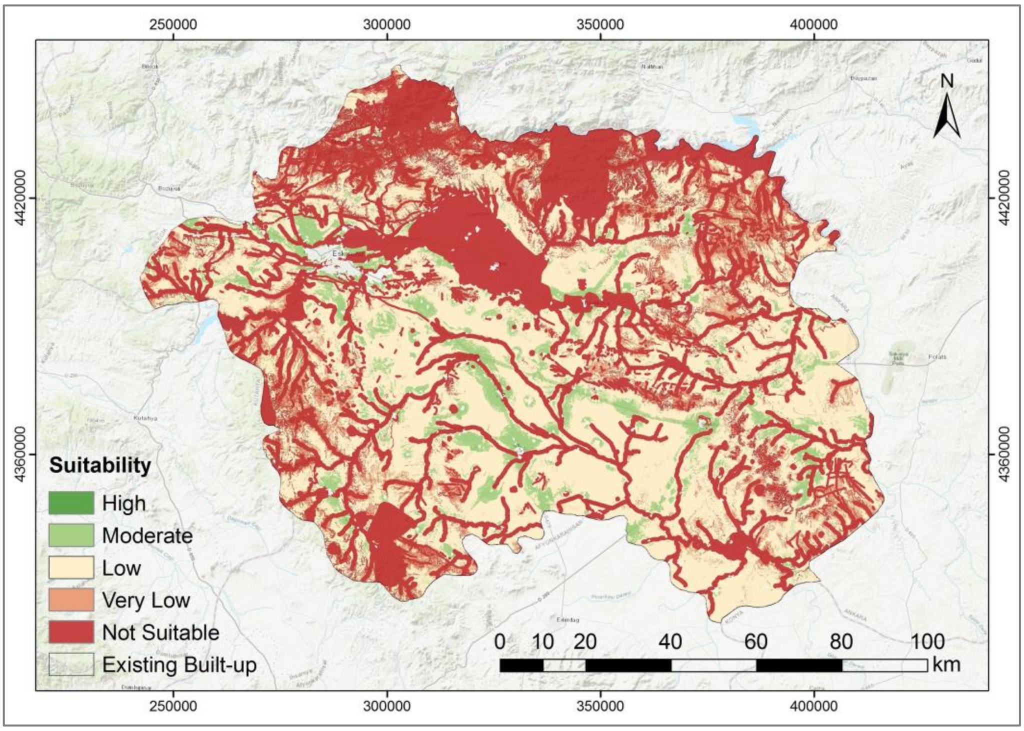

Figure 5. Final suitability map of sustainable urban development in Eskisehir city

Figure 6 illustrates the percentage and magnitude of areas shown in the final suitability map. Based on defined criteria, the findings of this study show that the largest area has low suitability with a rate of 44 %, while areas which are not suitable, represent 42 % of the total area. Areas with the highest suitability were rarely found (0.01 %). Areas with moderate suitability grade, form 7 % (964.06 km^2) of the total area, which is composed of well-connected areas. As Figure 5 & 6 illustrate, although adequate land with high suitability was not found, moderately suitable areas (shown in light green) can be used as potential candidate areas for future sustainable urban growth. Those areas comply with the aims of the study.

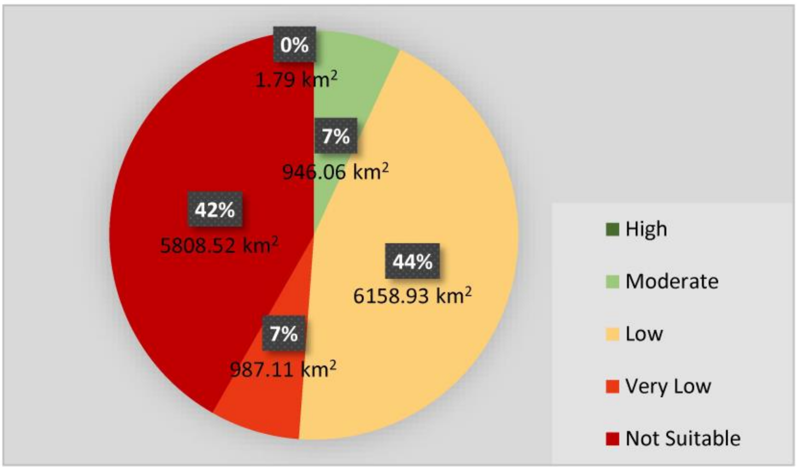

Figure 6. Pie chart showing land suitability areas in five suitability categories.

However, MCDA sometimes raises subjectivity in choosing the criteria and defining the weight of each factor, but the selection of criteria weights based on expert's opinion in the initial step increases the consistency of the results. The final step of multi-criteria evaluation is the validation of results. The following issues must be considered during the verification process:

- A field survey (ground truth verification) should be conducted to verify sample areas.
- Sensitivity analysis should be performed on the resultant map by altering the number of criteria and the respective weights of the factors to examine their influence on the result (by taking advantage of the model builder, this process is much easier).
- Reasonability and reflection of reality by the resultant map.

In this study, after obtaining the final suitability map, in addition to the analyses by changing criterion numbers and corresponding weights, visual observations were performed to evaluate and validate the results. The results were compatible with our field observations. Areas with high and moderate suitability are in proximity to established built-ups, major roads, and education and health services; these areas are neither located in protected areas nor prone to natural hazards. The findings reveal that unsuitable and less suitable areas such as forest, protected areas, and agriculture lands cover nearly half of Eskisehir, which means that using AHP and GIS techniques can significantly help to save the ecosystem in creating future sustainable development plans. This will highly reduce the negative impacts on the ecosystem and environment. The results also revealed that the main constraints to the development of the city are conservation areas and geohazards such as flood hazards, geological faults, materials, and steep slopes.

The finding of this study is consistent with the results of Aburas et al. (2017). They considered four main criteria (socio-economic, environment, utilities, and physical factors). In their findings, they indicated that using AHP and GIS technique is crucial in sustainable urban development.

Chen (2016) also used GIS-based MCDA in land-use suitability analysis for urban development. The method was found very effective in the complex process of sustainable urban development. Chen focusing on planning a compact city, concluded that the combination of MCDA and GIS in land-use decision support systems reduce both the time needed for the analysis of criteria and the errors. Our conclusion agrees with Chen's findings.

Akbulut et al. (2018) also applied the same method in Turkey. They recommended that the method can be replicated in other regions. It can help as a suitability evaluation framework for assessing the future urbanization plans on its broader implications for ecosystem services and sustainability functions. They concluded that by taking sustainability aspects into account, the consequences of eroding ecosystem resources, such as the increased risk of landslides, floods, and biodiversity loss, become evident and measurable to decision-makers.

Although criteria differ from study to study, in general, the findings of this study and the results of the previous research works indicate a common point that the integrated AHP and GIS approach can serve as a powerful suitability analysis and evaluation tool for preserving nature and sustainable development. This study provides basic information and awareness of sustainable urban expansion using GIS and RS to decision-makers and highlights the significant hazards and constraints that the city is facing. For harmonized and successful land-use planning, a multidisciplinary study and adequate data are required to protect the natural environment and reduce hazards. Lack of such an approach can lead to catastrophic hazards and failure of structures. This research represents only the first stage of the strategic planning process. In order for the identified areas of land to strongly contribute to the city's sustainability achievement goal, it is crucial that the model's fundamental principles also resonate in the detailed urban design phase of the planning process (Chen 2016). In this respect, GIS will continue to play an important role.

4. Conclusions

In this study, a GIS-based land suitability analysis based on critical factors was conducted to find the most suitable areas for sustainable urban development in Eskisehir province. To achieve the aim of the study, GIS and AHP were integrated; geophysical, cultural, socio-economic, and remotely sensed data were used. The results of the analysis revealed that for the selected criteria with the aim of economic and sustainability, there is an insufficient optimum area (1.79 km^2) available for urban growth, but regions with moderate suitability were found in a considerable total area (964.06 km^2), which those areas can be used for the future urban expansion. The results strengthen the effectiveness of using geospatial technology, particularly the use of GIS-based multi-criteria decision analysis in complex scenarios such as urban planning and environmental management, which can significantly impact the safety, sustainability, and the general quality of life in the city. GIS and remote sensing techniques can be used in many ways to protect the environment and promote economic development. Since using GIS in the urban planning process allows many factors to be taken into account, it helps to build an efficient, safe, economical, and organized city. The study provides decision-makers with fundamental information and insight into sustainable urban development using GIS and RS and highlights the major hazards and constraints that the city is facing. The results revealed that the main constraints to the sustainable development of the city are conservation areas and geohazards.

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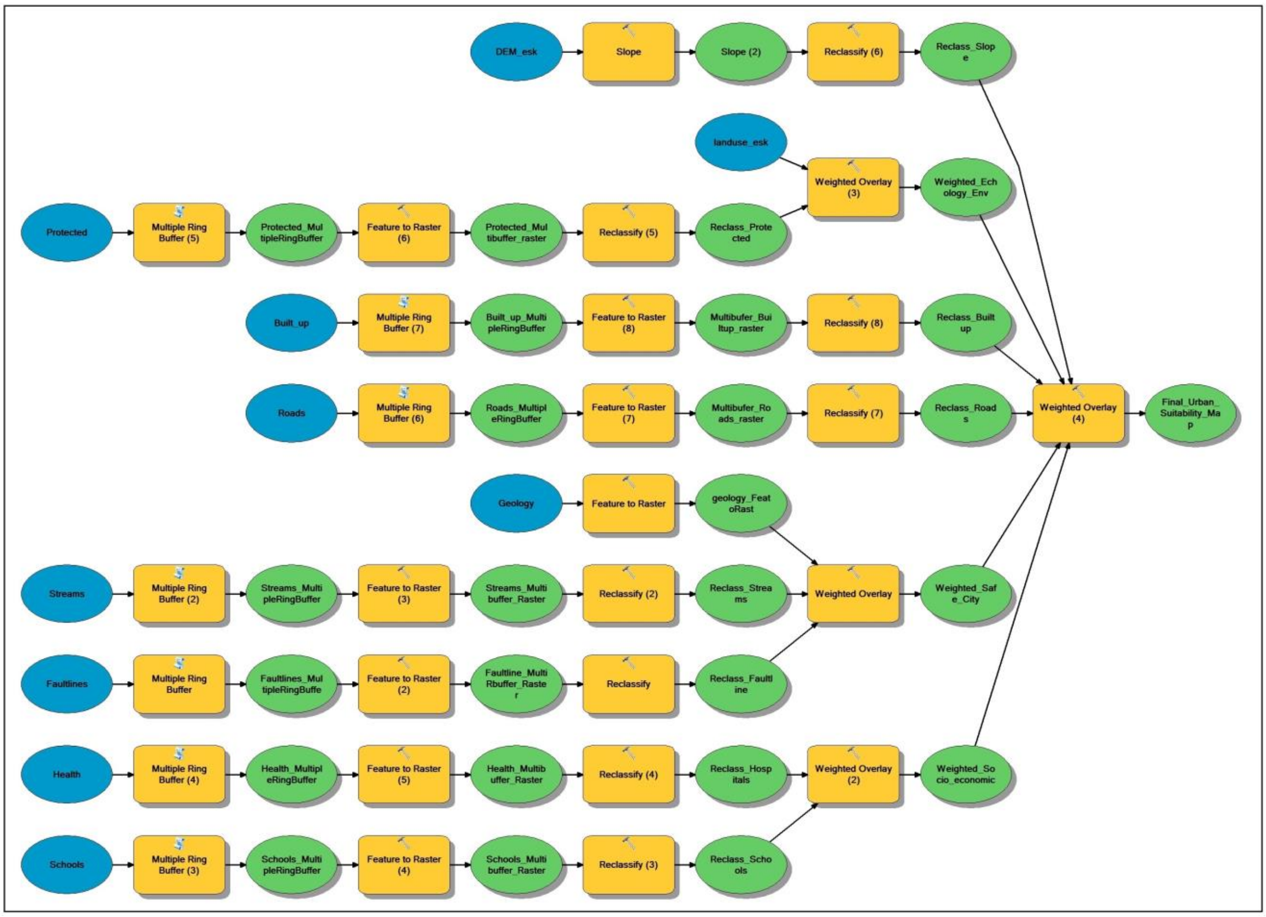
Appendix



Appendix A. Workflow of the land suitability analysis for sustainable urban development in ArcGIS