Determination of Urban Expansion Areas by Parcel Based Estimation Model (Saray Case Study)

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Abstract

Population growth causes urban spatial expansion and harms ecological units on the periphery of cities. Determining the growth trends of an urban area is vital in developing predictive planning techniques, defining manageable urban processes, directing investments to be made in the city, and increasing the quality of life with the balance between natural and built environment. It is a necessary planning tool for determining the dynamics affecting the expansion directions of the urban area and determining the possible urban growth areas with a holistic approach, detecting the possible problems that may occur in the future and finding solutions to these problems. The scope of this study is to build a model that predicts the possible urban expansion areas. The model is developed in line with the main criteria defined as proximity, natural environments, built-up environments, and plan decisions. The weights of each criterion and related sub-criteria were determined with the analytical hierarchy process (AHP). As a result of the study, the most probable urban development areas that will serve the 2040 projection population for the city of Saray were determined. This study aims to predict the growth direction of the urban area and determine the areas under the pressure of construction depending on the city's current dynamics. Thus, a practical urban growth estimation model has been put forward for future planning studies. The model results show that the city of Saray is inclined to continue its urban form as mono-centric and compact in the year 2040.

1. Introduction

As of 2018, 55 percent of the world's population lives in urban areas. This ratio is expected to be 2/3 of the total population in 2050 [1]. In Turkey, 92.3 percent of the total population lives in urban areas in the year 2018. This ratio was 64.9 percent in 2000. Approximately 50 percent of the urban population lives in small and medium-sized urban areas [2]. Although the concept of small and medium-sized cities is defined differently by various sources [3–6], it is possible to include cities with a population between 5,000 and 250,000 in this category [7,8]. Turkey has a total of 882 urban units in this category [9].

Opportunities such as jobs, education, health, culture offered by the urban area to the inhabitants constitute the main reasons for urban population growth in developing countries such as Turkey. The increasing population in urban space causes the city to grow and spread over time. The city, which has been positioned at the most appropriate place throughout the historical process, grows spatially over time, with various factors. However, the land that surrounds the urbanized area is not always suitable for new built-up. The fertile agricultural lands, streambeds, forests, and other ecologically vulnerable areas in the periphery of the city are destroyed and harmed sustainability in the urban growth process. Balanced development cannot occur in cases where spatial growth in urban areas cannot be accurately predicted and planned.

The literature emphasizes the importance of urban models [10]. The essentials of urban models are to anticipate the problems that urban areas may encounter and develop solutions before the occurrence [11]. In this context, there is an increase in the number of studies on the subject in the academic literature of urban science over time. Various methods and techniques are used for many different purposes, such as estimating the spatial growth of cities, predicting land-use changes, predicting the interaction between transportation and land use, determining the reflections of investments and spatial decisions to be made [12–15]. While some of these models are, micro-scale models produced for certain parts of the city; some also evaluate the city's relationship with its environment and evaluate the entire city as a whole. Also, some integrated models evaluate micro and macro scale together [16,17]. According to their predictive capacity, urban models can also be divided into short, medium, and long-term models. Besides, while many models were produced with spatial variables, some were tested by statistical data not dependent on the location. Models in which spatial and non-spatial data are evaluated together have also been developed [18–20]. According to the methods used in the model production process, many different models such as statistical models, geographical information systems-based models, cellular automata models, artificial neural networks models, agent-based models, and integrated models have been defined [16].

Undoubtedly, the models produced for urban areas do not reflect the actual situation exactly where very different systems coexist and different social, spatial, and economic actors interact continuously and mutually. In this context, it is possible to define urban models as a simplified simulation of reality without losing the essence[21]. Models can be constructed within the framework of many different criteria. However, there are primary factors that need to be considered in the construction of any model. In producing a model, the subject and scope of the study and the purpose of the model should be determined first. A pool of parameters directly related to the research subject should be created, and the relationship between these parameters and the degree of influence of each parameter on the result should be determined. The best version of the model should be selected in the next step, and the model should be tested under various conditions. In the last stage, the model's output should be compared with the actual situation, and the model should be revised if necessary.

In predicting urban growth, many criteria should be evaluated together in the natural environment, built environment, social and economic structure categories. Elevation, slope, aspect, geological condition, stream beds, seismicity, vegetation, soil capability are some of the natural environment criteria. In the built environment category, transportation networks, urban facilities, attraction points, existing urban boundaries, and infrastructure are the main drivers influencing urban development. It is possible to exemplify the socio-economic variables as the population, demographic structure, income status, vehicle ownership rate, and household size [22–25].

It is necessary to determine the population that the urban area will accommodate over the years by evaluating the demographic characteristics of the population, such as income status, household size, and vehicle ownership status, to predict urban spatial growth. After detecting the demand for the urban area, many elements should be evaluated together statistically and spatially in order to estimate the urbanization. At this point, multicriteria decision-making methods (MCDM) are used frequently.

MCDM refers to the determination of the relationship between variables and the severity and influence to reach the final output [26,27]. The method is functional for determining new urban development areas [28,29], as well as industrial facilities site selection [30], landfill site selection [31–34], energy facilities site selection [35–39], health facilities site selection [40,41], shopping mall site selection [42], public institutions site selection [43], parking lot site selection [44], urban greenways [45], vulnerability assessment [46–51] and sustainability assessments of urbanized areas [52,53].

The variables are determined by questionnaire, expert opinion, academic knowledge, literature research, or pre-acceptance. In the second stage, the weights of each variable are predicted or defined with expert-based scoring, statistical methods such as Analytical Hierarchy Process (AHP) [54–58], linear and logistic regression [59–61] or machine learning algorithms such as artificial neural networks, decision trees, support vectors, random forest, closest neighbor, deep learning [62–66]. In the last stage, the final product is obtained by evaluating the variable weights together.

In urban growth modeling, after determining the crucial variables directing urban growth, spatialization is vital to locate urban growth areas in the geographic space. Geographical Information Systems (GIS) technology is used as a tool for this purpose. The ability to analyze, visualize, and evaluate urban dynamics statistically and spatially is one of the main reasons GIS technologies are frequently used in urban growth modeling [31,67,68].

In urban growth modeling, MCDM, AHP, and GIS are used together to increase model prediction capacity. Akbulut et al. (2018) used AHP to determine the most suitable urban growth areas within the context of sustainable urban development. They evaluated six main criteria: slope, streambeds, natural protection areas, forest areas, agricultural areas, and water basin protection zones. They determined each criterion's weights by evaluating them with paired comparison matrices and scored the sub-criteria according to the degree of conformity. As a result of the study, they determined the most suitable areas for sustainable urban development [69]. Malmir et al. (2016) determined the most suitable urban development areas for the Ahwaz settlement of Iran, a small-medium-sized city, using the AHP method. Within the study's scope, 45 sub-criteria were selected using expert opinion, literature research, and legal documents. The relationship between these sub-criteria was analyzed with a matrix-shaped questionnaire applied to various experts. The results were visualized in five groups according to the degree of suitability for urban growth[70]. Zheng et al. (2017) aimed to find the most suitable areas for the expansion of the urban area by using various sub-criteria under three main groups as natural, socio-economic, and ecological. Altitude, slope, geological structure, proximity to rivers, lakes, and water reservoirs as natural; built-up area, transportation, port, population density as the socio-economic and coastal, agricultural areas, and ecological protection zones are evaluated as ecological criteria. The main criteria and sub-criteria were weighted by AHP[71]. Dong et al. (2008) weighted various sub-criteria such as elevation, slope, geological structure, average temperature, river density, land use type, highway density, railway density, population density with the help of AHP under three main headings: environmental, land resources and socio-economic factors to determine the most suitable urban expansion areas[72]. Aburas et al. (2017) determined the most suitable urban development areas for Seremban, Malaysia, by using various social, physical, economic, and environmental factors such as elevation, slope, soil type, population density, land cover, highways, railways, power transmission lines, and streambeds, residential, commercial and educational facilities[73]. Park et al. (2011) evaluated many criteria to detect the most suitable urban development areas by logistic regression and artificial neural networks[74].

In urban growth models, criteria such as slope, land use, land value, proximity to transportations, linearity, aspect, flood risk, groundwater level, geomorphology, the density of transportation infrastructure are weighted with the help of AHP in various studies and used in determining the most suitable urban development areas [75–77].

Low-resolution monotonous raster formatted data are used to determine the most suitable urban development areas as the smallest geographical unit [78–80]. Therefore, there is a lock of urban growth models with high spatial resolution. Exploring the possibilities, capabilities, and positive aspects of parcel-based urban growth modeling is the essential investigated topic in this study. Therefore, instead of pixel-based modeling, a high-resolution suitability analysis is performed using actual cadastral parcels, the smallest unit where urban growth occurs. Besides, a wide range of factors revealing the parcels' original characteristics is used to estimate construction pressure on each parcel. In this respect, it differs from the studies in the literature and expands the spatial capacity of urban modeling.

Urban growth occurs at the level of cadastral parcels on a micro-scale. Many of the unique conditions of the parcel, such as its location and proximity to various attraction points, its relationship with the natural structure, its interaction with the existing built environment, and spatial plans, define the degree of pressure and suitability for urban development. In this study, the 32 criteria affecting the urban growth potential of a parcel are compiled under four main groups, and the weight of each criterion is determined with the help of AHP based on expert opinions. The overall development pressure on the parcels is calculated by overlaying the weights of each criterion geographically by using GIS technics.

Furthermore, the demand for the urban area, calculated by simulated population density for the projection year, is allocated to the urban space according to the overall development suitability analysis of the parcels.

The primary purpose of this study is to build an urban growth model that predicts urban growth with high resolution and high accuracy. The proposed model can be used by city managers and stakeholders as a decision support tool to have a more sustainable and livable urban form with proactive policies in urban planning processes.

In the introduction part of the study, the importance of the subject and the relevant literature are evaluated. In the second part, the methods and techniques used in the study are expressed. In the last part of the study, the results of the proposed model are evaluated, the original contributions to the literature are explained, and the powerful and open-to-improvement features of the model are discussed. In addition, suggestions are made for future studies.

2. Material And Methodology

2.1 Study Area

The Saray District of Tekirdağ province, chosen as the study area, has not experienced significant population changes as a small-medium-sized city in the historical process. However, due to its proximity to Istanbul, one of the world's largest metropolitan settlements with a population of 15 million, and to the settlements of Çorlu and Çerkezköy, where decentralized industrial areas from Istanbul are located, rapid population growth and an increase in urban area are expected in the near future [81]. It is crucial to determine the most suitable urban growth areas for the settlement to protect from the adverse spatial effects of unplanned urban development and offer more livable and sustainable urban space. Saray district is adjacent to Kırklareli province’s Vize district in the northwest and Tekirdağ province’s Kapaklı and Çorlu districts in the South and Southeast (Figure 1). The city is established on the low slopes of the Yıldız Mountains, starting from Istanbul's provincial borders and extending through Bulgaria, meeting with the Ergene Valley, formed by the Ergene River and its branches. The main branch of the Ergene River, the most important river in the Thrace region of Turkey, also passes through the Saray city center. In this respect, it includes various ecological thresholds.

While the Saray city center population was approximately 10,000 in 1980, it increased to 27,457 in 2018 (Figure 2). In the Thrace Sub-Region Ergene Basin Environmental Plan, the projected population for 2040 is foreseen as 55,000 people [81]

2.2 Data

The official base map and the cadastral parcel data of the city were obtained from Saray Municipality. Environmental Master Plan and Zoning Plan decisions, plan reports, and analyses made within the scope of the relevant plan were provided by Tekirdag Metropolitan Municipality. The transportation networks and the current land use data were defined by the field study. The natural environment analyzes were produced by using the contour lines obtained from existing maps.

2.3 Methodology

In the study, the criteria that direct the spatial growth of the urban built-up area were selected by expert opinions and literature research. The weights of the criteria were determined with the help of a questionnaire and AHP. Possible urban growth areas were determined by overlapping the criteria and weights spatially with the weighted linear combination method. While determining possible urban growth areas, parcels within fertile agricultural lands, forest areas, military areas, pasture areas, stream beds, and energy transmission lines that will not be subject to urban growth were accepted as a constraint and removed. The demand for urban growth was calculated based on the projected population by Environmental Master Plan, and population density remains constant. In the last stage of the study, the amount of new parcel area to be built was distributed to space, starting from the most suitable parcels.

The data, sources, GIS tools, and flow of the study process are given in Figure 3. The codes on the figure are associated with the following tables and figures.

2.3.1 Determination of the criteria

The criteria that affect the direction of urban growth and the related sub-criteria were determined by the academic literature [82–86], expert opinions, and particular by considering the internal and external dynamics of the study area. Accordingly, it is accepted that proximity to roads and facilities, natural environment, built-up environment, and plan decisions have an incontrovertible effect on the direction of urban growth. The stated main criteria and related sub-criteria are shown in Table 1 and Table 2.

In the second stage, the criteria were spatialized with Esri’s ArcMap Version 10.3 [87], a GIS software. After the spatial preparation of the data set, each parcel's status considered as the smallest unit that urban growth occurs was analyzed based on the data set. For the proximity analysis, the distance of the parcel's geometric centers to the relevant unit was calculated using the "Arcmap / Near" tool as a function of the Euclidean distance. For slope and aspect analysis, the average slope and aspect value of the topographic unit within the parcel boundaries was calculated with the help of the "Arcmap / Zonal Statistic" tool and transferred to the parcel help of the "Armap / Extract Values by Point" tool. "Arcmap / Buffer" and "Arcmap / Join" tools were used to calculate the proportion of the built parcel in the neighborhood of the parcels, taking into account the neighborhood distance of 500 meters for each parcel. Neighborhood distance is defined in different sizes by different sources [88–90]. Moreno et al. (2008) expressed the units that fall within the area of various sizes, 10, 30, 60, and 120 m from the border of the parcels used in the model, as neighbors. Jr & Qiu (2012) tried three different distances and found no significant changes in the model as the distance changed. González et al. (2015) states that each parcel has a different neighborhood effect due to its different size and shape. Considering the push-pull effects of different land-use types, they stated that the units within a determined circular distance are neighbors of each other. By experimenting with various distances between 25 m and 1000 m, they determined that 500 m was the most suitable neighborhood distance for their case study. In this study, 500 m neighborhood distance was used considering the size and spatial characteristics of the study area. Relevant analyzes are shown in Figures 4 -11.

As a result of the analysis, each cadastral parcel received a value, starting from 0, based on the sub-criteria. To be able to do a weighted linear combination, all parcel values were normalized with the "minimum-maximum normalization method." According to this method, each analysis's smallest value is fixed to zero, and the largest value is fixed to one, and intermediate values are distributed between zero and one. The function used in the normalization process is given in equation (1). A sample part of the attribute table that illustrates the 6 of 32 criteria before and after normalization is shown in Table 1.

$$Z_i = \frac{x_i - \min(x)}{\max(x) - \min(x)} \qquad (1)$$

Z_i= normalized value of parcel i for analysis x

x_i= the real value of parcel i for analysis x

min(x) = minimum value for analysis x

max(x)= maximum value for analysis x

Table 1. Sample of the attribute table before and after normalization (* distance to related facilities in meters)

Parcel ID	City Center*	Nor	Secondary Center*	Nor	Primary Road*	Nor	Seondary Roads*	Nor	Commercial Areas*	Nor	Built-up*	Nor	...
1	1309	0.303	1674	0.306	1184	0.288	198	0.118	318	0.095	1	0.0005	...
2	3049	0.716	505	0.091	36	0.009	390	0.234	1966	0.588	92	0.0425	...
3	3021	0.709	467	0.084	70	0.017	373	0.223	1938	0.580	79	0.0365	...
4	2813	0.660	529	0.095	43	0.010	161	0.096	1731	0.518	43	0.0199	...
5	2848	0.668	506	0.091	50	0.012	200	0.120	1766	0.528	8	0.0037	...
6	2887	0.678	502	0.090	40	0.010	235	0.141	1805	0.540	32	0.0148	...
7	2907	0.682	450	0.081	86	0.021	276	0.165	1824	0.546	42	0.0194	...
8	2970	0.697	490	0.088	43	0.010	315	0.189	1887	0.565	80	0.0370	...
9	3068	0.721	1727	0.316	904	0.220	1001	0.601	2142	0.641	815	0.3766	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...
9562	830	0.189	3317	0.609	2137	0.520	80	0.047	79	0.024	2	0.0009	...

2.3.2 Weights of Criteria - AHP

AHP is a quantitative method used to evaluate more than one criteria together in the decision-making process and determine the importance level between criteria and making a selection. It is mainly used to solve problems that require the judgments of many decision-makers from different fields of expertise. It was first proposed by Myers and Alpert (1968) and later developed as a model by Saaty (1977). In the next period, it has been evaluated as a convenient tool for solving complex problems by various disciplines. Especially, it is frequently used to determine the effect of criteria that cannot be objectively measured and evaluated together. The criteria are prioritized based on the supposition that the criteria affecting the problem have different degrees of influence than each other.

In the AHP method, the problem and the criteria affecting the problem are structured in a hierarchical order. The criteria affecting the problem are compared with pairwise matrices, and their importance levels are determined with respect to each other. The complexity of the process is significantly reduced as many criteria that affect the problem are compared in pairs. It is essential to determine the consistency ratio by performing a consistency analysis after obtaining the weights of the criteria with the paired comparison matrices applied to the decision-makers. While comparing the criteria, decision-makers are asked to compare the relationship between the criteria by giving 1 to 9 points with 1 equal importance and 9 very strong, and a paired comparison matrix is created [96]. Calculations were made to find the highest Eigenvalue, consistency index (CI), consistency ratio (CR), and normalized values for each criterion. The normalized index values are used as final weights when the expected Eigenvalue, consistency index, and ratio are reached. If the expected values are not reached, the calculations are reviewed, and the process is repeated [97].

AHP is used in many areas such as urban growth modeling [28,54,70], planning and development [98–100], selection of the best alternative [101–103] resource allocation and site selection (Erden & Coşkun, 2011; Ertuğrul & Karakaşoğlu, 2008; Korpela et al., 2002; Saaty et al., 2003; Yang & Lee, 1997), setting priorities [109,110], various estimation processes [111,112] and many fields such as personal, social, production, politics, engineering, education, industry, sports, and management.

In the scope of this study, the weights of the main criteria and the related sub-criteria were evaluated using AHP. In this context, a questionnaire formed as pairwise matrices was applied to a total of 20 experts in the field. The comparison matrices were filled by the experts. The weights for the criteria and sub-criteria were determined with the "Superdecision" software Version 3.2 (Superdecision, 2017), an analytical hierarchy method software, by considering the average of the points compiled from each paired comparison. Table 2 shows the weights obtained as a result of AHP.

Accordingly, it is possible to show the total score of any parcel for the criteria with equations (2), (3), (4), and (5). The codes used in the formulas are associated with the sub-criteria codes used in Table 2 and Figures 4-11.

$$S_A = \sum_{a_1}^{a_n} a_n \times w_n \qquad (2)$$

S_A = Suitability score for urban growth based on proximity analysis

$a_1, \ldots a_n$ = Sub-criteria of proximity analysis

w_n = Sub-weight of sub-criteria n

$$S_B = \sum_{b_1}^{b_n} b_n \times w_n \qquad (3)$$

S_B = Suitability score for urban growth based on natural environment

$b_1, \ldots b_n$ = Sub-criteria of natural environments

w_n = Sub-weight of sub-criteria n

$$S_C = \sum_{c_1}^{c_n} c_n \times w_n \qquad (4)$$

S_C = Suitability score for urban growth based on built up environment

$c_1, \ldots c_n$ = Sub-criteria of built up environment

w_n = Sub-weight of sub-criteria n

$$S_D = \sum_{d_1}^{d_n} d_n \times w_n \qquad (5)$$

S_D = Suitability score for urban growth based on plan decisions

$d_1, \ldots d_n$ = Sub-criteria of plan decisions

w_n = Sub-weight of sub-criteria n

After the suitability analysis made by the sub-criteria level for each main criterion separately, the main criteria were weighted using the AHP again. Accordingly, the total assessment for the possible urban development areas was made with equation (6).

$$S_T = \sum_A^D S_{A,B,C,D} \times W_{A,B,C,D} \qquad (6)$$

S_T = Overall suitability score

$S_{A, B, C, D}$ = Suitability scores based on proximity, natural environment, built-up environment, and plan decisions, accordingly

$W_{A, B, C, D}$ = Weight of criteria; proximity, natural environment, built-up environment, and plan decisions, accordingly

Table 2. Weights of criteria and sub-criteria

Criteria		Weight	Criteria		Weight
S_A	Proximity	0,30	S_B	Natural Environment	0,10
Sub-criteria (distance to)		**Sub-weights**	**Sub-criteria**		**Sub-weights**
a_1	City center	0,18842	b_1	Slope	0,75
a_2	Secondary center	0,01273			
a_3	Primary roads	0,06474			
a_4	Secondary roads	0,12415	b_2	Aspect	0,25
a_5	Commercial areas	0,20482			
a_6	Built-up areas	0,09584			
a_7	Educational facilities (primary)	0,04402	S_D	Plan Decisions	0,30
a_8	Educational facilities (secondary)	0,03245	**Sub-Criteria (distance to)**		**Sub-weights**
a_9	Recreational facilities	0,02873	d_1	Plan boundary	0,07342
a_{10}	Health facilities (primary)	0,0619	d_2	Primary roads	0,06261
a_{11}	Health facilities (secondary)	0,01953	d_3	Secondary roads	0,17729
a_{12}	Social and cultural facilities	0,04065	d_4	Commercial areas	0,27981
a_{13}	Official facilities	0,03818	d_5	Proposed housing	0,13667
a_{14}	Industry (primary)	0,01367	d_6	Educational facilities	0,08219
a_{15}	Industry (secondary)	0,0137	d_7	Recreational facilities	0,02455
a_{16}	University	0,01647	d_8	Industry (secondary)	0,0192
			d_9	Industry (primary)	0,01858
S_C	Built-up Environment	0,30	d_{10}	Health facilities	0,04712
Sub-criteria		**Sub-weights**	d_{11}	Social and cultural facilities	0,04252
c_1	Amount of built-up parcels in the neighborhood	0,75	d_{12}	University	0,03604
c_2	Rural-urban land status	0,25			

3. Results

All All criteria and sub-criteria that are effective in determining the direction of urban growth were mapped. An attribute determination process was carried out in line with the main criteria of proximity, natural environment, built-up environment, and plan decisions and sub-criteria affecting these criteria for each of the total of 12,231 parcels of 4,592 ha within the boundary of the study area (Figure 12). In other words, each parcel has been questioned in line with the specified criteria. On the other hand, in parallel with this process, the criteria were weighted with the AHP. The final output of urban growth potential for each parcel was acquired using the weighted linear combination technique.

After the suitability analysis for all parcels was created, areas that are not suitable for urban settlements, military areas, streambeds and 20 m surroundings, energy transmission line and 20 m surroundings, irrigated fertile agricultural land, and pasture areas have been removed from the model. Since 805 parcels with a total size of 510 ha were located within the 20 meters from the energy transmission lines, 20 meters from the streambeds, on the military area, pasture area, fertile agricultural land; it has been considered to be restricted in terms of construction (Figure 13). These constraints, which create a threshold effect on urban development, have also been defined by benefiting from expert opinions.

After removing the constraints, the final output of possible urban development areas proceeded for the urban growth allocation process. In the output dataset, each parcel has an attribute value from 0 to 1, 0 as the most possible for built up and 1 as the least possible.

Population growth was needed to determine the amount of urban growth demand for the simulation year 2040. The amount of built-up area required for the projection year was calculated based on the Environmental Master Plan projections and the current population density. In the Thrace Sub-Region Ergene Basin Environmental Master Plan, the study area's urban population is predicted to be 55.000 people for the year 2040 [81]. The projected population envisaged by the Environmental Master Plan has also been accepted in this study.

While calculating the amount of area to be built up for the projection year, it was assumed that the current population density would continue as it is. To calculate the population density, the population data of the study area in 2018 and the total built-up parcel area in the same year were taken into account. Accordingly, the current population density in the study area has been calculated as approximately 107 people per ha.

Under the conditions where the projected year's population density remains constant, the built-up area will be approximately 509 ha, according to the population foreseen by the Environmental Master Plan. Approximately 255 ha of parcel area was expected to be newly built up for 2040 (Table 3). After the new parcel area to be built up was determined, the growth was allocated to the urban space, starting from the parcels with the lowest score, based on the values obtained from the suitability analysis. The city of Saray will cover an urban area of approximately 255 ha for 2040; accordingly, a total of 3.445 parcels will be built. The parcels to be built are mostly located in the north and northwest directions of the city. Saray, a small-medium-sized city with a single center, will maintain its dynamics over the years. Urban macro form spreads outward in a circular form (Figure 14).

Table 3. Demand estimation for 2040.

	Population	Built-up Area (Ha)	Population Density (per Ha)
2018	27,457	254	107
2040	55,000	Total 509	107
		Need 255	

4. Discussion

The increasing urban population causes the urban growth pressure on fertile agricultural areas, forest areas, pasture areas, water basins, geologically risky areas, and other ecologically sensitive land uses in the periphery of the cities. The main concern of urban researchers is to investigate for more sustainable and livable urban land use planning. Measuring the suitability of the existing land for urban growth in the context of various criteria is a frequently used method. In search of more sustainable and livable urban forms, various criteria are compiled and evaluated together by weighting with the help of expert opinions, academic knowledge, and literature research. This process is designed in line with urban planning principles. However, the analysis of existing urban dynamics and identifying areas under possible growth pressure is ignored. In these studies, while determining the most suitable urban development area in the context of urban planning principles is the primary concern, determining the areas currently under the pressure of urban growth remains in the second place.

Another essential issue in urban growth models is the spatial resolution of the model. In the vast majority of models produced on this subject, the urban space is divided into pixels of various sizes, and the average values of these pixels based on various criteria are considered. The pixel sizes vary between 50*50 m and 500*500 m depending on the size of the study area where the model is built for. However, in reality, the urban growth is shaped based on cadastral parcels, and the parcel sizes in an urban area are much smaller than the sizes mentioned above. For this reason, the predictive capacity and the power to explain the spatial change of the proposed models remain low. On the other hand, in some parcel-level models, a small part of the city is chosen as the study area instead of the holistic approach. This situation causes the environmental relations to be ignored and the adverse effects on the prediction capacity of the model.

While large-scale urban areas are commonly investigated in urban growth models, small-medium-sized cities do not receive the necessary attention. Small-medium-sized cities need more practical urban growth models, where the well-educated urban researcher human resources capacity is relatively low.

Another factor that affects the forecasting capacity of urban growth models is the analysis of spatial growth demand and its inclusion in the modeling process. Spatial growth demand is increasing mainly due to population growth. However, in some models, demand is determined by reference to past spatial growth, while in some studies, it is ignored. Evaluating the spatial demand in parallel with the population growth allows analyzing urban growth depending on the amount of population growth and the distribution of the population in the urban space. Various scenarios and urban growth results can be discussed by using the total population and population density data foreseen for the projection year.

Planning studies is one of the essential elements shaping the urban space. In an ideal system, it is expected that urban growth will not develop apart from the planning decisions. However, in urban dynamics that are constantly changing like a living organism, planning studies alone are not capable of directing the urban area, especially in developing countries. Changing socio-economic and spatial structure, political decisions, and various external effects cause plans to change over time. However, it is an undeniable fact that planning studies affect and direct urban growth in many ways. Nevertheless, most of the modeling studies do not cover this reality. In this study, natural structure, built environment, and accessibility criteria, as well as plan decisions, were taken into consideration.

In this context, the urban growth model proposed in this study has been designed for a small-medium-sized urban area with high spatial resolution, considering the environmental effects and the city as a whole. The construction pressure on actual cadastral units is examined according to the criteria of the natural, structural, accessibility, and planning decisions. The probable urban growth pattern is revealed based on the construction pressure on the parcels and the population amount and population density scenarios foreseen for the future year. These features improve the urban growth modeling methodology based on suitability analysis and constitute the original contribution of the study to the literature.

5. Conclusion

This article presents a parcel-based urban growth estimation model to reveal possible urban growth patterns under the spatial demand scenario. Literature research, expert opinions, field studies, MCDM, AHP, and GIS techniques were used within the scope of the model. The related criteria were compiled by expert opinions, literature research, and field studies. The weights of criteria and each sub-criteria were defined with the help of AHP and expert opinions. The total suitability of the main criteria and overall suitability of all criteria was calculated by the weighted linear combination method, one of the MCDM. GIS was used to create the database, analyze spatial relationships of criteria, and overlay analysis layers spatially.

The following stages have been carried out: (1) identification of the relevant criteria and sub-criteria, (2) calculation the weights of the main criteria and sub-criteria through the AHP, (3) extracting and vectorization of the necessary data from the official base maps, the master plan, field study and the zoning plan, (4) creating the parcel level database for relevant criteria by GIS tools, (5) normalization of the attributes of each criterion, (5) obtaining the total suitability scores of all parcels for main criteria by the weighted linear combination method, (6) obtaining the overall suitability scores of all parcels by the weighted linear combination method, (7) removing constraints, (8) creating the scenario with population growth and population density, (9) calculation the necessary urban growth area based on a scenario for the projected year, (10) allocation of the growth based on overall suitability scores of parcels.

A total of 32 sub-criteria under four main criteria were evaluated together. Proximity to roads and facilities, natural environments, built-up environments, and plan decisions are identified as main criteria. The opinions of the experts were sought about these main criteria and their sub-criteria.

This study, it is aimed to determine possible urban growth areas based on the assumption that actors make rational decisions while fulfilling urban land demand in city dynamics. The suitability in terms of planning principles or sustainability is beyond the scope of this study. Possible pressures of urban growth are investigated with the proposed model. The model's outputs can be evaluated within the scope of planning principles and sustainable urban growth criteria. The model can be used as a tool in predicting possible proactive urban land management policies.

The model assumes that the location selection of urban actors occurs in accordance with various criteria in an urban area and its interaction zone. However, the criteria that affect the location selection of urban land uses in real life can be interpreted with the actors' subjective judgments. Land ownership, ethnicity, citizenship, kinship relations, income status, perception of the city, political decisions beyond the plan hierarchy, citywide or countrywide investment decisions, land speculations, unpredictable population growth, and disasters influence the urban growth demand allocation. The model did not include the mentioned variables because of insufficiency, subjectivity, and paucity of geo-related sociological and economic data. However, these variables can be more critical than all other variables in developing countries such as Turkey. Besides, it should be considered that the amount of urban area per capita may differ over time by exceeding various thresholds.

This study may further be improved by including geo-coded social and economic criteria when performing suitability analyzes. Also, the characteristics and location choice priorities of the inhabitants over citywide and neighborhoods can be evaluated. On the other hand, the spatial growth demand can be calculated by more sophisticated methods by considering household size, income status, car ownership, urban area per capita, and other socio-economic factors.

The proposed parcel-based, demand stipulated urban growth model is practical for urban managers and researchers to reveal urban growth pressures on the periphery of small-medium-sized cities. The model's strengths are the ease of access to the necessary data, well-defined model process, and applicability in the GIS environment. The model is useful as a decision support tool in urban planning studies to determine the city's spatial expansion direction and prevent possible negativities before they occur.

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Availability of data and material

Not applicable

Code availability

Not applicable

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by AK. Supervisions, review and editing were done by MAY. The first draft of the manuscript was written by AK and MAY commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

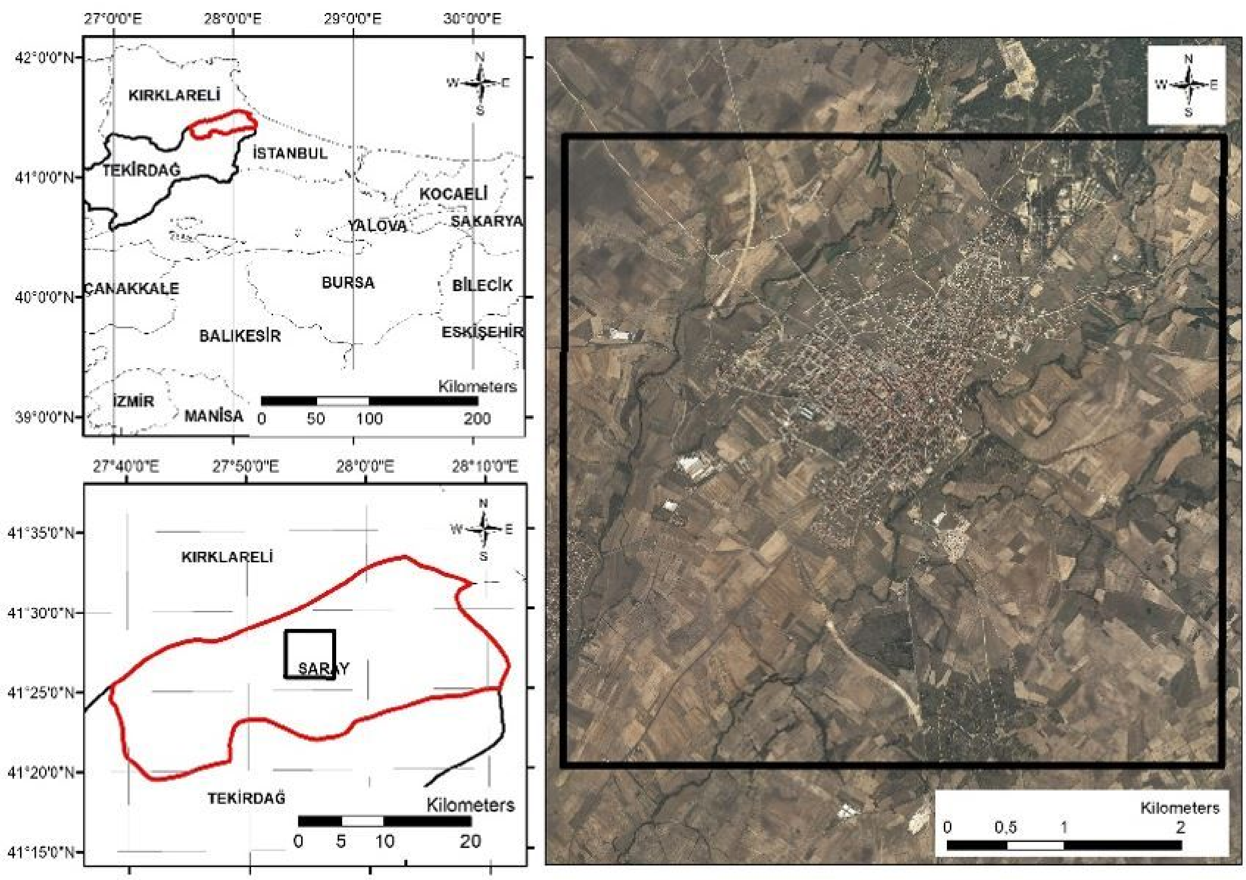

Figure 1

Location of the study area.

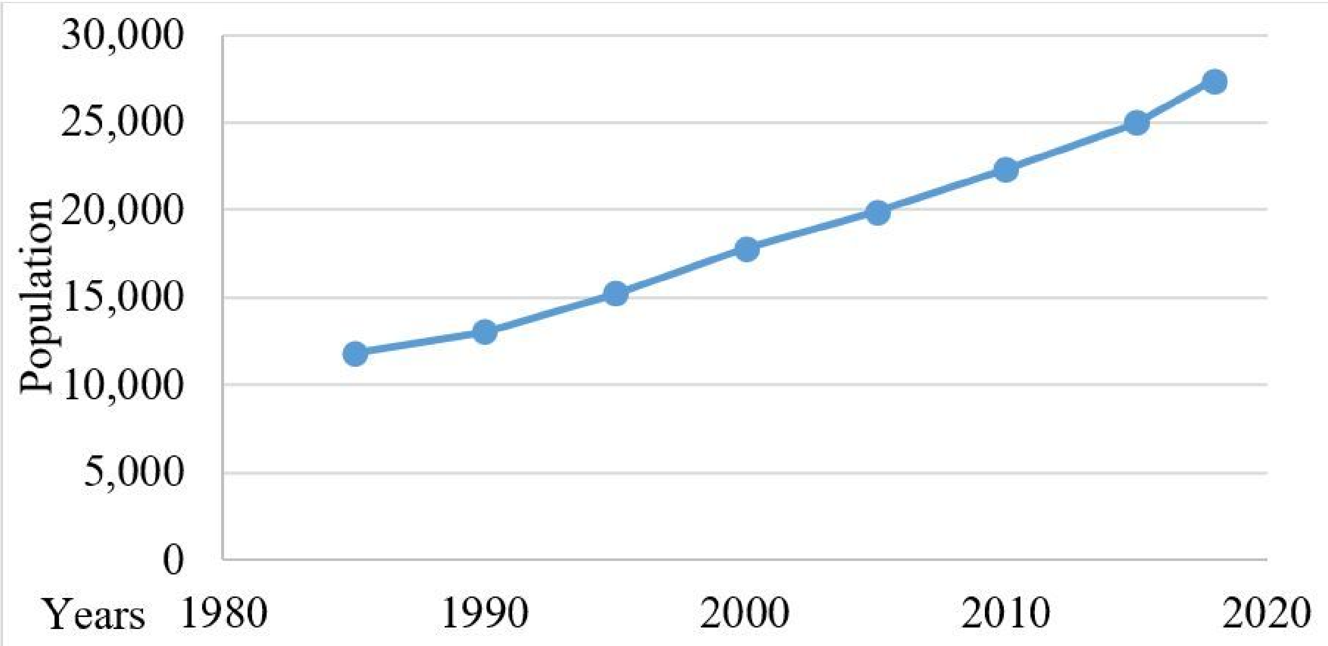

Figure 2

Population growth by year [2].

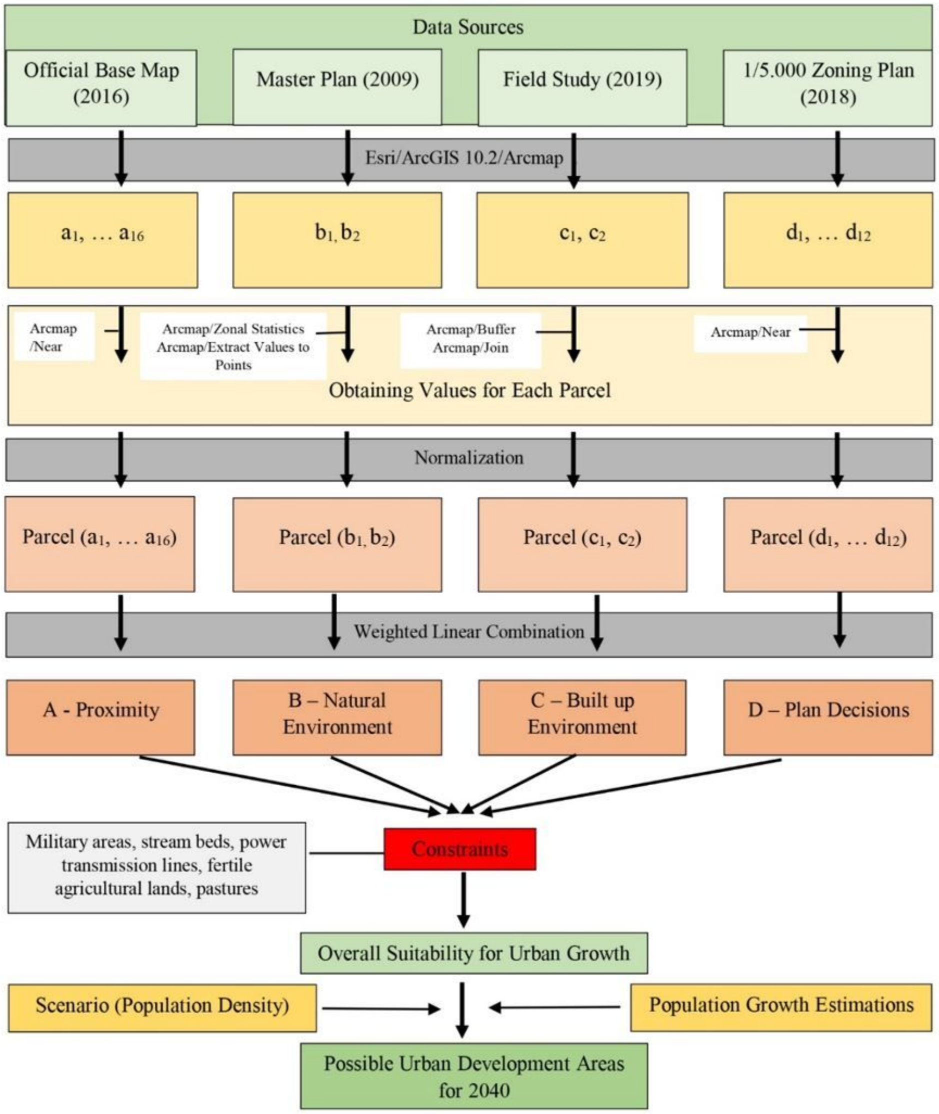

Figure 3

Flowchart of the methodology.

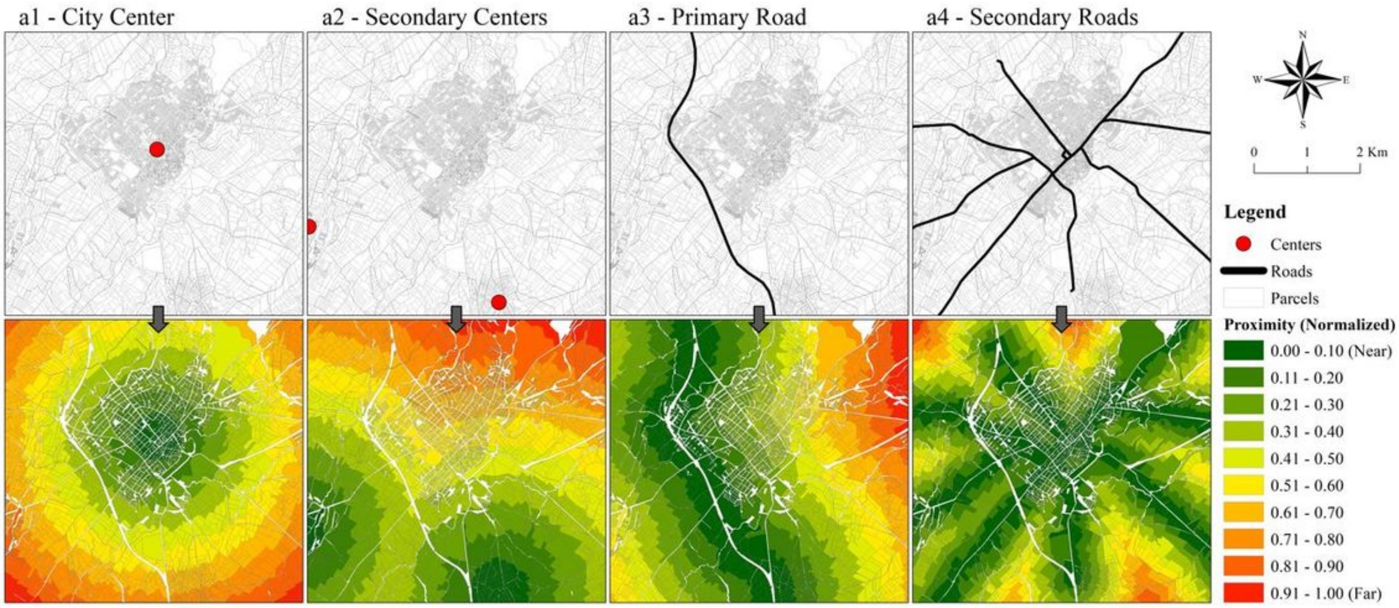

Figure 4

Proximity analysis (first 4 of 16).

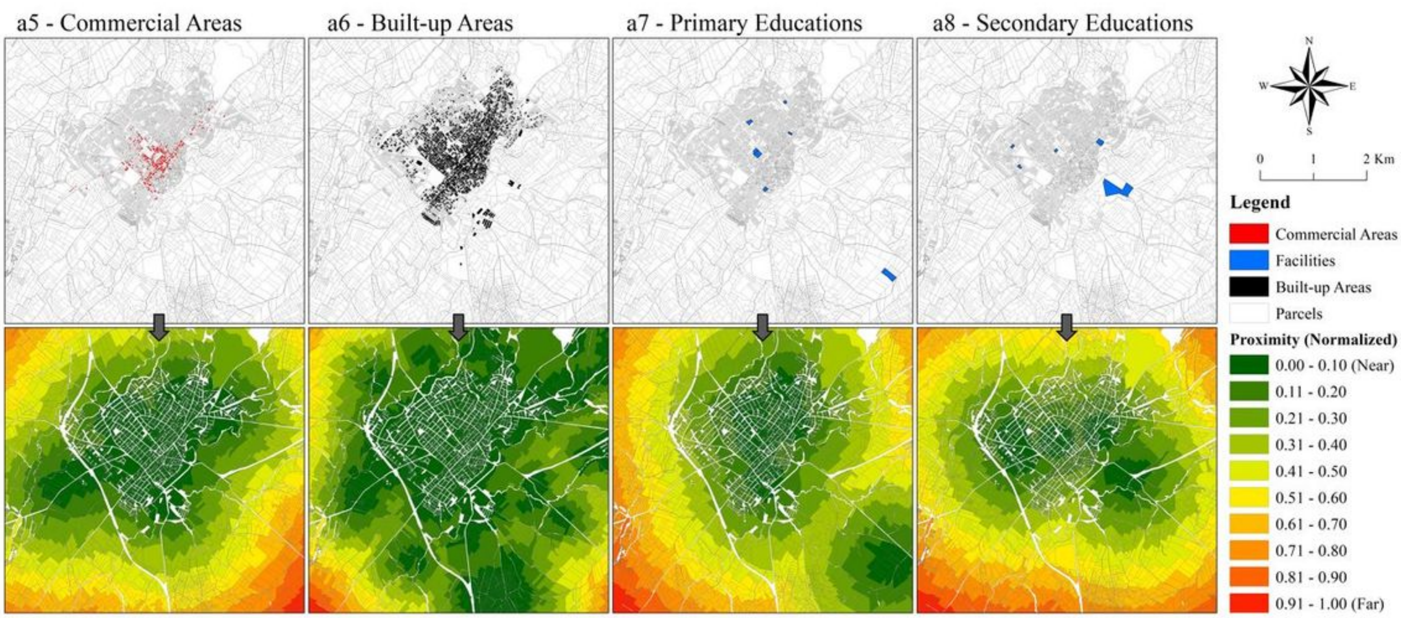

Figure 5

Proximity analysis (second 4 of 16)

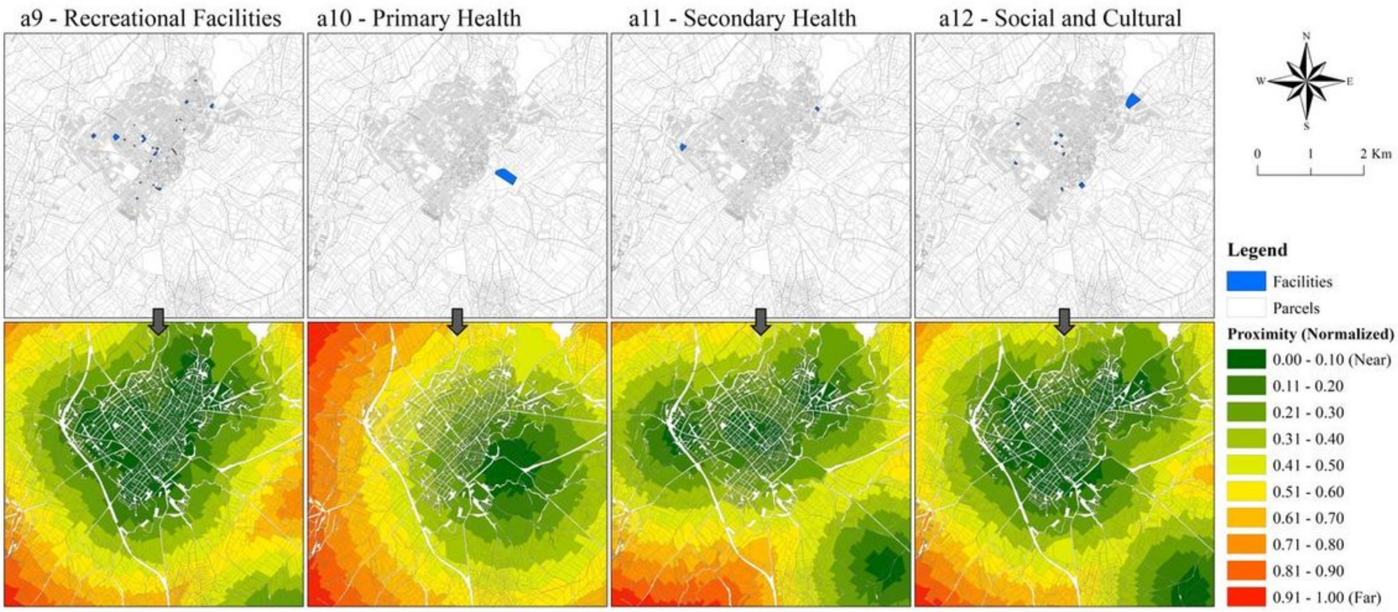

Figure 6

Proximity analysis (third 4 of 16).

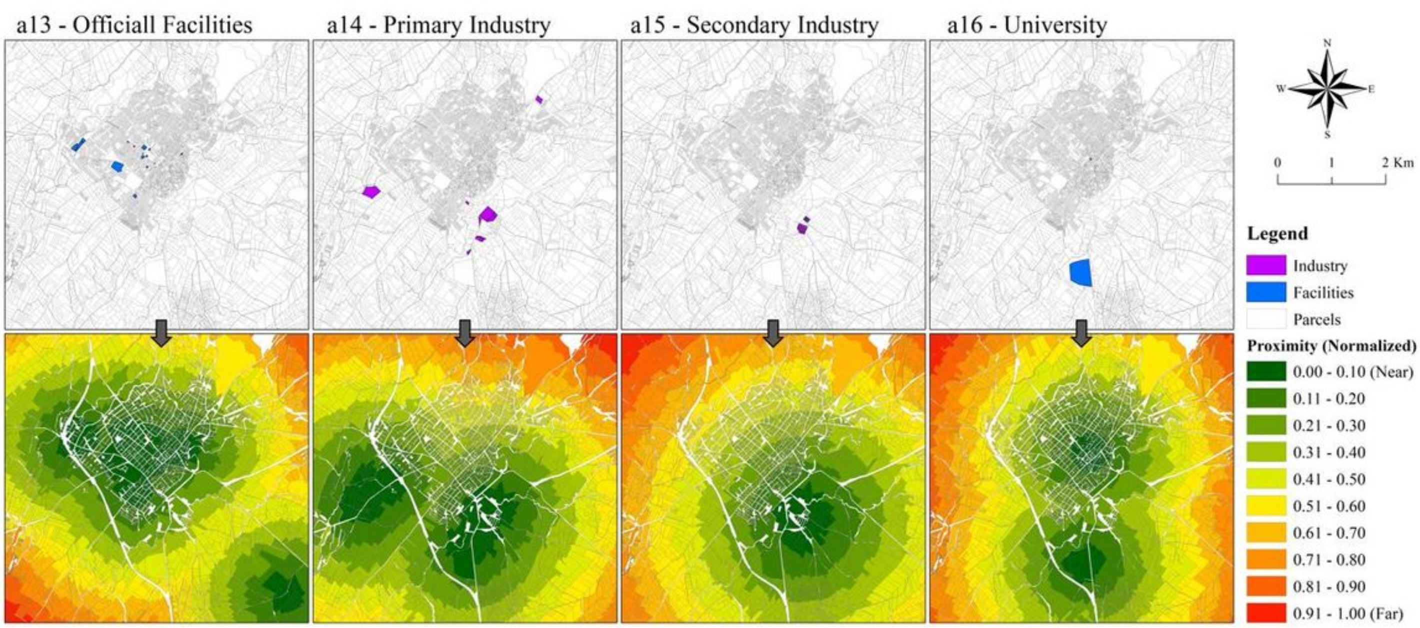

Figure 7

Proximity analysis (last 4 of 16)

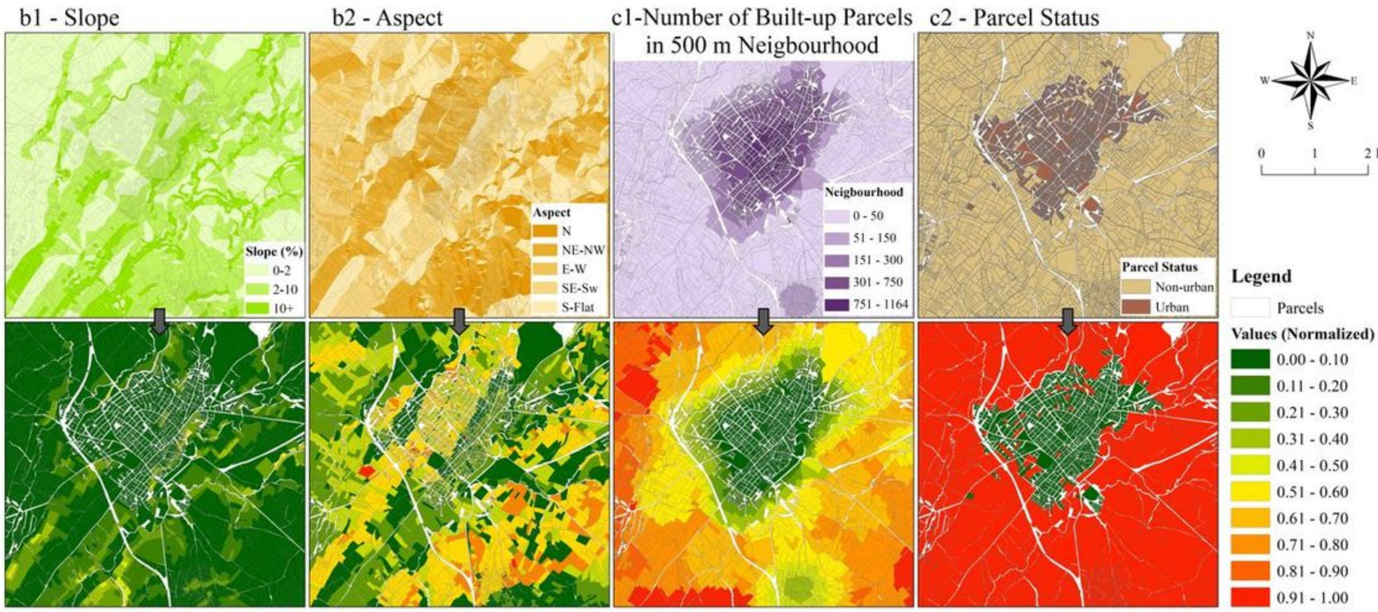

Figure 8

Natural and built-up environment

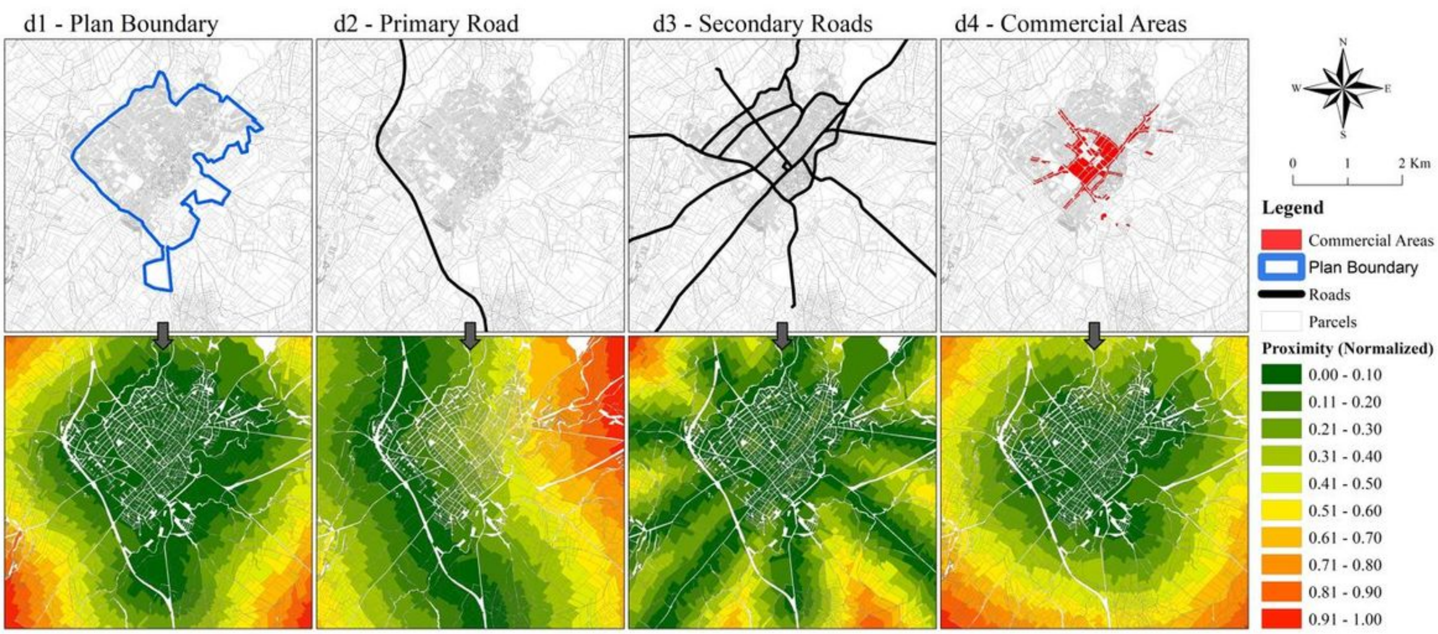

Figure 9

Plan Decisions (first 4 of 12).

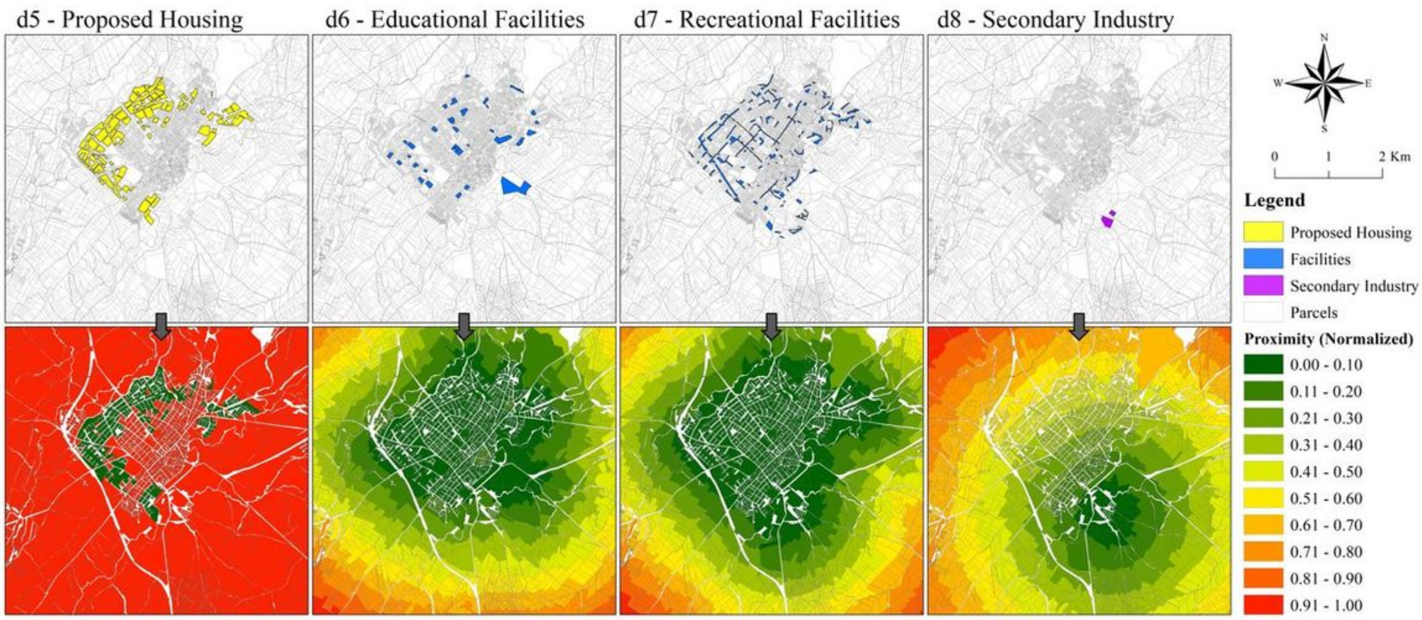

Figure 10

Plan Decisions (second 4 of 12)

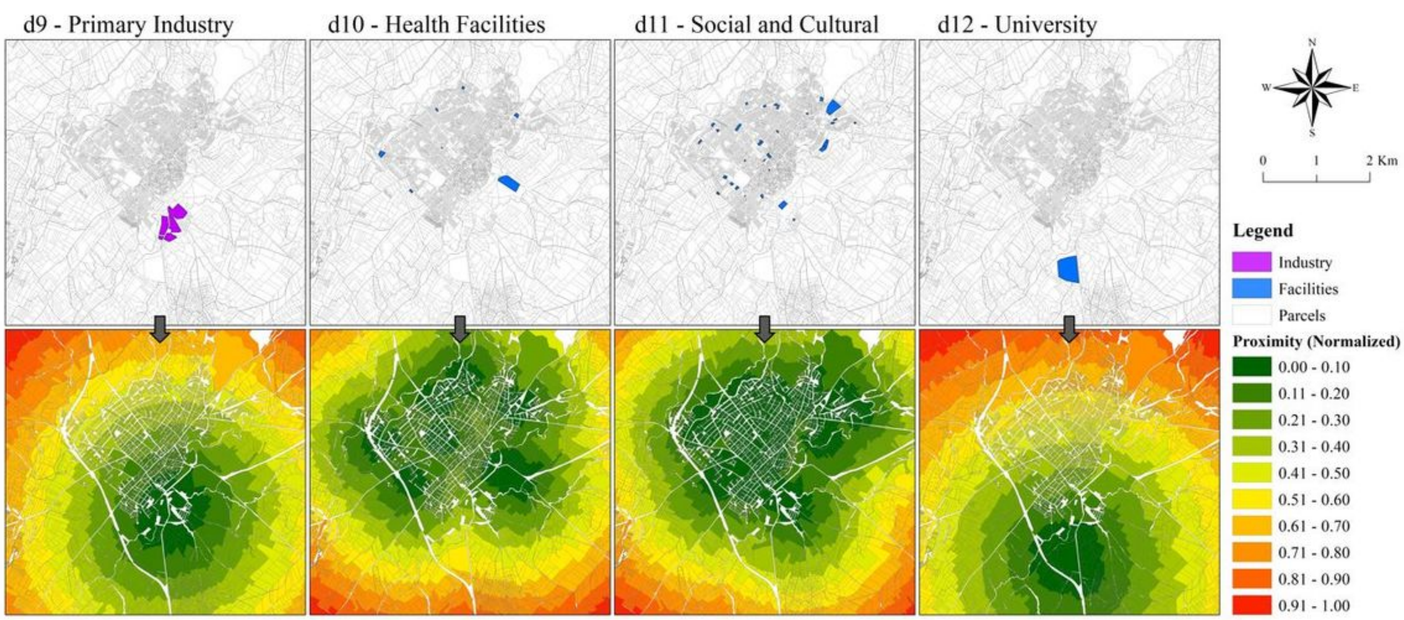

Figure 11

Plan decisions (last 4 of 12).

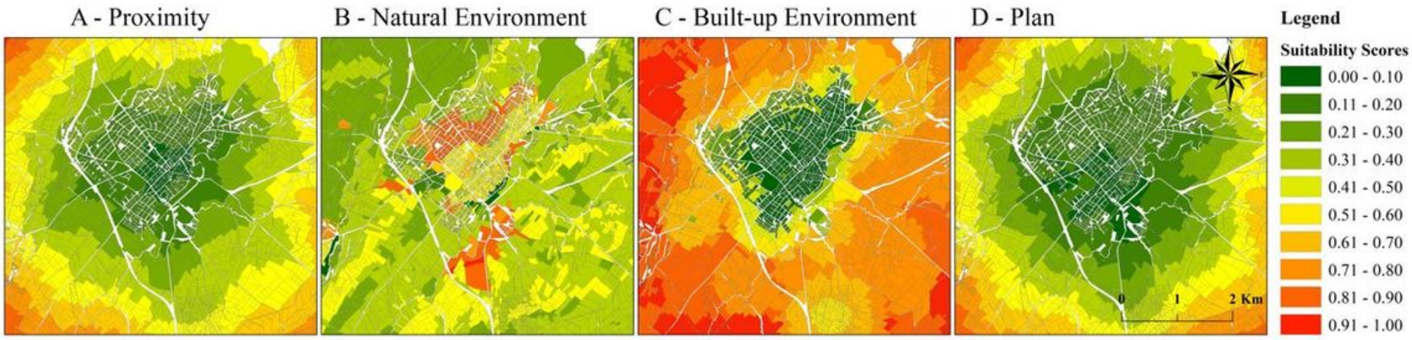

Figure 12

Suitability by criteria.

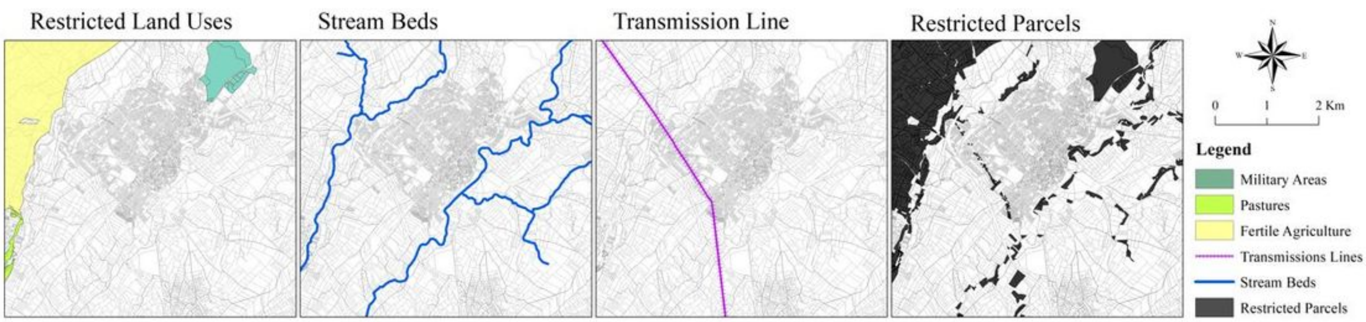

Figure 13

Constraints and restricted parcels.

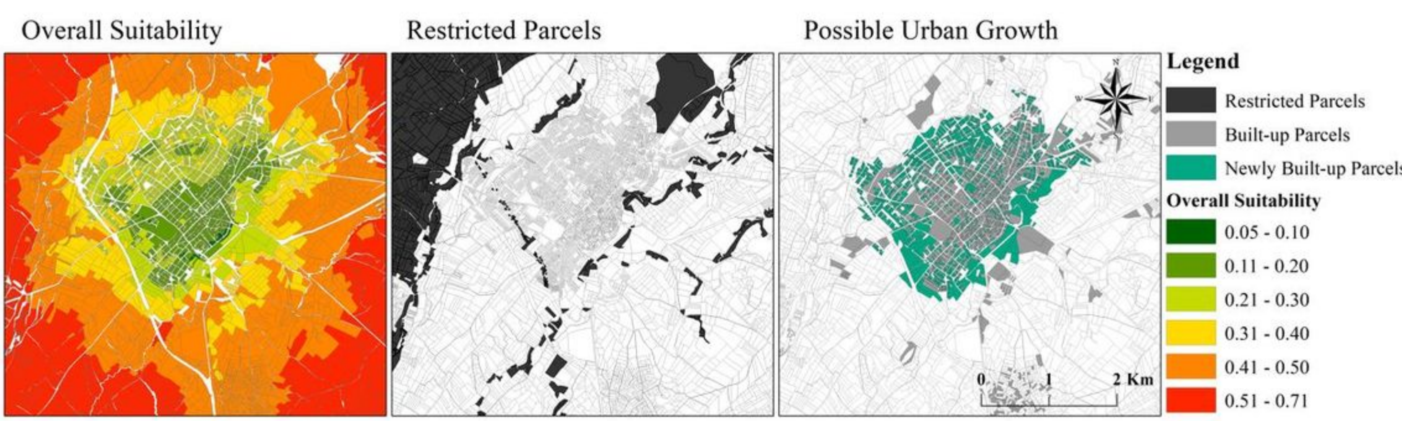

Figure 14

Overall suitability and possible urban growth areas by 2040.