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Creating a Land Cover Change Simulation Model with SLEUTH, The Case of Istanbul Province

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ABSTRACT

Population growth leads to the growth of cities and the destruction of natural areas. Urban growth triggers changes in land cover. Determining the effects of change in land cover is necessary for sustainable urban management. For this reason, simulation applications are used extensively in planning studies. The cellular automata (CA) based simulation methods are often preferred to investigate land cover/use changes caused by urban growth. In this study, it is aimed to create a simulation model for the year 2040 in line with the ongoing urban growth trends of Istanbul by using CA-based SLEUTH model. The temporal data required by the model are generated from CORINE Land Cover data for the years 2000, 2006, 2012 and 2018. With the simulation model created, the effects of possible urban growth and land cover change in Istanbul were investigated. According to the simulation model produced, it was determined that 25% of Agricultural Land, 2% of wetlands and 14% of forests could be turned into residential areas. It is estimated that there may be 24% urban growth in Istanbul between 2018 and 2040. The results showed that the province of Istanbul is under intense urbanization pressure.

1. INTRODUCTION

With the population growth in the world especially after 1950, migration from rural to urban areas accelerated urbanization. (Satterthwaite 2005). This high acceleration has caused unhealthy or excessive urbanization (Saadani et al. 2020). Thus, the destruction of the environment brought along physical unplannedness, settlement irregularity, planning and management problems. With the transformation of open lands, forests and agricultural lands into residential areas, the pressure on natural resources is increasing day by day. (EEA 2016). Tourism, urbanization and industrialization in particular have accelerated the destruction of natural resources.

Many models and simulation tools have been developed by researchers to determine changes in urban growth and land cover. When researches on this subject are examined, cellular automata (CA)-based models are preferred due to their ease of calculation, simplicity of use, and their inherently spatial nature (White et al. 2004).

CA-based SLEUTH (Gigalopolis 2020b), which is used in many studies worldwide, was first applied in San Francisco and Washington-Baltimore regions (Clarke et al. 1997; Clarke and Gaydos 1998). In the following period, a series of studies were carried out in Santa Barbara to determine the technical development of the urbanization process (Candau and Clarke, 2000; Goldstein et al. 2004; Herold et al. 2003). It has been applied for the first time in Europe by Portugal's Lisbon and Porto metropolitans (E. A. Silva and Clarke 2005; E. Silva and Clarke 2002). On the other hand, SLEUTH has the highest number of applications in China. Simulations were produced under the ongoing conditions of the city or under alternative scenarios to assess the impact and extent of urbanization in rapidly growing cities such as Beijing (Yi and He 2009), Lanzhou (Xie et al. 2010), and Nanjing (Zhang et al. 2010). In the study conducted in Istanbul, it was applied for the changes in land use caused by the 3rd bridge and the main transportation networks of the city (Ayazli et al. 2015).

The SLEUTH model is divided into two sub-models as UGM (Urban Growth Model) and LCD (Land Cover Deltatron). UGM is the core module and constitutes urban growth simulations. The LCD matches the UGM if desired, simulating the land cover changes triggered by

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urban growth. In this context, LCD works integrated with UGM and is not independent.

In this study, the answers to the following questions were investigated:

- How do possible urban growth trends in Istanbul affect land cover changes?
- How does the urban growth rate change between 2018 and 2040 according to the scenario produced?
- How will the land cover of the region change in 2040 in Istanbul?

In order to create a model for this purpose, first CORINE land cover data for 2000, 2006, 2012 and 2018 were used. The input data of this model were generated using 2000, 2015 and 2018 transportation network data obtained from the Open Street Map service and digital elevation model (DEM) data obtained from the General Directorate of Mapping (HGM). Thus, an urban growth model has been prepared for 2040.

2. METHOD and METARIALS

2.1. Cellular Automata

The Cellular Automata concept consists of five basic components. These are; grid network, status, neighborhood, conversion rules and time. (Benenson and Torrens 2004). Cells are the smallest units that are adjacent to each other. Cells come together to form the grid network. Each cell has a state Depending on the state of neighboring cells, the conversion function changes the cell states. In urban modeling techniques, CA is suitable for modeling complex and dynamic natural phenomena such as urban areas (Tobler 1970).

2.2. SLEUTH Model

The model is a Unix-based software developed with the C language running on cellular automata. Since it is an open source software, the researchers developed the model according to local research areas.

The process of the model takes place in three main stages. These are the testing, calibration and prediction stages. In the test phase, the compliance of the input data required by the model with the model standards is questioned (Ayazli et al. 2015). If it is successful, the calibration phase is started. The calibration stage is also made in four stages as coarse, fine, final and forecast (Gigalopolis 2020a). At the calibration stage, the parameters of the model's growth rules are calculated using historical data. The five coefficient values from 0 to 100 are narrowed at each stage and reduced to a singular value (Gigalopolis 2020a). Possible singular values are investigated using the Brute Force Calibration (BFC) method according to 13 criteria. (Clarke and Gaydos 1998). With BFC, the model calculates the current situation in control years from the core year by comparing it with the regression method. In this way, the accuracy of the model is checked by calculating the regression values between the model and the calculated values.

In this study, OSM (Optimum SLEUTH Metric) was used as the calibration method. The method developed by Dietzel and Clarke is considered the most powerful of the methods used today. Coefficient ranges are selected by ranking the score values obtained from the multiplication of Compare, Pop, Edges, Clusters, Slope, X-Mean and Y-Mean criteria as in the 1st formula (Dietzel and Clarke 2007). The fact that the OSM score value is close to 1 indicates that the selected coefficient sequence represents the area with high accuracy, while the fact that it is close to 0 indicates that the area representation of the determined coefficient sequence is weak (Dietzel and Clarke 2007).

$$OSM = Compare * Pop * Edges * Clusters * Slope * X\text{-}mean * Y\text{-}mean \quad (1)$$

2.3. Input Data

CORINE is the land use/cover data produced by computer-aided visual interpretation method over satellite images according to the land cover/use classification in line with the standards determined by the European Environment Agency (EEA) (EEA 2020). The project, approximately 5.8 million km^2 area, including in Turkey, is carried out in 39 countries. It is aimed to create a standard database in all member countries (Ministry of Agriculture 2020). According to EEA criteria and classification units, changes in land cover/ land use for monitoring land via satellite images are detected using remote sensing and geographic information systems. CORINE data are served at three different classification levels (EEA 2020). The land cover data used in this study were used at the level 1 (City, Agriculture, Wetlands, Forest and Water Body).

Table 1. Data and sources used in the study

Data Type	Source	Year
Land Use	CORINE	2000 2018
Urban	CORINE	2000 2006 2012 2018
Transportation	Open Street Map	2000 2015 2018
Slope	HGM	-
Hillshade	HGM	-
Excluded	IMM Administrative Border	-

Urban data was obtained by subtracting residential areas from CORINE Land Cover data for four periods. Transportation data is obtained from Open Street Map, an open source and free service. Considering the routes of 1st degree importance in the region in transportation data, other routes are not included in the data. Transport data is prepared for 2000, 2015 and 2018. The slope and Hillshade data are produced from the Digital Elevation Model obtained from HGM.

3. RESULTS

Parameter values were determined according to the results of the calibration process for the urban simulation model of Istanbul Province. These parameters were used in the estimation phase. When the values are examined, it is concluded that the road effect of the model and urban growth are intense. According to the intervals in the calibration stages and the calculated OSM scores, the highest three coefficient information is presented in "Table 2", "Table 3" and "Table 4".

Table 2. Coarse calibration results

Coefficients	Starting Ranges			OSM TOP 3		
	START	STEP	STOP	1	2	3
Diff	0	25	100	25	25	25
Breed	0	25	100	1	100	100
Spread	0	25	100	25	25	25
Slope	0	25	100	75	75	75
Road	0	25	100	1	100	50

Table 3. Fine calibration results

Coefficients	Starting Ranges			OSM TOP 3		
	START	STEP	STOP	1	2	3
Diff	25	1	25	25	25	25
Breed	1	25	100	1	1	26
Spread	25	1	25	25	25	25
Slope	75	1	75	75	75	75
Road	0	25	100	76	51	1

Table 4. Final calibration results

Coefficients	Starting Ranges			OSM TOP 3		
	START	STEP	STOP	1	2	3
Diff	25	1	25	25	25	25
Breed	1	5	26	21	26	16
Spread	25	1	25	25	25	25
Slope	75	1	75	75	75	75
Road	1	15	76	61	1	31

The coefficient values obtained after the calibration process are presented in "Table 5". These values were used in the creation of the urban growth simulation model of Istanbul Province.

Table 5. Calculated coefficient values

Coefficent	BEST_FIT
Diff	25
Breed	21
Spread	25
Slope	75
Road	61

Change analysis was conducted between 2018 and 2040. As a result of the analysis, the rates of the land cover classes transformed into each other were calculated. Results are presented in "Table 6".

Table 6. Amounts of conversion to urban space

Class	2018-2040(ha)	%
Agriculture	29,561	25.18
Wetlands	3	1.96
Forest	37,826	14.06
Water Body	0	0

As a result of the change analysis, an urban growth possibility of 24% in Istanbul was determined until 2040.

4. CONCLUSION

The rapid population growth in Istanbul and the irregular urbanization brought about by this caused unplanned land use. Therefore, the Istanbul metropolis needs an urban growth model that can describe land uses and local government decisions to assess the potential impact of growth policies. CA-based SLEUTH model has been preferred in modeling Istanbul city development due to its independent, dynamic and conforming to the basic conditions of urban growth simulation. In order to determine the urban development of the region in the model, it is necessary to determine the current situation at certain dates.

In this direction, especially given the urban growth structure of Istanbul, it is believed that the unstructured areas and their surroundings in Istanbul are under intense urbanization pressure. According to the results of the simulation model created, between 2018 and 2040, urban areas increased by 67390 hectares. Of this amount, 29561 hectares have been transformed from agricultural lands, 3 hectares from wetlands and 37826 hectares from forest lands. For this reason, whether forest and farmland will be protected will directly affect planning and local government decisions.

When developing policies that can control growth, legislators can use urban growth simulation models as a prediction. Simulation models should be produced under alternative scenarios in order to evaluate the possible effects of infrastructure projects that trigger dynamic and complex land cover changes in the metropolis of Istanbul.

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