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Simulating future urban growth in the city of Kahramanmaras, Turkey from 2009 to 2040

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Abstract

City of Kahramanmaras has witnessed a rapid growth in the last five decades due to its agricultural and industrial potential. Urbanization has brought great challenges to the sustainable development of cities, especially in developing countries. A modeling system that could provide regional assessments of future development and explore the potential impacts of different regional management scenarios would be useful for the future health of the cities. The main goal of this study was to create a modeling system capable of depicting, quantitatively and graphically, the growth impacts of two land use policies and trends in the city of Kahramanmaras. Given its success with regional scale simulation, its ability to incorporate different levels of land protection through an "excluded" layer, and the relative ease of implementation and computation, the model developed by Keith Clarke from University of California at Santa Barbara, known as SLEUTH, was adopted for this study. SLEUTH is a pixel-based cellular automaton (CA) model and has been applied to several cities worldwide successfully. The model was calibrated using historic time series of developed areas derived from Landsat Thematic Mapper (TM) imagery between 1984 and 2009, and future growth was projected out to 2040. Two alternative growth scenarios were modeled: (1) current trends, and (2) managed growth: regions with high landscape potential were protected from urbanization. This application of the SLEUTH model demonstrates an ability to address a range of regional planning issues and provides useful information for the cities' future planning and development.

Key words

SLEUTH, Future urban growth, Land use/land cover change, Remote sensing

Introduction

During the past decades, urban growth has been accelerated with the population migration from rural areas to cities. Urban population in the world is estimated as 3.4 billion in 2010 and predicted to reach 5.7 billion in 2040 (Fig. 1). World's urban population is also expected to exceed the world's rural population first time in the history (UN, 2007).

According to Masser (2001) urban growth is inevitable for the next two decades and that most of this growth will occur in the developing countries. As a developing country, Turkey is experiencing extensive growth of its urban areas due to a number of factors, most notably population growth via rural-urban migration. In Turkey, the rural population has been declining steadily, while the urban population has been increasing rapidly (Fig. 2). Urban population in Turkey is estimated as 54.1 million in 2010 and predicted to reach 78.4 million in 2040 (UN, 2007).

Unplanned urban expansion can pose many environmental problems on a regional scale, including habitat fragmentation, loss of agricultural land, formation of urban heat islands, reduction of biodiversity, and significant landscape changes, all these play an important role on global climate change (Han *et al.,* 2008).

Given the long research tradition in the fields of urban geography and urban modeling (Batty, 1989; Knox, 1994), new sources of spatial data and new techniques offer better analysis, understanding, representation, and modeling of urban dynamics. The innovative techniques and combination of new data are going to support more informed decision-making for resource managers. Dynamic spatial urban models provide an improved ability for the resource manager in order to forecast future growth and to develop and test planning scenarios. Yet, the performance of the model is still limited by the input data needed for their calibration and validation (Herold *et al.*, 2003).

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SLEUTH is a CA model that has been widely applied (Jantz *et al.*, 2010; Rafiee *et al.*, 2009; Oguz *et al.*, 2007,2008; Jantz *et al.*, 2003; Yang and Lo, 2003; Clarke and Gaydos, 1998; Clarke *et al.*, 1997). In this study, the SLEUTH model has been used to predict the future urban growth by the year 2040 in the study area, Kahramanmaras. Two alternative scenarios were developed and tested using the model: (1)Current trends scenario with no protection and (2) Ecologically sustainable growth that protects agricultural lands, forests and open-green areas from urban development with maximum restriction.

Materials and Methods

Study area: Kahramanmaras is located on the northeastern part of the Mediterranean region of Turkey and surrounded by Ahir mountain in the north, Sir Dam lake and Aksu stream in the west, and fertile agricultural land in the south and east (Fig. 3).

The study area covers 33,934.05 ha of land between the altitudes of 392 m in agricultural land in the south and 1802 m in the Ahir mountain in the north. Also, 83% of the study area holds a slope between 0 and 25%. The average annual temperature is 17.2^{o}C and the annual precipitation is about 737 mm (TSMS, 2007). The region offers rich alternatives for various agricultural activities due to its optimal climate and fertile soils. Kahramanmaras hosts approximately 240 factories, ranging from textile to food (Cinar *et al.*, 2004). The region grew rapidly because of these agricultural and industrial potential. The population has increased rapidly during the past five decades because of the migration from rural areas into the city (Fig. 4) (Doygun *et al.,* 2008).

Data: SLEUTH is an acronym and derived from the initial letters of the model's input layers: Slope, Landuse, Excluded, Urban, Transportation and Hillshade. The SLEUTH model requires inputs of at least four historic urban extents, two historic land use layers, which are only required if land cover change will be modeled, at least two transportation networks, one excluded layer, one slope layer and one hillshade layer.

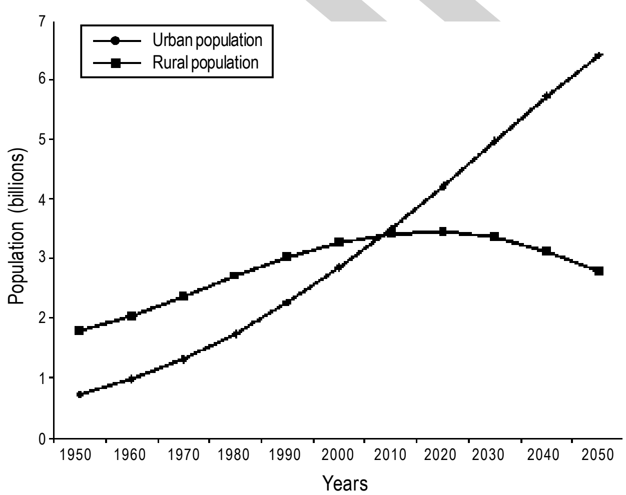

Fig. 1: Urban and rural population of the world (Source: UN, 2007)

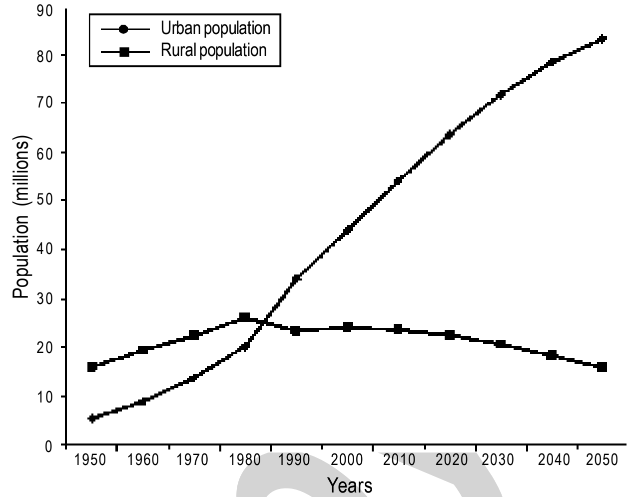

Fig. 2: Urban and rural population of Turkey (Source: UN, 2007)

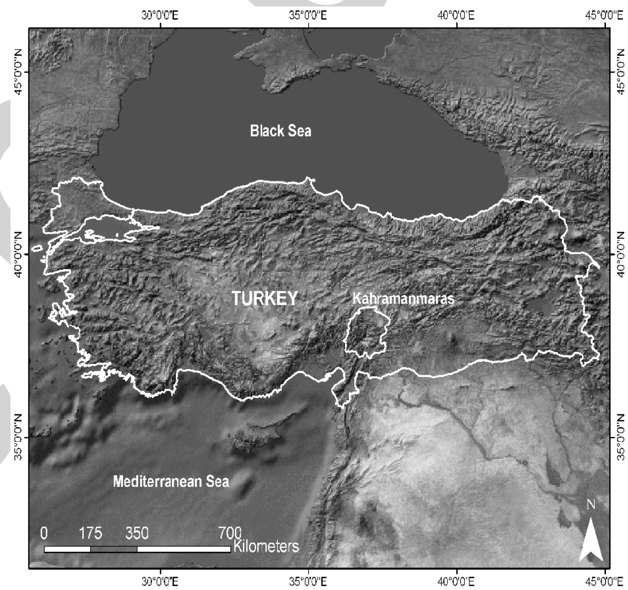

Fig. 3: Location of the study area

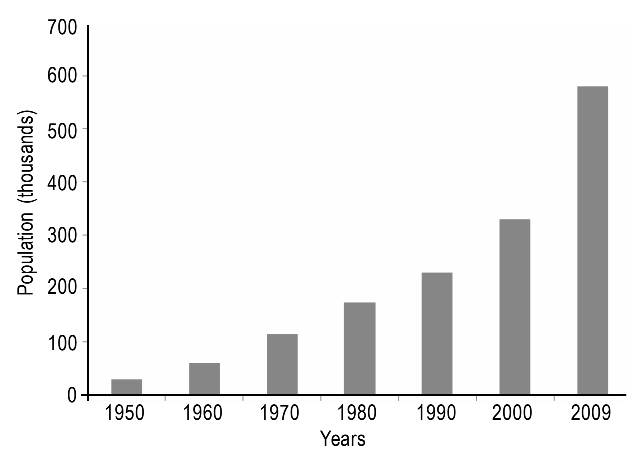

Fig. 4: Population growth in Kahramanmaras (Source: TSI, 2009)

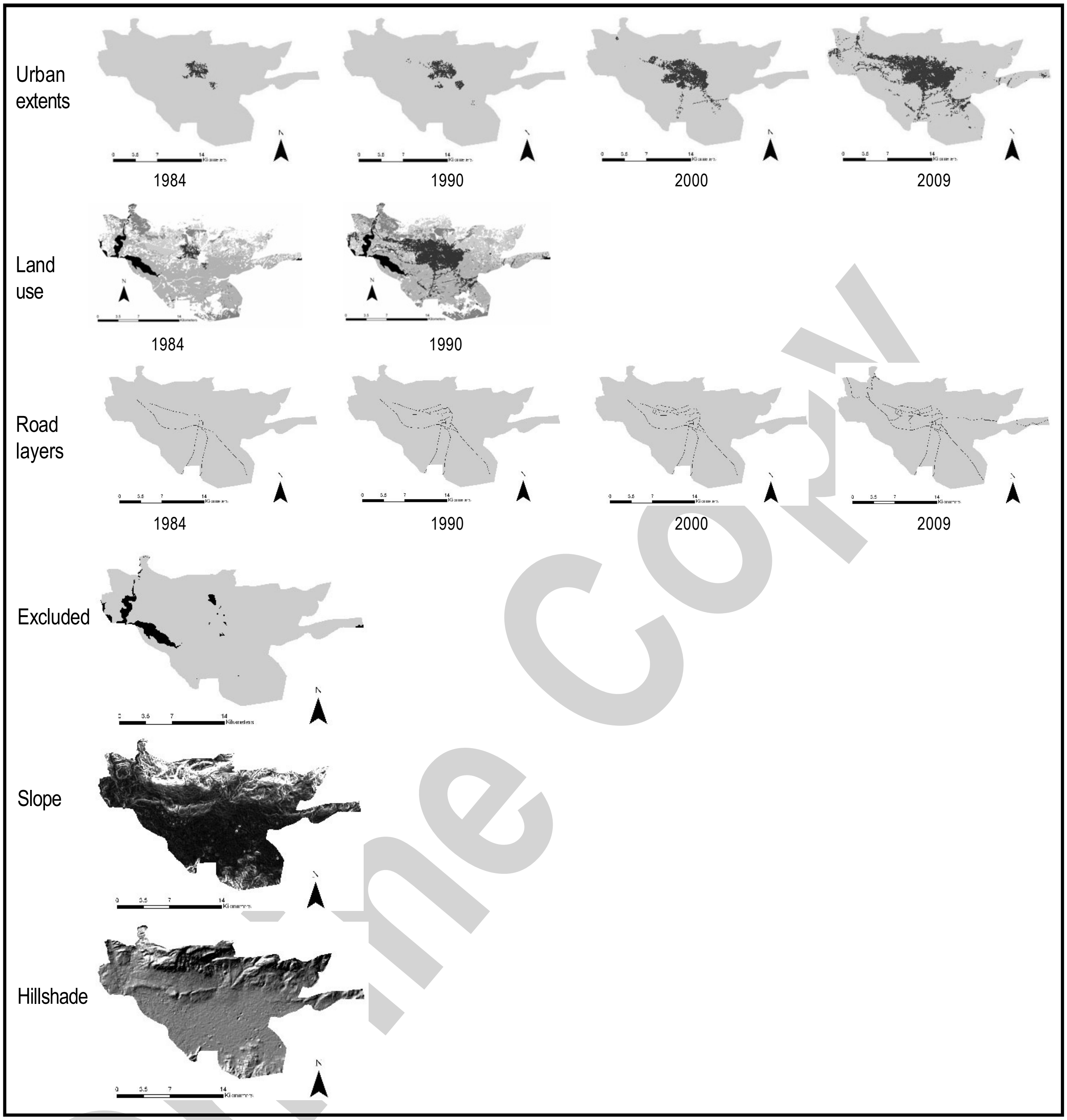

Fig. 5: SLEUTH input dataset

The implementation of the SLEUTH model is composed of three phases: input dataset preparation phase, calibration phase, where historic growth patterns are simulated, and prediction phase, where historic growth patterns are projected into the future. The input dataset (Table 1) for the model was processed and compiled using Remote Sensing (RS) and Geographic Information System (GIS) techniques. SLEUTH requires that all input data must be in the same extent, same projection and same resolution. Therefore, all data were rectified with an acceptable root mean square error (RMSE) and resampled into 30 m using nearest neighbor algorithm. Then, study area was clipped out from the Landsat 5 TM satellite images.

To derive land use layers, 1984 and 2009 clipped Landsat TM images were classified into 6 classes: 1- urban, 2- forest, 3- agriculture, 4- water body, 5- Rangeland and 6- Barren land, using both unsupervised and supervised classification techniques. There was no water body (Sir Dam) in the 1984 land use layer since Sir Dam was built in 1991. Therefore, the water body of 2009 land use layer was extracted and added over 1984 land use layer

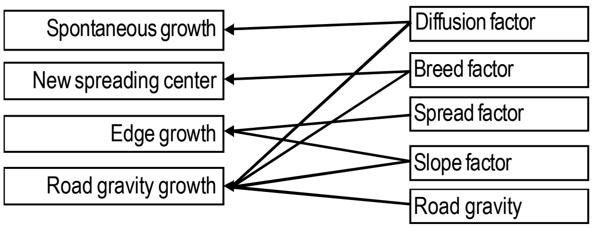

Fig. 6: Relationship of growth rules and urban growth coefficients (Source: Ding and Zhang, 2007)

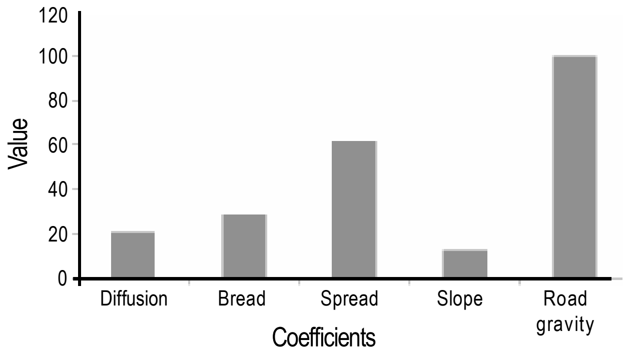

Fig. 7: Parameters used in prediction phase

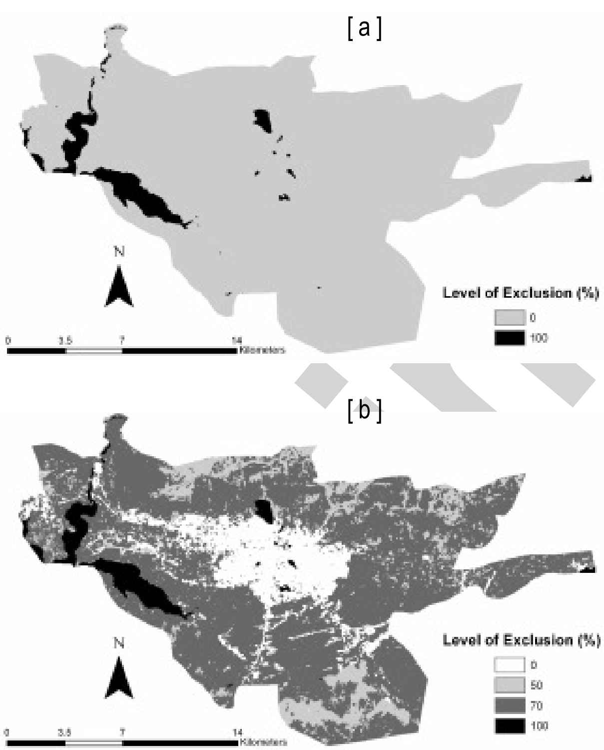

Fig. 8: Excluded layers for (a) current trends, (b) managed growth scenarios for the study area. 0% indicates land which is theoretically open to development

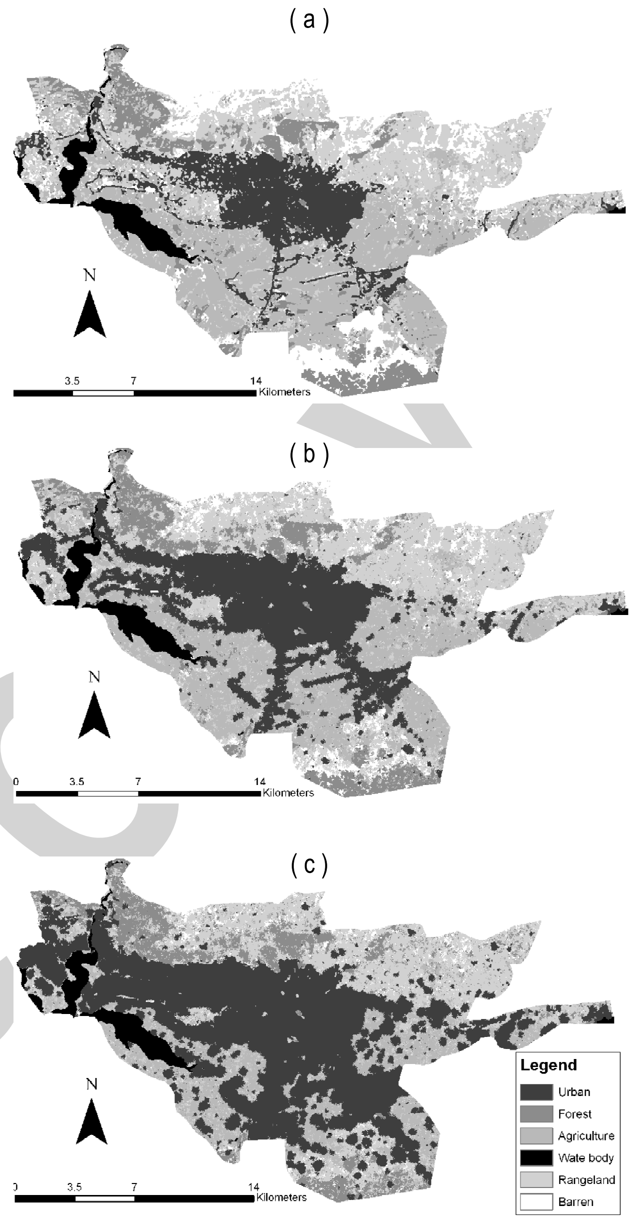

Fig. 9: Predicted outputs for land use/land cover change (a) Real image for 2009, (b) Managed Growth scenario output for 2040 and (c) Current Trends scenario for 2040

so that both land use layers have the same water body extent for SLEUTH modeling. The urban classes of these land use layers were extracted to be used as 1984 and 2009 urban extents. 1990 and 2000 clipped Landsat TM images were then classified into only 2 classes: (1) urban, and (2) non-urban. Transportation layers were prepared by digitizing only the major highways of the study area from Landsat TM and topographic map, and then converted into raster format. Percent slope and hillshade images were created from the digital elevation model (DEM). Various scenarios can be prepared and applied to the model with excluded layer, which indicates areas that are partially or completely excluded from development (Jantz *et al.,* 2010). After preparing the input dataset, it was converted into 8-bit grayscale graphics interchange format (GIF) image format (Fig. 5).

Method: SLEUTH forecasts urban growth by four growth rules: spontaneous growth, which simulates the random urbanization of

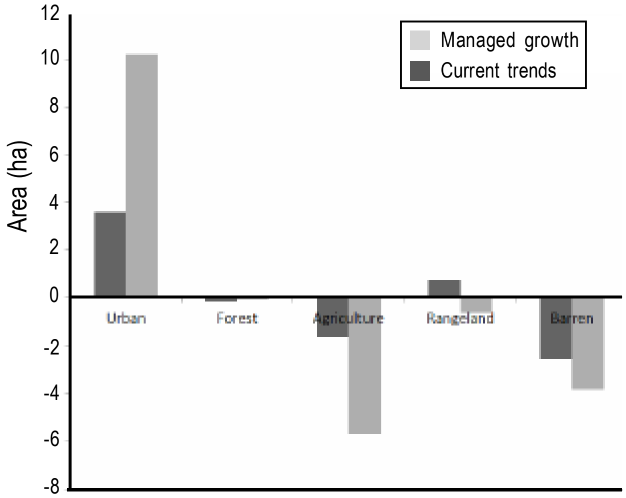

Fig. 10: Results of impact assessment for the both scenarios

land; new spreading centers, which simulates the development of new urban areas; edge growth, which simulates growth occurring on edges of already urbanized land; and road-influenced growth, which simulates the influence of transportation network on development. These growth types are controlled by five growth coefficients diffusion, breed, spread, slope resistance and road gravity (Fig. 6).

The model was tested with the prepared input 8 bit grayscale GIF images before proceeding exhaustive and rigorous calibration phase. The model was calibrated using Coarse, Fine, and Final calibration phases. The metric used in the model was the product of Compare, Population, Edges, Clusters, Slope, Xmean, Ymean, and Fmatch as suggested by Dietzel and Clarke (2007). After rigorous calibration phase, the parameter values were obtained. These values were used in prediction phase to forecast the future urban growth (Fig. 7).

In this study, two scenarios were developed using two excluded layers: (1) current trends and (2) managed growth (Fig. 8). The current trends scenario reflects no protection over semi natural resources such as forests and agricultural land. Parks are protected from development 100% in both scenarios. This scenario could also be named as unmanaged growth. The managed growth scenario, however, reflects a strong commitment to resource protection (Table 2).

Results and Discussion

The results of the scenario predictions (Fig. 9) show higher dispersed development patterns for the current trends than the managed growth scenario, with most occurring in and around (edges) existing urban centers. Fig. 10 below shows the impact of development on resource loss for both scenarios. According to the results, agricultural land was most affected due to development, and forest, however, was least affected (Fig. 10). Most of the forested areas are located generally on the outskirts of the Ahir mountain, which has slope values over 25%. Therefore, forested areas were the least affected from development under both scenarios.

Table - 1: Input dataset

Number of layers	Type	Years	Source
4	Urban extent	1984, 1990, 2000, 2009	Landsat 5 TM
2	Land use	1984, 2009	Landsat 5 TM
4	Transportation	1984, 1990, 2000, 2009	Digitized from topo map and Landsat 5 TM
1	Excluded	NA	NA
1	Slope	NA	DEM
1	Hillshade	NA	DEM

Table - 2: Levels of protection for each scenario

Lulc classes	Current trends	Managed growth
Water body	100	100
Parks	100	100
Forest	0	70
Agricultural land	0	70
Green space / Rangeland	0	70
Barren land	0	50

The results from this local scale assessment have provided thought-provoking insights into the future of the region. Jantz *et al.* (2003) stated that the accuracy of the SLEUTH model was improved significantly when results were generalized to meaningful special units. The model's best feature is the visualization tool it has. The visualization of potential land use change makes the model powerful for raising public awareness. After evaluating the findings from this study, SLEUTH could be used to guide more localized modeling efforts.

Although excluded layer is ideal for simulating the future development, the SLEUTH model does not have an adequate mechanism to simulate the potential impacts of incentive policies. Also, the use of different data sources used for preparing input dataset may compromise the accuracy of the model. Therefore, a highly consistent and reliable dataset, which was derived from RS imagery, was used in this study.

In the study of urban growth and land use change, a realistic modeling system that can be employed to simulate future growth and change is critically needed. Due to the ability to predict the complex behavior of urban systems, CA models represent a viable approach. Moreover, consistent and reliable dataset derived from satellite imagery can be easily integrated into the CA modeling environment. This study explored the suitability of utilizing a CA-based SLEUTH model for planning applications. This model's best features are interactive scenario development and visualizing/ quantifying spatial outcomes. Besides some weaknesses that the model has, it is found the SLEUTH model to be useful tool for assessing the impacts using alternative policy scenarios.

Acknowledgments

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