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Predicting urban sprawl for Rajkot city using SLEUTH model and GIS techniques

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Abstract: Unplaned Urban growth along with populationin the fast-growing urban world need to be monitored in order to have proper preparadeness plan for sustainable urban habitat. Thus Urban growth models are used as planning tools for the analysis of urban sprawl. These models play vital role in the planning process for the city. This paper presents a study that integrates the use of remote sensing, GIS and spatial modelling for predicting urban sprawl which has become one of the major challege in the fast growing world. The SLUETH is spatially explicit cellular automata model that has been used to simulate future sprawl of Rajkot city. Sprawl has been predicted for 2031. Input maps for the built-up theme used for five years, i.e, 1980, 1992, 2001, 2005, and 2011; input layer for roads three years 2001, 2005, and 2011, one exclusion layer, land use layer for two years 2005 and 2011, one slope layer and one hill shade layer.It took seven days to calibrate each stage of this model and approximately took one month to calibrate the model for one scenario. The results of this study shows the possiblity of urban sprawl, and the type of landuse that would converted to urban (built-up). Results of SLEUTH showed that organic growth is predominant in Rajkot, which shows major growth would occurre along the fringes of existing settlement. The sprawl is observed in the southern and the north western part of the city. This may be due to industrialisation. This study demonstrates the use of model – based prediction of urban sprawl in preparation of the master plan for the city.

Keywords: Urban sprawl, Satellite imagery, GIS, Decision support system, SLEUTH model

1. Introduction

Urban is defined as all places with a municipality, corporation, cantonment board or notified town area committee, etc. and all other places which satisfied the following criteria: i) A minimum population of 5,000; ii) At least 75 per cent of the male main working population engaged in non-agricultural pursuits; and iii) A density of population of at least 400 persons per sq. km. (Census of India 2011). According to Clark (1982), urban growth is a spatial and demographic process and refers to the increased importance of towns and cities as a concentration of population within a particular economy and society. However, nowadays, the word 'urbanization' means percentage of people living in urban areas in a region. Geographical Information System techniques can be applied on remote sensing data to map, monitor, measure, analysis, and model the urban sprawl. Remote Sensing can give detailed information about spatial and temporal information of urban morphology, infrastructure, land cover / land use patterns (Bhatta, 2010). Remote Sensing and GIS have proved to be effective means for extracting and processing varied resolutions of spatial information for monitoring urban growth (Masser, 2001), and therefore important in study of urban growths.

In developing countries such as India (Thangavel, 2000) and China (Yeh and Li, 2001), patterns of urban growth (compact or sprawling) have been studied in the context of their special social and economic circumstances. There is no universal solution to prevent urban sprawl. However, it is recognized that scientific management and planning should be based on a proper understanding of the spatial and temporal processes of urban growth. This model was originally developed by Keith Clarke, University of California at Santa Barbara (Clarke et al., 1997). Its main purpose is to examine the type of urban growth in surrounding areas. It predicts both, urban growth and land use change. As the aim of this study is to model and forecast urban sprawl, the best suited model will be the SLEUTH. This model has been tested on various cities in North America, Europe, China, South America, Portugal, Africa, Brazil, Egypt, Finland, India, Italy, Iran, Mexico, Netherlands, Oman, Spain, Taiwan, Thailand and Australia. Studies have been taken up in India using SLEUTH model for Pune and Hyderabad. SLEUTH Model is scale independent, dynamic and future oriented Model. It can be used under different conditions by modifying some initial, conditions and changing input data layers. It can be applied to all regions with different datasets (Yang and Lo, 2003). In the SLEUTH model, the growth rules are uniform throughout a gridded representation of geographical space and are applied on a cell-by-cell basis. A single time span is iteration of the CA, and all changes are applied synchronously at the end of each period (Clarke et al., 1997).

2. Study area

Rajkot was founded by the ruler of Sardhar in 1608 A. D. on the west bank of the river Aji as a small fortified town which is now one of the most rapid developing cities in the state of Gujarat. Population of Rajkot was 36151 in the year 1901, which has increased to 1286678 by the Census year 2011. An area of Rajkot city was 5 sq. km in 1901 which has reached to 68 sq. km by the end of 2011. Rajkot is situated in the middle of the peninsular Saurashtra in central plains of Gujarat State of Western India at a height of 138 m above mean sea level and it lies between latitude 20.18 N and longitude 70.51 E. Rajkot city is well connected with other parts of the country by Rail, Road and Air. Rajkot city is developed on the bank of river Aji. It has many natural water reservoirs (lakes) on the eastern part. The climate in the city is hot and dry. Figure 1 shows the study area.

3. Data used

Supplemented by LANDSAT Thematic Mapper and IRS LISS IV imagery are the major primary sources in this research, fieldwork and interviews to capture local knowledge. Data used for this study are listed in table 1.This study has been carried out on multi- date optical remote sensing data. LANDSAT sensor series have a long lasting history of image acquisition. LANDSAT TM images have spatial resolution of 30 m. High Resolution Linear Imaging Self-Scanning System IV (LISS-IV) of IRS RESOURCESAT – 1 having spatial resolution of 5.8 m is used for mapping urban sprawl. These satellite images have been classified using digital and visual image interpretation to create input layers. Thematic Maps of Ward boundary, Road Network, Slums Location have been provided from Rajkot Municipal Corporation GIS Department. General Development Control Regulations (GDCR) Report has been provided from Rajkot Municipal Corporation Collector Office, Rajkot. This data is used to analyze socio economical parameters effecting the urban growth. City Development plan was obtained from Rajkot Urban Development Authority. The demographic data is then combined with thematic maps to provide an in depth understanding of the effect of different factors on urban sprawl. Thirty-one years of multi temporal data sets from different sources dating back from 1980 to 2011 have been utilized in order to prepare the input data sets. For statistical calibration of the model in this study at five temporal urban extends, three road layers and two land use layers along with slope and excluded and hill shade layer are taken on the same spatial resolutions with same projected coordinate system and extent.

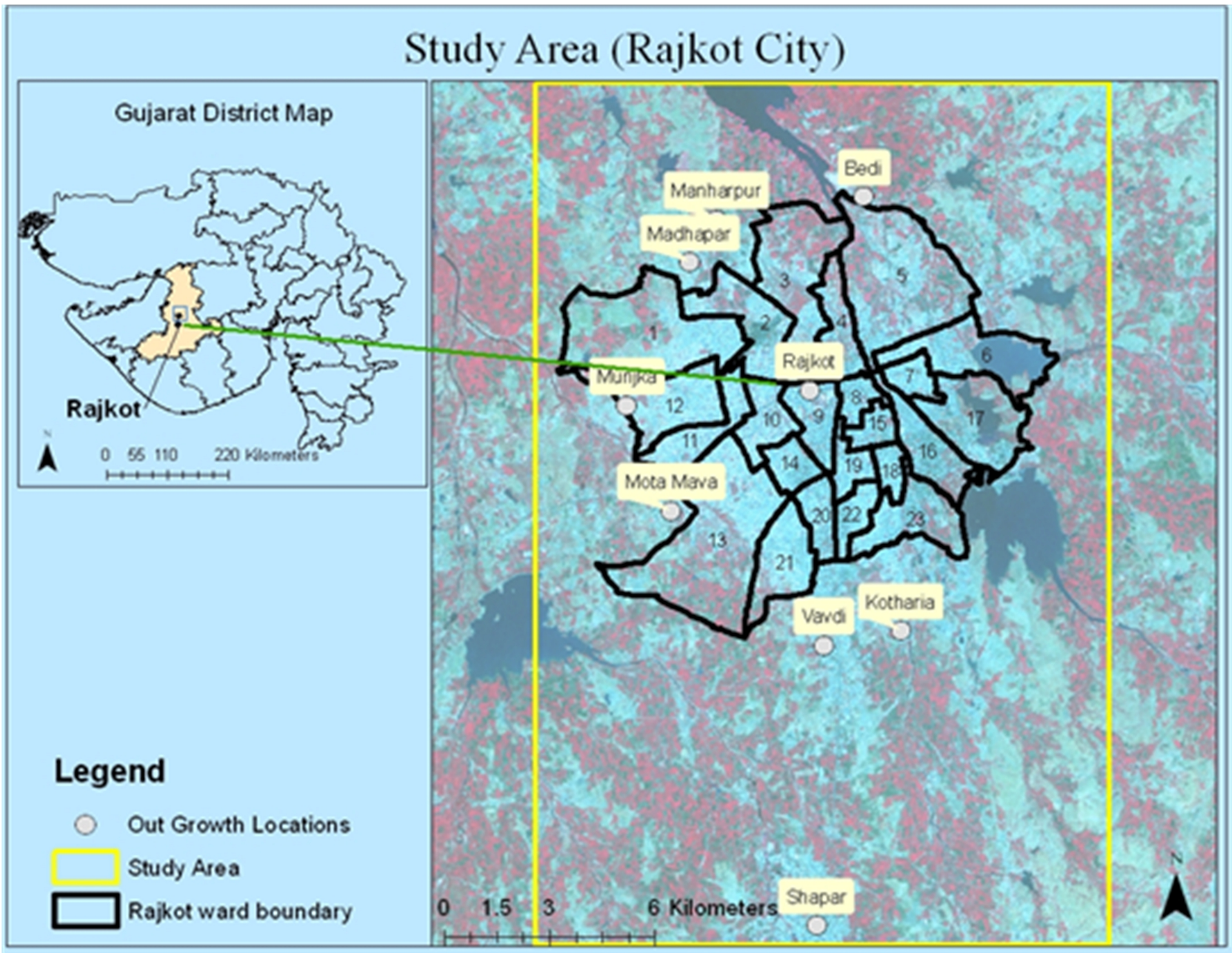


Figure 1: Study area (Source : IRS LISS IV 2011 image)

Table 1: List of data used for the study

Data	Source		
Remote sensing data	LANDSAT TM (30m) 1980, 1992, 2001	IRS LISS IV (5.8 m) 2005 2011	ASTER DEM (30 m)
Thematic Maps Ward boundary, Road Network, Slums Location, GDCR Report	Rajkot Municipal Corporation Collector Office, Rajkot		
City Development Plan	Rajkot Urban Development Authority		
Population data	Census of India: 2001, 2011		

4. Methodology

A proposed methodology work flow is shown in figure 2, which is based on monitoring temporal urban growth from remotely sensed imagery. This methodology consists of several steps: data collection from multiple sources, data processing such as image fusion and digitizing, temporal mapping, evaluation based on spatial indicators and comparisons. The main quantitative analysis includes morphology analysis, spatial pattern analysis and land use structure change with future sprawl prediction.

Visual image interpretation has been performed on this remote sensing data. Visual image interpretation different layers like land use, urban, exclusion and transportation have been digitized. Ground truth has been performed to verify the results. Factors effecting sprawl like outgrowth, roads, slope, land use are collected from ancillary data source and integrated to study probability of sprawl.

4.1 SLUETH input data

For this study five temporal dataset of urban area from 1980, 1992, 2001, 2005, and 2011 have been digitized from satellite images. The model requires a binary classification of urban/non-urban data. Urban is given a value of 100 and non-urban is given a value of 0. This layer was converted to raster and exported to GIF format with 30m resolution. It assigns a value of 100 to urban areas and 0 to non-urban areas. Urban development is attracted to locations of increased accessibility. A transportation network can have major influence upon how a region develops. To include this effect, SLEUTH requires two road layers that change the city's growth over time. Three time period road network for 2001, 2005 and 2011 has been digitized from the satellite images. Road network images are binary, road/non road. Road is given a value of 100 and non-road is given a value of 0. These combined layers were exported as GIF format (Fig. 3). Slope is derived from Digital Elevation Model. DEM data from ASTER sensor with 30m resolution was used. Using Spatial Analyst toolbar, percent slope at each pixel was computed. Slope is reclassified and exported to GIF format with 30m cell size. Thus all the layers will be exported as GIF format, UTM projection and 30m resolution. Slope ranges are given as 0-5 percentage is given 0 weight which is highly suitable for urban growth is shown in dark green color. Slope range from 5-10 percentages is given 25 weight which is suitable is shown in light green color. Slope range 10-20 percentage is given 50 weight which means moderately suitable is shown in orange color and all the slope ranges above 20 percentages is given 100 weight which is not suitable is shown in red color in figure 4.

A classification of land use was prepared based on using visual interpretation classification. Each land class was assigned a unique pixel value in attribute table. This layer was converted to raster and exported as GIF layer with 30m cell sizes. SLEUTH requires at least one layer of land use. In this study two land use layers have been prepared for 2005 and 2011. In the classified output shown in figure 5, urban is given value 1 (red), agriculture is given value 2 (green), waste land is given value 3 (yellow) and water body is given value 5 (blue).

The excluded image defines all locations that are resistant to urbanization. Areas where urban development is considered impossible are given a value of 100. These areas include water bodies, public and semi-public areas, mining areas, forest lands, airports and recreational areas. Locations that are available for urban development have a value of zero (0). These areas include open areas, vacant lands, construction sites and waste lands. Locations that are available based on conditions or they represent partial exclusion, are given a value of 50. These areas include wetlands and agricultural lands. SLEUTH requires 1 layer of exclusion. In the figure 7 violet color shows urban area which is given exclusion weight as 100. All the region which have neutral changes of converting into urban are shown in green color and weight given to them is 50 and areas shown in red are the areas which are non-urban and have high chances of converting to urban weight given to this class is 0. Two excluded layers have been created using 2005 and 2011 (Fig. 5).

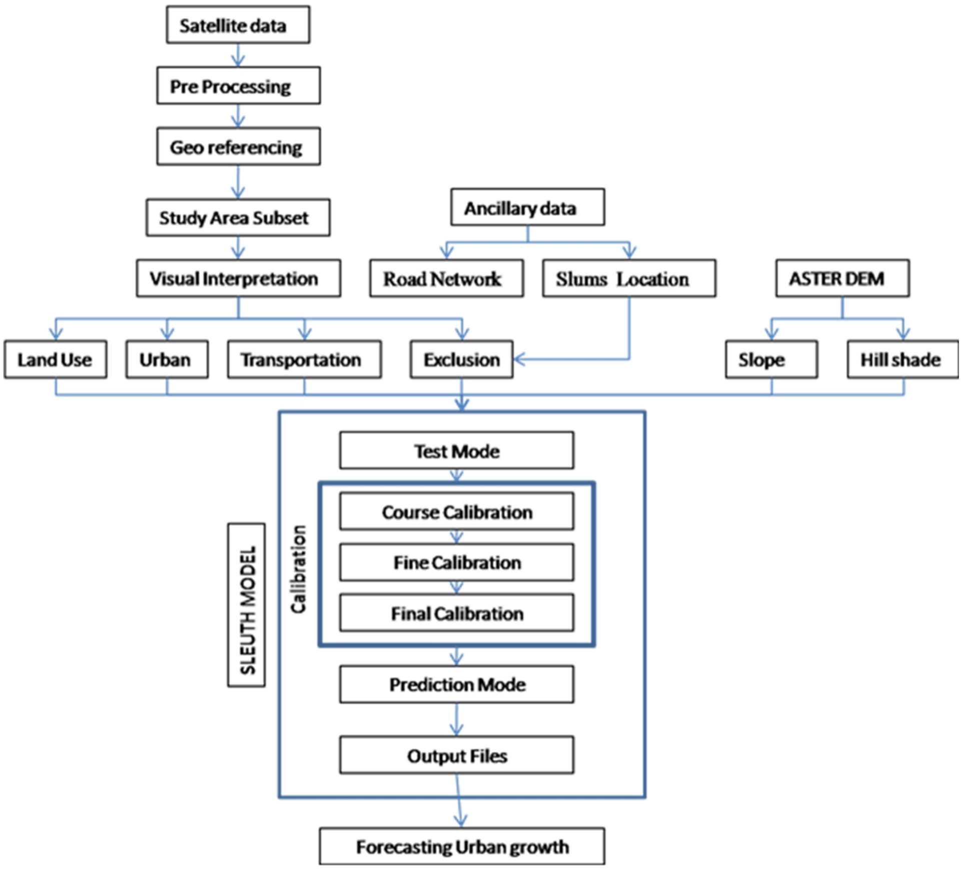


Figure 2: Methodology flow chart

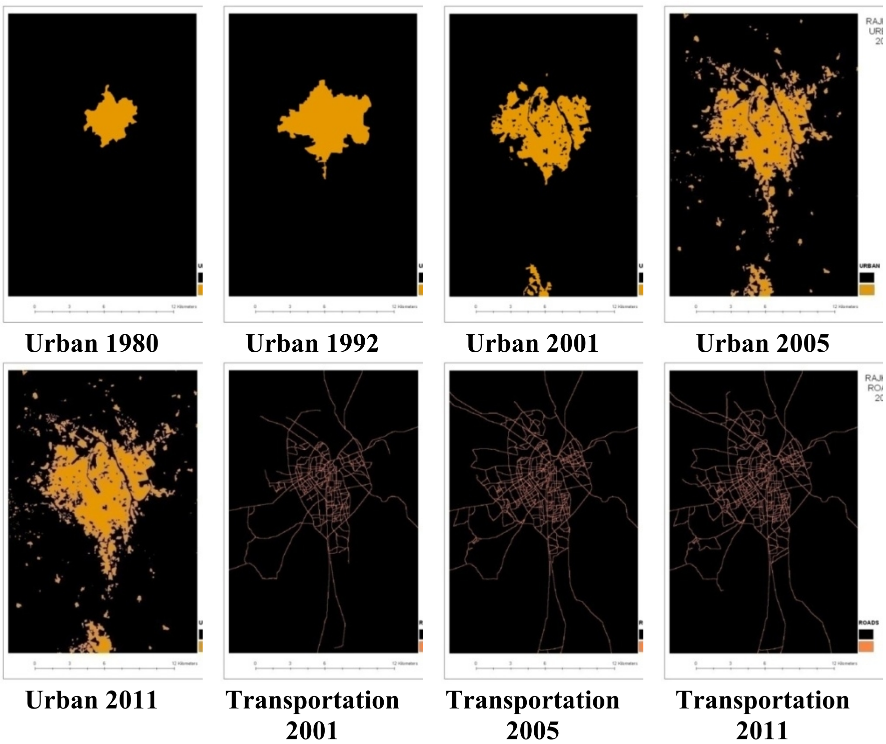
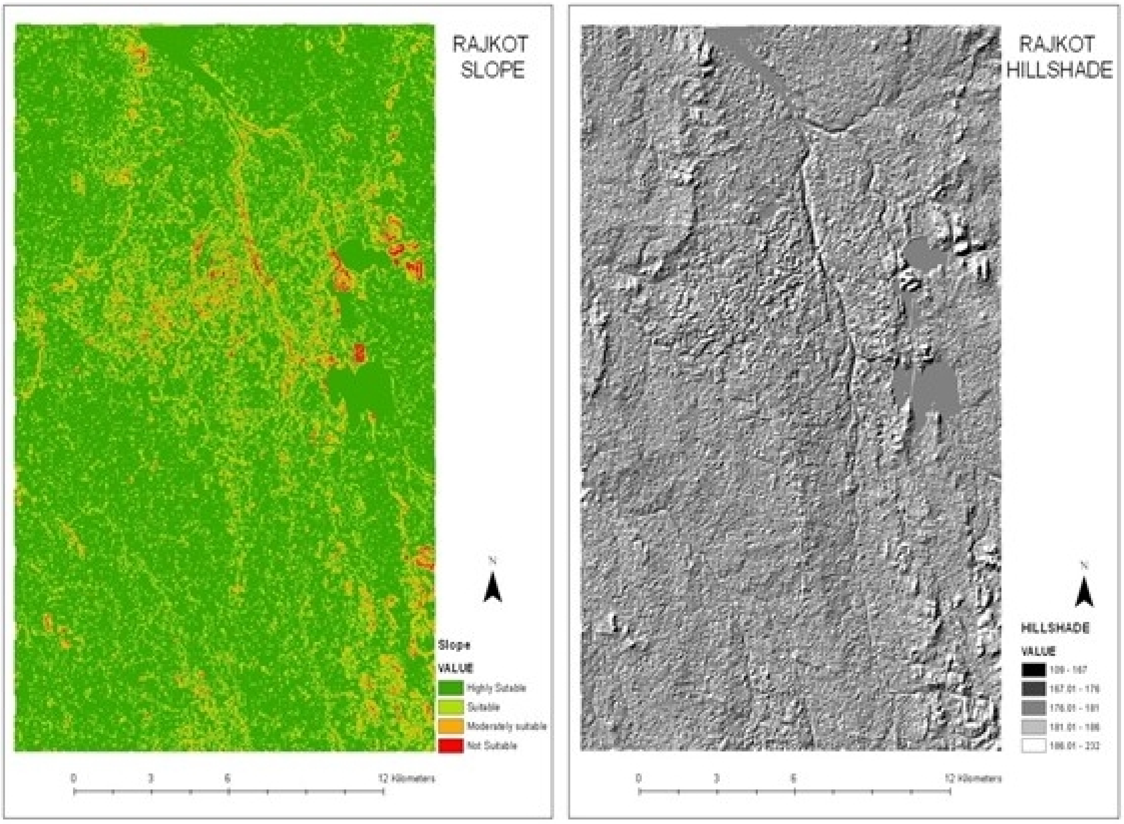
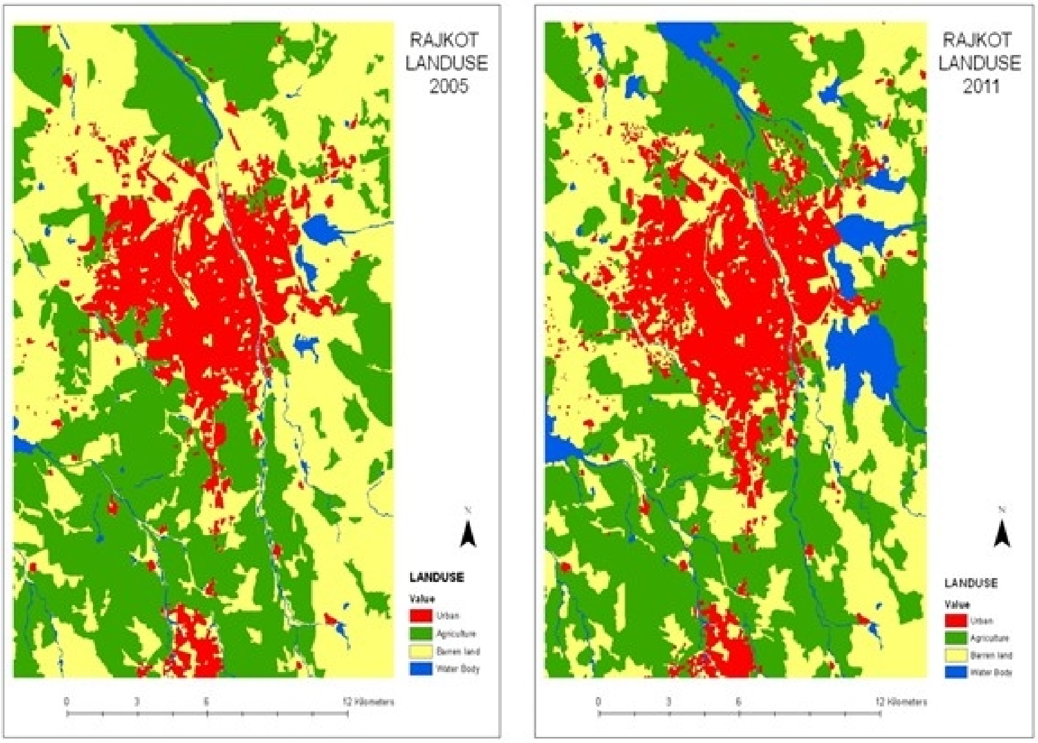


Figure 3: Urban and transportation input layer



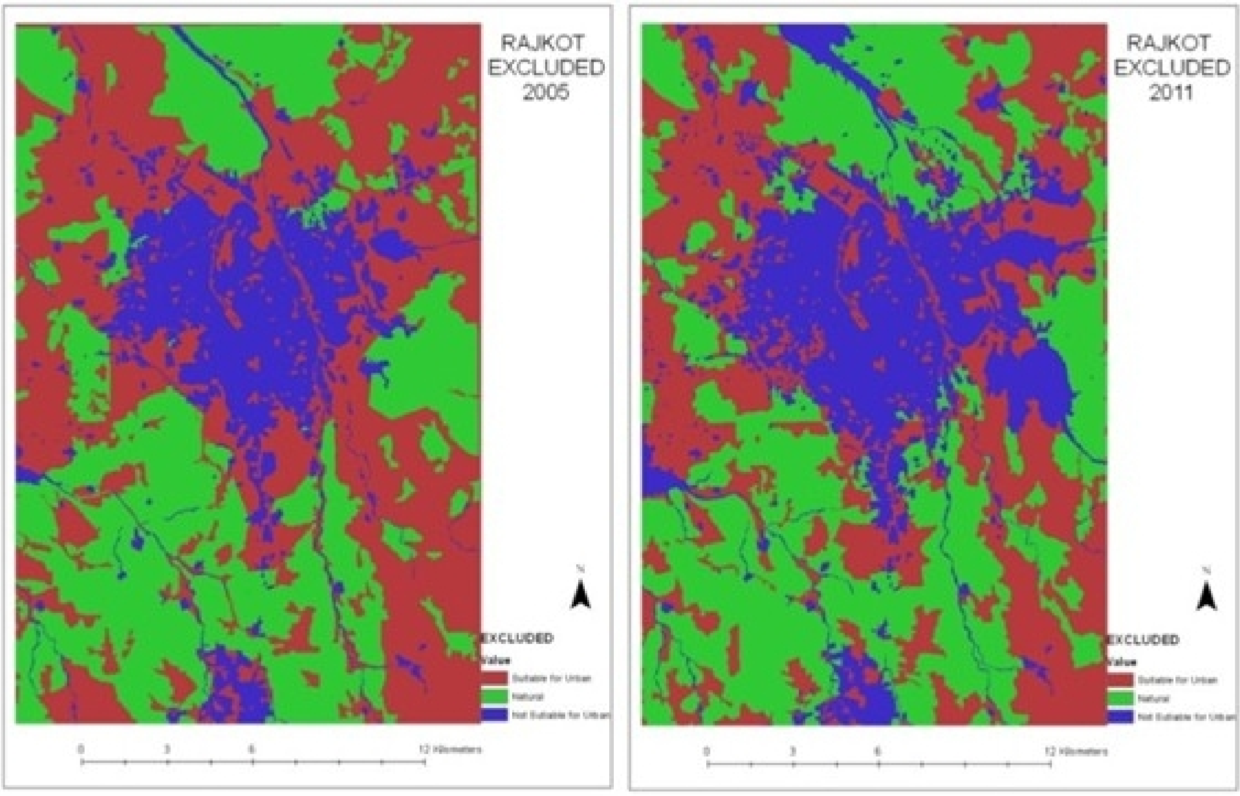
Slope **Hillshade**

Figure 4: Slope and hill shade input layer



Land use 2005 **Land use 2011**

Figure 5: Land use input layers



Excluded 2005 **Excluded 2011**

Figure 6: Input excluded layers

All these layers are given as input to SLEUTH model which calibrates the data with predefined rules in which the parameters are modified on the basis of the input data. Once the data is ready model is calibrated for which the input file names are modified in the scenario file. The model is run for coarse, fine, final and forecasting stages as shown in figure 2. In each of the stages the parameters are modified as the growth rule is applied which leads to self-modification and give the output statistics. For selecting the range of Coefficient range for the next step OSM (optimal SLEUTH Metric) is used and at the end it gives one value for coefficient for inputting in the predict stage. Prediction is done on the basis of the values obtained by calibrating the SLEUTH model. Output of the model is in graphical as well as statistical format which is then projected in GIS and analyzed. This model gives the future urban growth pattern.

4.2 SLUETH Implementation

In SLUETH growth rules are applied on a cell-by-cell basis and the array is synchronously updated at the end of each year. The modified array forms the basis for urban growth in each succeeding year. Potential cells for urbanization are selected at random and the growth rules evaluate the properties of the cell and its neighbors such as whether or not they are already urban, what their topographic slope are, how close they are to a road (Clarke and Gaydos, 1998)

In the model there are five factors controlling the behavior of the system: Breed Factor (Coefficient) determines how likely a newly generated, detached or road-influenced settlement is to begin its own growth cycle. Diffusion Factor (Coefficient) controls the overall depressiveness of growth. Spread Coefficient controls how much diffusion expansion occurs from existing settlements. Slope Resistance influences the likelihood of settlement extending up steeper slopes Road Gravity encourages new settlements to develop near the transportation network (Clarke and Gaydos, 1998).

According to (Clarke et al., 1996), urbanization is the sum of the four types of the growth: Spontaneous Growth models the development of urban settlements in undeveloped areas. Diffusive Growth permits the urbanization of isolated cells, which are flat enough to be desirable locations for new urban spreading centers. Organic Growth promotes the expansion of established urban cells to their surroundings. Road Influenced Growth promotes the urbanization along the transportation network because of increased accessibility.

Newly urbanized cells must pass the random tests of breed and diffusion coefficient, slope resistance and road gravity. During the urban growth computation, a second level of growth rules called “self-modification” prompted by an unusually high or low growth rate above or below a threshold or critical number (Clarke et al., 1996). In that case, the model modifies certain parameters to emphasize trend. Therefore, self-modification is quite important to ensure reasonable results (Yang and Lo, 2003). The finishing values of all the coefficients were used to find the final best values that describe the boom and boost periods in the system. This utility averages the finishing coefficient values stored in the param.log file, and returns set of five integers that represent the best coefficient values resulting from the entire process of calibration, reflecting both the growth rules, and the self-modification rules (Silva and Clarke, 2002).

4.3 SLUETH calibration

The model runs in three modes; test mode, calibration mode and the prediction mode. In test mode data is tested for readiness of calibration and prediction. The purpose of the model calibration phase is to determine the best-fit values for the five growth control parameters including coefficients of diffusion, breed and spread, slope resistance and road gravity with historical urban extent data. (PROJECT GIGALOPOLIS, 2003). Optimum SLEUTH Metric was developed by (Dietzel and Clarke, 2007) which helps to select the values for the next phase of calibration is used in this study. OSM (optimal SLEUTH Metric, product of compare, population, edges, clusters, slope, X- mean and Y- mean metrics was created) which provides most robust results for SLEUTH calibration. OSM code can be run using the control_stats.log file to find out the 'top 50' best fit values. Hence this helps in selecting the values for next phase. Hence OSM is used to get the best fit values in this study. (Dietzel and Clarke, 2007)

5. Results and discussions

Coarse calibration for predicting 2011 sprawl using the past data has been performed by taking a step value of 20 with 3125 Monte Carlo iterations, followed by fine and final calibration using the step values derived from the previous steps. In this study OSM Values are used to define the step and start end values for the next step.

From table 2 OSM code can be run using the control_stats.log file to find out the 'top 50' best fit values. Hence this helps in selecting the values for next phase. Here it is observed that OSM value is 0.456 in coarse calibration which is considered to be good which is refined to 0.459 in fine calibration and in final calibration value is 0.462.

From table 3 it is observed that OSM value is 0.564 in coarse calibration which is considered to be good which is refined to 0.586 in fine calibration and in final calibration value is 0.588. These values are high as the number of input has increased from the previous model and 0.588 is a good value.

From the above table 4 and 5 coefficient range is consent for coarse stage. This starts changing from Fine where the range is almost similar to for all the models but as we move towards final more of the values change as in this model both growth rules and self-modification rules are the core of the model. By running the model, a set of control parameters is refined in the sequential calibration phase. And the range is narrowed down in every stage. Comparison between best fit values derived from the top OSM value in the final stage for both the years’ prediction from the output of forecasting phase with Monte Carlo iteration as 200.

Table 2: OSM values and calibration data for 2011

Top50 : Coarse calibration (2011 Urban growth model)					
OSM	Diff	Brd	Sprd	Slp	Road
0.4566	25	75	75	50	50
0.4495	50	25	75	25	50
0.4411	25	100	100	75	100

Top50 : Fine calibration (2011 Urban growth model)					
OSM	Diff	Brd	Sprd	Slp	Road
0.4596	25	85	99	65	50
0.4541	25	45	93	25	60
0.4538	25	85	99	65	70

Top50 : Final calibration(2011 Urban growth model)					
OSM	Diff	Brd	Sprd	Slp	Road
0.4628	25	75	98	55	60
0.4575	25	45	98	25	50
0.4536	25	85	95	65	65

Table 3: OSM values and calibration data for 2031

Top50 : Coarse calibration (2031 Land use Model)					
OSM	Diff	Brd	Sprd	Slp	Road
0.5649	25	75	50	25	50
0.5554	50	25	100	50	50
0.5518	25	100	100	75	50

Top50 : Fine calibration (2031 Land use Model)					
OSM	Diff	Brd	Sprd	Slp	Road
0.5867	30	35	100	25	50
0.5763	45	45	90	75	50
0.5752	40	45	100	65	50

Top50 : Final calibration (2031 Land use Model)					
OSM	Diff	Brd	Sprd	Slp	Road
0.5834	36	41	94	55	50
0.5784	30	39	100	35	50
0.5753	36	39	100	55	50

Table 4: Coefficient values for 2011 urban growth model

	Coarse		Fine		Final		Predict
	Start	Stop	Start	Stop	Start	Stop	Best Fit
Diffusion	0	100	25	50	25	25	25
Breed	0	100	25	100	45	85	75
Spread	0	100	75	100	93	99	98
Slope	0	100	25	75	25	65	55
Roads	0	100	50	100	50	70	60

Table 5: Coefficient values for 2031 LULC growth model

	Coarse		Fine		Final		Predict
	Start	Stop	Start	Stop	Start	Stop	Best Fit
Diffusion	0	100	25	50	30	45	36
Breed	0	100	25	75	35	45	41
Spread	0	100	50	100	90	100	94
Slope	0	100	25	75	25	75	55
Roads	0	100	50	50	50	50	50

The self-modification internal cellular model enhances phase changes. Thus the values of the coefficient changes with change in input data. Diffusion shows the overall scatter of the growth which is moderate. It shows the opportunity for new urban centers. Breed show the likelihood of new settlements being generated which is seen high when only 4 urban layers were given to predict 2011 sprawl but it has greatly decreased on adding 2011 data and has still gone down when Land Use data is added. Spread shows the outward and inward from existing spreading center here the value of spread is high as we have seen over a period of time Rajkot has maximum development along its fringes. We can say more people are moving out from urban Center to suburbs (census 2011). Slope resistance is low and is not having much of effect as our study area is flat land and very less hilly region is present. Road gravity shows the attraction of the urbanization to roads and diffusion of urbanization along the roads. Here in Rajkot City development has taken place along the roads hence the value of this coefficient is also high.

Similarly, it is observed that when the best fit values for the predict stage is identified spread has the highest influence with the value 94. Thus most of the development in 2031 would be along the fringes. Scope of development along the roads with best fit value 50 and slope having best fit value 55 are moderate. Breed has best fit value 41 which shows very less scope of new settlements being generated. Finally, we can say minimum growth will happen diffusion which has best fit value as 36.

5.1 Validation of the model

According to the avg.log file urban area of 2011 is predicted as 72.25sq km (Pop: 80280.43, pixel size: 30 x 30 m) and according to the actual data urban area of 2011 is predicted as 67.55 sq. km (Pop: 75528, pixel size: 30 x 30 m).

This model gives 96.18 % matching urban pixels of urban area with the actual urban area (see table 1). To validate the model prediction of 2011 has been carried out using the past data, here over all accuracy urban model prediction for 2011 using the past years data is 96.18%. And Users accuracy for urban is 90.52% and producers accuracy for urban area is

86.61%. Models with over all accuracy above 95% are considered acceptable hence we can use SLEUTH model for Rajkot city to predict the future sprawl.

From figure 7 it is seen that urban area is predicted from 2006 to 2011 as 2005 was the last year data input for this model the year wise area increase is compared with projected population data for 2006 to 2001 using the census data. Here it is seen that both urban area and population both are growing in but the gap between has narrowed with time which shows that density of population is increasing with time.

Maximum growth has happened due to spread of spatial growth which means urban growth along the fringes, few new urban areas are observed as shown in figure 8 which have actually come up over the time period. White color in the figure 8 shows the spread growth and red color shows the urban area of 2005. As it is observed extensive growth along the road in the east side near Lalpari Lake which did not take place due to the lakes and land use in that area was not suitable for urban growth. Growth on the North West side has also not taken place in actual scenario due to extensive industrialization.

From figure 9 it is seen how urban area is predicted from 2012 to 2031 as 2011 was the last year data input for this model. The year wise area increase is compared with projected population data for 2012 to 2031 using the census data of the past years. The graph shows the how population is expected to increase and in 2029 there is intersection in population and urban growth area. Hence the gap between the population growth and urban area will be decreased from 2012 to 2029 and inverse situation is observed from 2029 to 2031, changes will be observed in the population density which will increase till 2029 and will decrease after 2029.

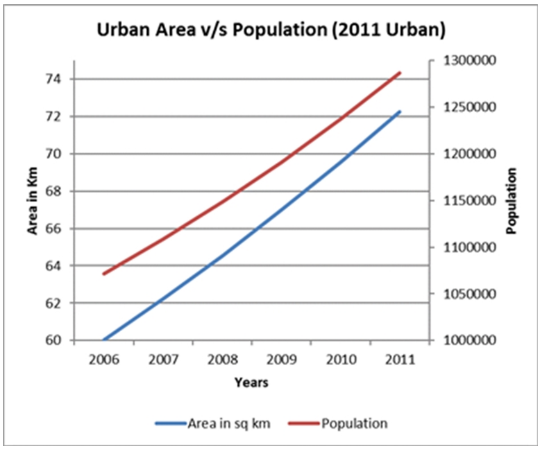


Figure 7: Urban area predicted v/s population (2011 Urban model output)

Table 6: Accuracy assessment for SLEUTH model

		Satellite Data			
		Urban	Non-Urban	Total	User accuracy
Model Prediction	Urban	65416	6852	72268	90.52%
	Non-Urban	10112	361251	371363	97.28%
	Total	75528	368103	443631	
	Producer accuracy	86.61%	98.14%		
overall classification accuracy			96.18%		

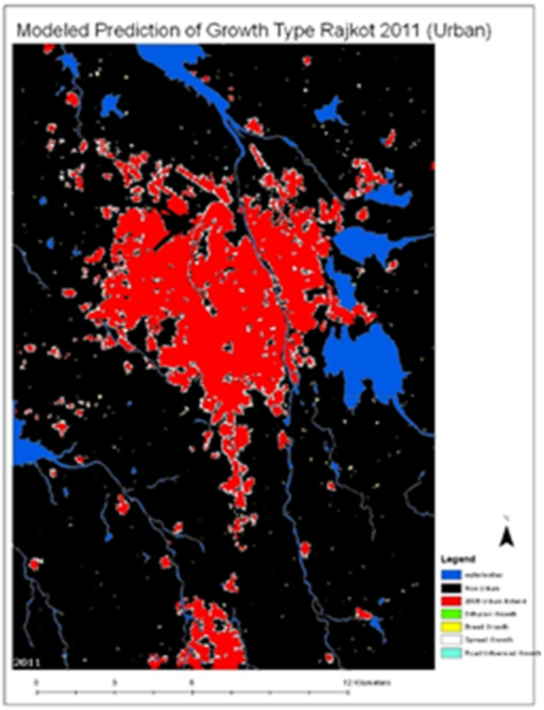


Figure 8: Modelled prediction of growth types Rajkot 2011

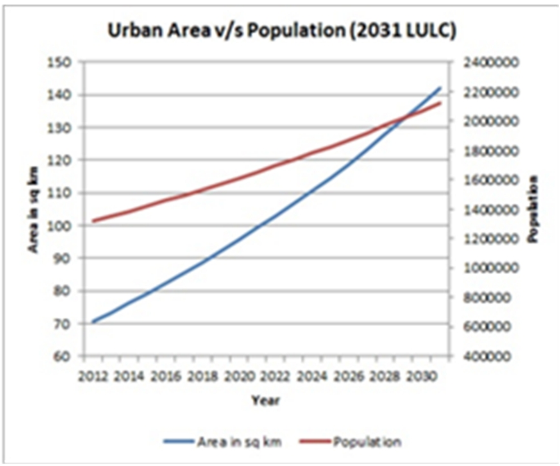


Figure 9: Urban area predicted v/s population (2031 LULC model output)

Map (figure 10) shows the probability map in which yellow color shows the existing urban area and grey shows no probability of growth it covers water body, airport and all the land use which cannot be converted to urban. Low value of diffusion and breed and high value of spread co-efficient is seen in the above output and low slope indicates that growth clearly occurs at urban fringes. Spread growth is seen maximum along the fringes of the city in all directions maximum growth is seen in the southern direction. More of sprawling is observed in the western part. There is industrial zone in the south and north western part makes it more prone to sprawl which is clearly seen in figure 10 in red color ranging from 70 to 100 percentage probability of growth. Maximum slums have been observed along range shown in shades of blue color. Road the river and other water bodies. Less of growth is observed East zone as it has more of Slums population. Increase in suburbs and exurbs have increased organic (edge) growth. There is low development in the east zone as it has two Lakes and this area falls under low line hence there is problem of water log age during monsoons. Less of growth occurs due to road influence which is seen from 30 to 60 percentage probability Influenced growth is seen in the eastern along the Jamnagar – Rajkot highway due to industrialization and southern direction along the national highway 8B which passes through Rajkot and goes towards Shapar in the south has also shown good amount of growth on both sides of the highway.

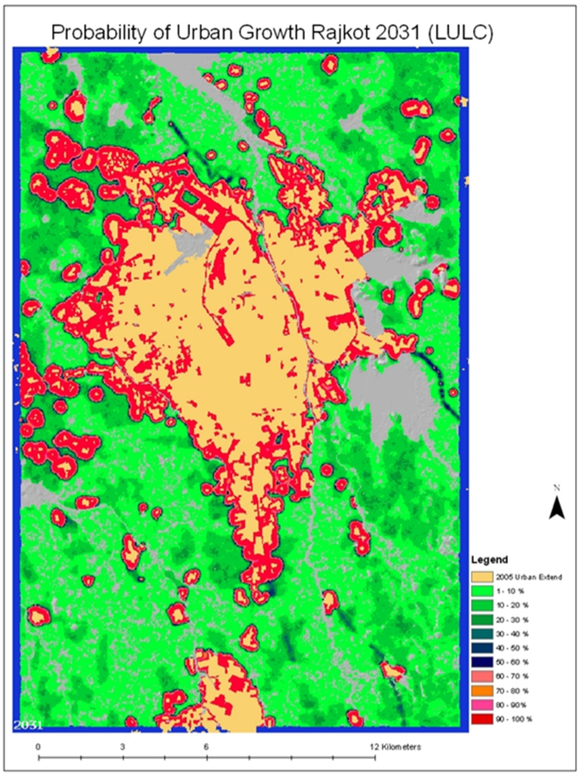


Figure 10: Probability of urban growth rajkot 2031 (LULC)

Bhavnagar-Rajkot road which passes in eastern direction between the two lakes shows some road influence growth along the highway. More growth is seen in the southern part and the north western region of the city due to industrialization land use. In the above figure 10 green color shows 10 to 30 percent probability of urbanization. According to the avg.log file urban area of 2031 is predicted as 141.93 sq. km (Pop: 157703.2, pixel size: 30 x 30 m). Prediction results of this model can be used in preparing the master plan for the city.

6. Conclusion

SLEUTH model is 96.18% accurate matching urban pixels in the predicted urban area of 2011 and actual urban area identified from the satellite image for Rajkot city. Rajkot has higher value for spread development. Spread shows the outward and inward from existing spreading center here the value of spread is high as we have seen over a period of time Rajkot has maximum development along its fringes. We can say more people are moving out from urban center to suburbs. More Growth is seen in the southern part and the north western region of the city in 2031 and 2031 prediction. Population growth rate is decreasing and urban growth rate is also decreasing. Minor changes are required in SLEUTH to improve performance in the Indian context as this model is scale independent, dynamic and future oriented can be used under different conditions with some modifications. By studying the outputs of weighted overlay, growth rates, index and prediction model it has been observed that Higher growth is seen in the southern part and the north western region of the city which could be the upcoming urban areas.

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