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URBAN SPRAWL PREDICTION USING CELLULAR AUTOMATA: A CASE STUDY OF AHMEDABAD CITY

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ABSTRACT

Human population continues to accumulate in urban centers. This inevitably increases the urban footprint with significant consequences for biodiversity, climate, and environmental resources. Urban growth prediction models have been extensively studied with the overarching goal to assist in sustainable management of urban centers. There are various existing models, which have their own advantages and limitation. Here by using cellular automata, the prevailing modeling technique to obtain sustainable result.

The study is based on the data availability from LISS III. This model assesses developer and user perceptions and critically discusses existing urban growth prediction models, acting as a reference for future model development.

The potential of the use of satellite images for Ahmedabad, Gujarat, the assessment of urban growth on which future work should focus as the key factors of economic-environmental sustainability based on parameters taken into considerations that directly influence the land use.

1. INTRODUCTION

1.1. Urban sprawl: Definition

Urban sprawl or suburban sprawl describes the extension of human being populations away from inner built-up patches into previously out-of-the-way and rural regions, basically which results in low-density communities. Urban sprawl is a versatile concept of community planning particularly relevant to developed nations concerning topics that series from the external spreading of a city and its suburban, to low-density and development on rural territory, assessment of impact of high separation between residential and commercial uses. Urban sprawling has happen to incredibly chief issue of learning to deal with city expansion and financial system

1.2. Cellular Automata

Cellular automata (henceforth: CA) are discrete, abstract computational systems that have proved useful both as general models of complexity and as more specific representations of non-linear dynamics in a variety of scientific fields. Firstly, CA is (typically) spatially and temporally discrete: they are composed of a finite or denumerable set of homogeneous, simple units, the atoms or cells. At each time unit, the cells instantiate one of a finite set of states. They evolve in parallel at discrete time steps, following state update functions or dynamical transition rules: the update of a cell state obtains by taking into account the states of cells in its local neighbourhood (there are, therefore, no actions at a distance). Secondly, CA is abstract, as they can be specified in purely mathematical terms and implemented in physical structures. Thirdly, CA are computational systems: they can compute functions and solve algorithmic problems. Despite functioning in a different way from traditional, Turing machine-like devices, CA with suitable rules can emulate a universal Turing machine, and therefore compute, given Turing's Thesis, anything computable.

The mark of CA consists in their displaying complex emergent behaviour, starting from simple atoms deterministically following simple local rules. Because of this, CA attracts a growing number of researchers willing to study pattern formation and complexity in a pure, abstract setting. This entry provides an introduction to CA focusing on some of their philosophical applications: this range from the philosophy of computation and information processing, to philosophical accounts of reduction and emergence in metaphysics, and debates in fundamental physics.

2. ABOUT THE STUDY AREA: AHMEDABAD CITY

Human population continues to cumulate in urban centers. This inevitably increases the urban footprint with significant consequences for biodiversity, climate, and environmental resources. Urban growth prediction models have been extensively studied with the overarching goal to assist in sustainable management of urban centers. There are various existing models, which have their own advantages and limitation. Here I will be using cellular automata the prevailing modeling technique. The study is based on the data availability from LISS III and LandSat. This model assesses developer and user perceptions and critically discusses existing urban growth prediction models, acting as a reference for future model development.

Study area: former capital of the Indian state of Gujarat, Ahmedabad.

Latitude: 23.0300° N

Longitude: 72.5800° E

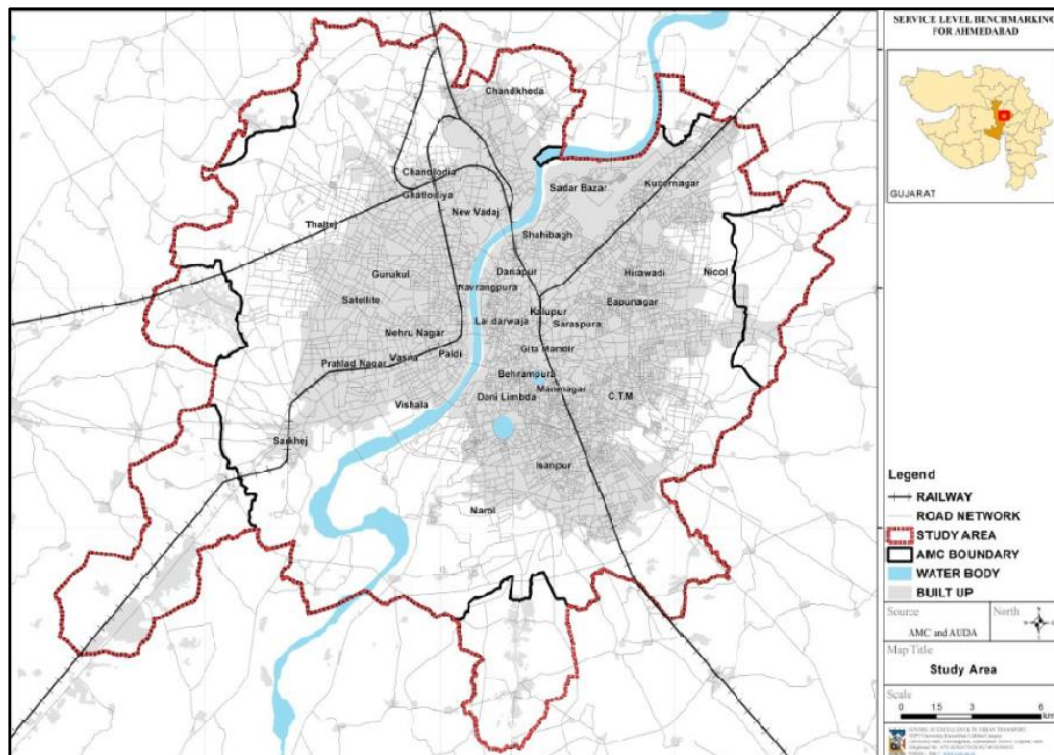


Figure 1: Ahmedabad City Area Limit Map
[Ref.] Ministry of Urban Development, Government of India
Center for Excellence (CoE) in Urban Transport, CEPT University, Ahmedabad

2.1 City of Ahmedabad

The city of Ahmedabad is ranking on top among the largest metropolis in India. It is the first largest city in the State of Gujarat. According to Census of India 2011, the population of urban agglomeration reached to 7.2 million. The city is situated on 23°00'N Latitude and 72° 00'E Longitude. The city remained as a capital for the State till the year 1970. Currently it is a district headquarters. River Sabarmati is passing through the city divides into two parts, East and West. The western part of the city is comparatively newly developed. Therefore it is planned and sparsely built in comparison to the eastern part.

2.2. Infrastructure Services

The city of Ahmedabad provides mandatory services to the citizen. Those are water supply, sewerage, solid waste etc. are the physical infrastructure the city government provides and maintains



Figure 2: Location Map of India

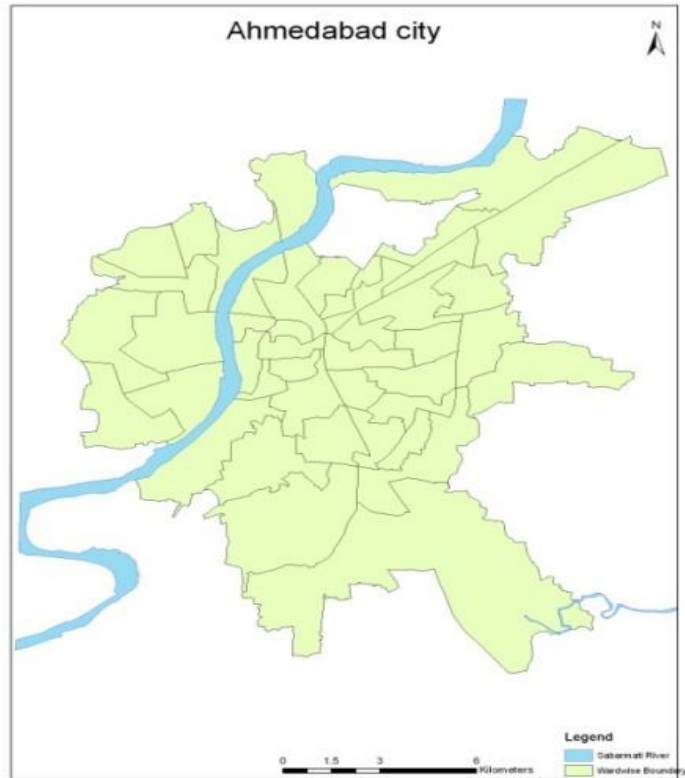


Figure 3: Location Map of Study Area: Ahmedabad City

3. OBJECTIVES OF THE STUDY

- a) Map the extent of urban growth for the largest city and former capital of the Indian state of Gujarat, Ahmedabad.
- b) Develop and calibrate an urban growth simulation model based on historical urban growth to predict future urban growth.
- c) The potential of the use of satellite images for the assessment of urban growth on which future work should focus as the key factors of economic-environmental sustainability based on parameters taken into considerations that directly influence the land use.

4. DATA & SOFTWARE USED FOR STUDY

4.1. Satellite Data Used

Table 1: Satellite Image Used Information

Sr. No.	Satellite	Sensor	Date of Pass	Path/Row	Source
1	IRS Resourcesat-1	LISS-III	1-Nov-2008	093/056	NRSC/ISRO
2	IRS Resourcesat-1	LISS-III	16-Dec-2011	093/056	NRSC/ISRO

4.1.1. IRS P6/Resourcesat-1

The IRS (Indian Remote sensing) satellites form a large family of Earth observations satellites operated by the Indian space agency.

IRS P6/Resourcesat-1 & Resourcesat-2 provides data of medium and high resolution by the twin satellites IRS-2C and IRS-1D. These two, launched in 1995 and 1997 respectively. Resourcesat satellites carry a LISS-III sensor as well as a wide field AWiFS sensor, but the high resolution (5.8 m) LISS-IV sensor replaces the panchromatic sensor. The high resolution data are useful for applications such as urban planning and mapping, while the average resolution is used for vegetation discrimination, land mapping, and natural resources management.

4.1.2. LISS-III

The LISS-III (Linear Imaging Self Scanning Sensor) sensor is an optical sensor working in 4 spectral bands (Green, red, near infrared and short wave infrared). The Linear Imaging Self Scanning Sensor (LISS-III) is a multi-spectral camera operating in four spectral bands, three in the visible and near infrared and one in the SWIR region, as in the case of IRS-1C/1D. The new feature in LISS-III camera is the SWIR band (1.55 to 1.7 microns), which provides data with a spatial resolution of 23.5 m unlike in IRS-1C/1D (where the spatial resolution is 70.5 m).

The Data products are categorized as Standard and have a system level accuracy.

LISS-III Standard Products comprise Path/Row Based products, Shift Along Track product, Quadrant products and Georeferenced products. Path/Row Based products are generated based on the referencing scheme of each sensor. Shift Along Track applies to those products covering a user's area of interest which falls in between two successive scenes of the same path, then the data can be supplied by sliding the scene in the along track direction. LISS-III full scene is divided into four nominal and eight derived quadrants. LISS-III photographic quadrant products are generated on 1:125,000 scale. Georeferenced products are true north oriented products. These products are supplied on digital media only.

Standard Path/Row Based products cover an area of 141 x 141 km and are characterised by 3 Bands. Path/Row Based products comprise Raw, Radiometrically corrected and Geo referenced levels of corrections. Quadrant products cover an area of 70 x 70 km and are characterised by 3 or 4 Bands (Geo Referenced). Quadrant products comprise Standard and Geo referenced levels of corrections.

Table 2: IRS-P6 Radiometric Characteristics (micron) or Specifications

Sr. No.	Band	Spectral Band	Resolution
1	Band 2(Green)	0.52-0.59µm	23.5*23.5m
2	Band 3(Red)	0.62-0.68 µm	23.5*23.5m
3	Band 4(NIR)	0.77-0.86µm	23.5*23.5m
4	Band 5(SWIR)	1.55-1.70µm	23.5*23.5m

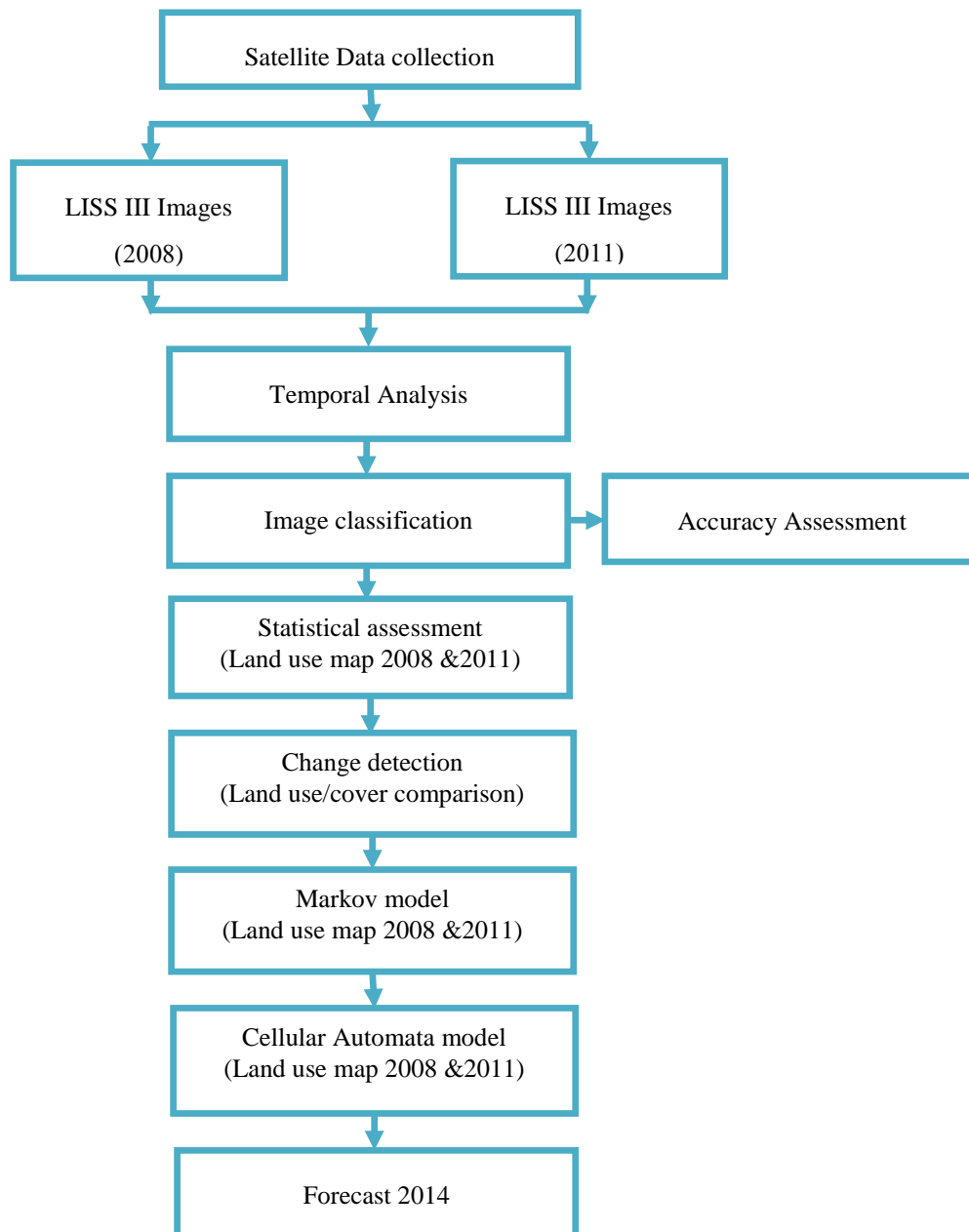
Table 3: IRS-P6 - Resourcesat-1 Technical Characteristics

Sr. No.	Space Vehicle Name	IRS-P6 (ResourceSat-1)
1	Country	India
2	Designers	ISRO
3	Operator	ISRO
4	Booster	PSLV C5
5	Launch Date	October 17th 2003
6	Orbit:	Sun-Synchronous Polar
	a) Altitude - km	817
	b) Inclination - deg	98.7
	c) Revisiting Period - min	101
7	Platform:	IRS-1
	a) Survey Equipment	LISS-4, LISS-3, AWiFS
	b) Declination Angles - deg	+26°
8	Survey Repeatability - days	5
9	Active Life - years	5
10	Space Vehicle Dimensions - m x m	-
11	Space Vehicle Mass - kg	1360
12	Applications	Agriculture (Afforestation/Reforestation Protection), Land (Soil , Vegetation , Landscape Topography), Solid Earth (Tectonics), Water (Water Management) and etc.,

4.2. Software Used

- i. ArcMap 10.1
- ii. Erdas Imagine 2011
- iii. IDRISI Selva 17.02
- iv. Microsoft Excel 2007

5. METHODOLOGY FOR STUDY



Flow Chart 1: Methodology Flow Chart

In this module, the main components of the urban growth model applied on Ahmedabad, an overview of the workflow as shown in fig2. which is comprised of various stages: a) Classification of satellite images and b) computation of transition probability maps. These maps, in combination with the land use maps, were required for Markov Change detection and cellular automata simulation model to predict future urban growth (for 2014).

5.1 Extraction of Land Use Map

Spatiotemporal mapping includes quantitative time series analysis and transformation of land cover classes. Because land use maps are a fundamental prerequisite for modeling future growth, individual land use classes were extracted from the remotely sensed images for each timestamp. After geometric corrections, the land use maps were initially classified based on the maximum likelihood algorithm and further accuracy assessment is observed onto classified images.

5.2 Urban Growth Model

Urban Growth Prediction Models (UGPMs) are tasked to capture intrinsic and complex relationships in space and time. The spatial complexity reflects the impact of numerous biophysical and socioeconomic factors and as a result heterogeneous patterns appear across location and scale thus making urban development a dynamic and non-linear process.

The IDRISI Selva version 17.02 has been used for the analysis of images. Markov chain model has been applied to find the future change of LU/LC in the study. The land use information of the year 2014 is predicted according to the land use classification using supervised approach with maximum likelihood.

5.3 Markov Chain

Markov chain models have been used to model landscape changes in understanding and predicting the behaviour of complex systems using discrete state spaces. All landscape spatial transition models can be expressed in a simple matrix equation as follows:

$$N_{t+1} = N_t * P$$

where N_{t+1} and N_t are vectors composed of the fractions of each landscape type at time $t + 1$ and time t , respectively; P is a square matrix, whose cell P_{ij} is the transition probability from landscape i to j during times t and $t + 1$. The transition probabilities P are derived from the landscape transitions occurring during some time interval.

Theoretically, the Markov chain model assumes that the transition probability is spatially independent (Brown et al. 2000). However, the future trend of a pixel to change is not a simple function of its current state, but is often affected by its neighbouring cells. The resulting probabilities were summarized in a transition probability matrix, not directly transferable to spatial representations. Therefore, additional steps are needed to incorporate both spatial and temporal information using CA.

5.4 Cellular Automata

Cellular automata (CA) were introduced by Ulan and Neumann in 1940 and since 1980 numerous models have been developed for simulating urban growth CA is defined as discrete dynamics systems, represented by a grid of cells, in which local interconnected relationships exhibit global changes.

Generally, the state of each cell depends on the value of the cell on its previous state as well as the values of its neighbours according to some transition rules and there are two possible values for each cell (0 or 1). As a rule-based model, its topological grid characteristics make CA an appropriate model for incorporating spatial interactions between a cell and its neighbourhood. For example, assuming a 3*3 cell neighbourhood, a cell's state is influenced by its eight adjacent cells. These models are typically calibrated using training data (i.e., past land use maps), which are then compared with an actual land use map, although the quantity of change is neglected. If statistical evaluation, using the kappa index for example, provides valid results, the calibrated model can be applied to the prediction of future urban spatial patterns.

6. ANALYSIS AND RESULTS OF STUDY

6.1. Supervised Land Use/Cover Classifications

The 2 successive supervised land use/cover classifications images for the year 2008 & 2011 discriminated in 5 classes using maximum likelihood are:

Table 4: Supervised Land Use/Cover Classifications

Sr. No.	Classes	Year 2008 in sq.km.	Year 2011 in sq.km.	Difference in sq.km.
1	Urban	179.66592	254.648125	74.982205
2	Vegetation	481.992192	254.66255	-227.329642
3	Water	8.299008	24.358125	16.059117
4	Sand	16.9776	43.615	26.6374
5	Fallow	283.725504	475.95625	192.230746
	Total	970.660224	1053.24005	

6.2. Change Detection using LCM in IDRISI:

Land Change Modeler (LCM) was used to analyze the land use/cover changes between various classes during the period of 2008 to 2011 in order to predict future urban.

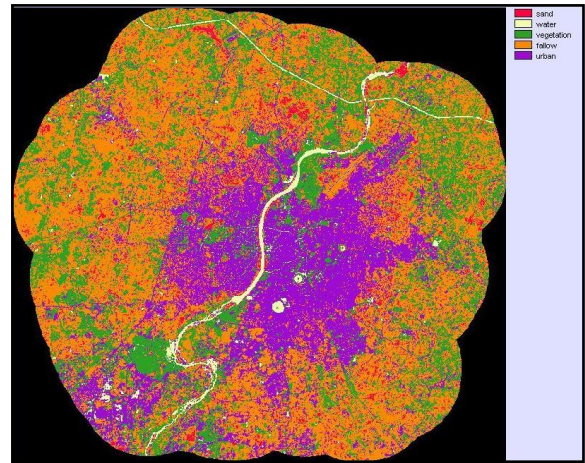
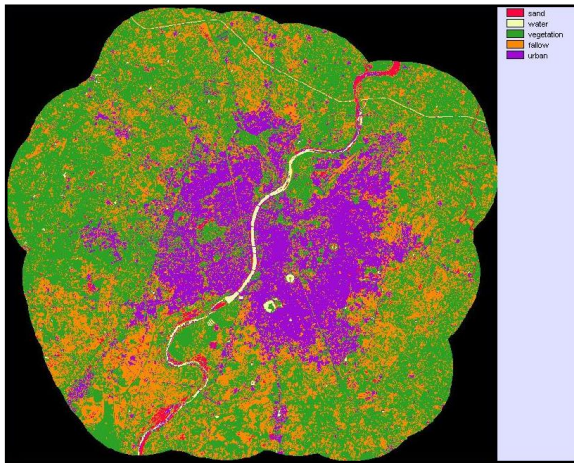


Figure 4: Land Use/Land Cover Change Detection - 2008

Figure 5: Land Use/Land Cover Change Detection - 2011

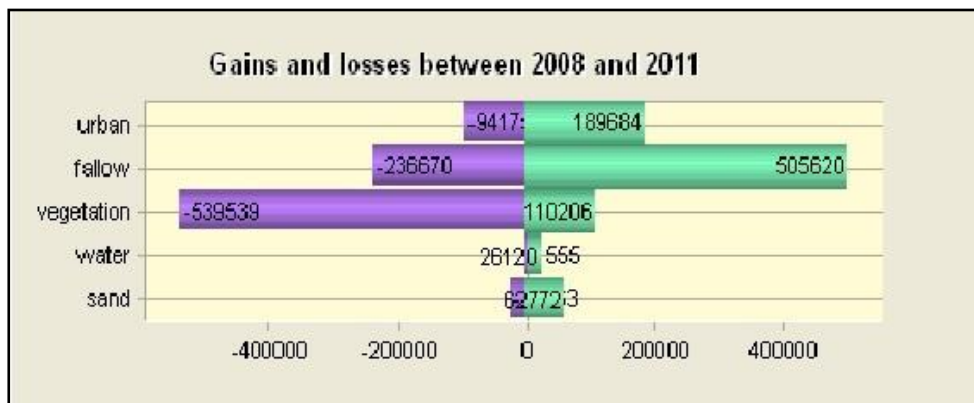


Figure 6: Gain and Losses between 2008 & 2011

Here it is observed that there is change in ratio of vegetation, urban and other classes as well, which can be seen graphically using change analysis in IDRISI.

6.3. Cellular Automata Markov Modelling

Based on land use conditions during the periods 2008 to 2011, transition potentials were computed using a Markovian process. The transition probability matrices of each land use type for both periods are produce. The diagonal elements represent probability values for self-replacement, referring to land use types that remain similar (Guan et al., 2011). In contrast, off-diagonal values indicate the probability of change from one land use category to another.

CA first input the transition probabilities for these years. The CA allocated the cells by means of a 5*5 or 3*3 matrix as per user requirements and iteration per year. Careful model validation was conducted to assure accuracy and to ensure an applicable simulation that predicts effectively.

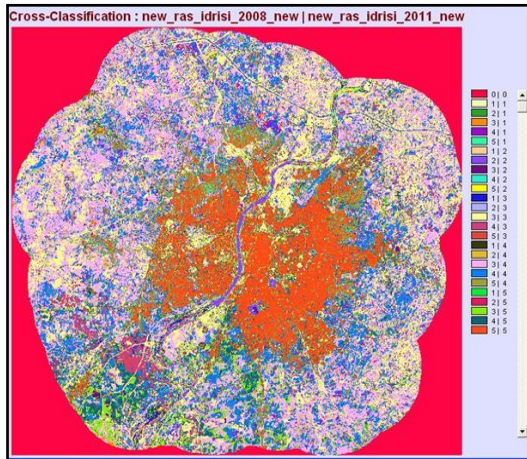


Figure 7: Cross Tab Classification for 2008 and 2011

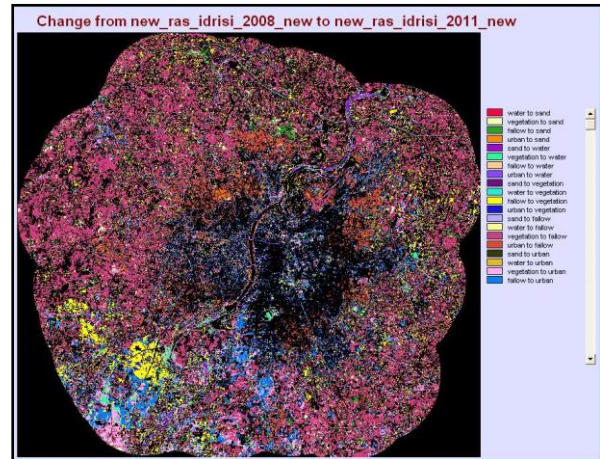


Figure 8: Change from 2008 and 2011

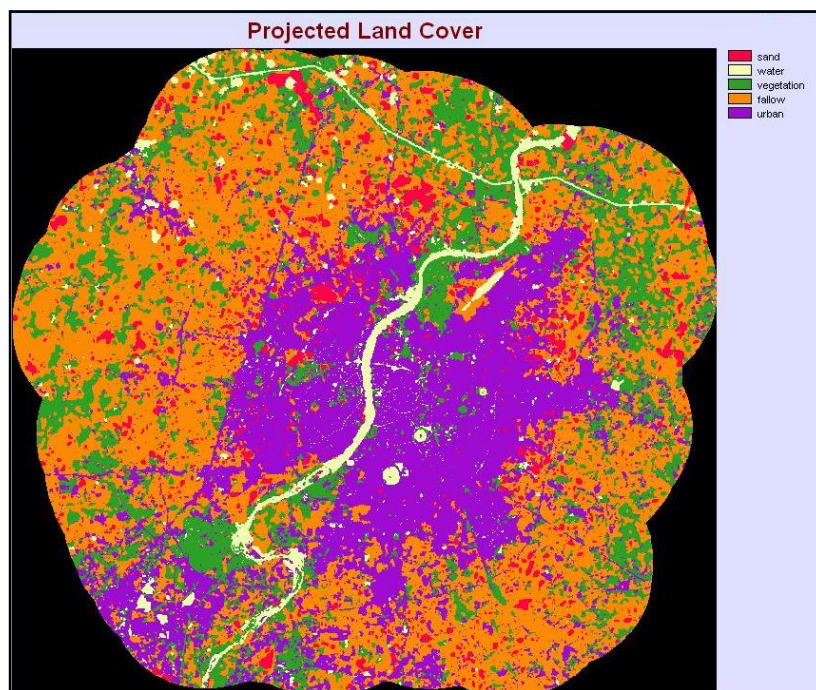


Figure 9: Predicted Land Cover for Ahmedabad City in 2016

7. ACKNOWLEDGEMENTS

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