Modelling and Visualization of Urban Trajectory in 4 cities of India

T. V. Ramachandra, Bharath H. Aithal, Vinay S,, Uttam Kumar, Venugopal Rao K and Joshi N V

Abstract— **Urbanisation and Urban sprawl has led to environmental problems and large losses of arable land in India. In this study, we characterize pattern of urban growth and model urban sprawl by means of a combination of remote sensing, geographical information system, Cellular Automata (CA) and agent based modelling. This analysis uses time-series data to explore and derive the potential political-socio-economic- land based driving forces behind urbanisation and urban sprawl, and spatial models in different scenarios to explore the spatio-temporal interactions and development. Agents were integrated successfully into modelling aspects to understand and foresee the landscape pattern change in urban morphology. The results reveal built-up paved surfaces have expanded towards the outskirts and have expanded into the buffer regions around the city. Population growth, economic, industrial developments in the city core and transportation development are still the main causes of urban sprawl in the region. Agent Based modelling approach as seen in this paper clearly shown its effectiveness in capturing the micro dynamics and influence in its neighborhood mapping. Study concludes that integration of remote sensing, GIS, and agent based modelling offers an excellent opportunity to explore the spatio-temporal variation and visualisation of sprawling metropolitan region. This study gives an overview of urbanisation and impacts due to urban sprawl in the region and help planners and city managers in understanding the future pockets and scenarios of urban growth.**

I. Introduction

Urbanisation gained momentum with the globalization and consequent market relaxations in developing nations. Spatial patterns of urbanisation is the most studied issue in the current times across the globe [1-2]. Rapid urbanization and urban sprawl are associated with the developments that are complex, unsustainable and unstable, leading to increasing social, economic and environmental related problems [3-4].

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Rapid urbanization in India, at the metropolitans since early 2000's has captured the global attention due to the availability of resources (human or land) for investors and industries, social, political and cultural aspects. Favorable environment gave impetus to the uncontrolled and unprecedented growth in the core and fringes [5]. The process of urban sprawl due its uncontrolled dynamics has a devastating effect on the natural resources [6] such as vegetation, quality and quantity of surface and sub-surface water resources [7], climatic factors [8] such as rainfall, temperature [9], etc. In order to monitor the dynamics of urbanization and other associated land use changes remote sensing [10] technology is being used since it has the ability to cover large areas, cost effective and faster compared to ground based surveying techniques. The remotely sensed data is classified into different land uses based on different classification techniques to understand the distribution of heterogeneous features [11] Gaussian maximum likelihood classifier algorithm was used to classify land uses from the remote sensing data. Multi temporal land use analysis helps in understanding the factors that have caused the change, potentially allowing for management strategies targeted toward cause rather than simply the symptoms of the cause [12-13]. The temporal information helps to measure, quantify and monitor changes, which are necessary to model and simulate the likely changes in spatial patterns [14]. Different modeling techniques have been used in order to predict the land use changes, such as simple rule based models or agent based models, which includes Cellular Automata, CA-Markov, Geomod, AHP-CA-Markov, LCM, MCE, Regression, Bayesian [15-16], etc.

Cellular Automata Markov Chain integrated model is a rule based model where in multiple rules are used in order to simulate the future scenario though historical data sets. The Markov chains (MC) are stochastic non-spatial processes [17] that shows how likely does one state change to another, and is used to develop transition probability matrix controls temporal change among the land use types [18] using the two map sets i.e., current map and historical map set [19] to define the site suitability's of the land use. The cellular automata (CA) process introduced by Von Neumann and Ulam [20] is a systematic process consisting sequence of cells carrying 0 or 1 arranged in a matrix, the value of each cell evolves deterministically based on the rules and involving the neighboring pixels [20]. Cellular Automata algorithms define the state of the cell based on the previous state of the cells within a neighborhood, using a set of transition rules. Coupled MC and CA eliminates the short comings of CA and MC respectively, MC quantifies future changes based on past changes, thereby serving as a constraint for CA, which addresses spatial allocation and the location of change [21], although CA-Markov gives promising results, it fails to achieve accurate results since the driving forces are not accounted in this model [22].

Analytical Hierarchical Process based modeling on the other hand is an agent based modeling which accounts the agents of change those include drivers or constraints, socio-economical and infrastructural activities, human actions [23] in order to model and simulate the land use dynamics, providing ample opportunities and challenges which complement or extend to other approaches [24]. ABM's weigh/rank the growth factors and constraints as reflected by the real world scenarios [23] to develop site suitability maps in order to model the land use. The site suitability maps provide the transitional areas describing where the particular land use has the probability to change or retain its state. The site suitability maps area combined with the CA-Markov in order to simulate and predict the land use dynamics. ABM emerges as a promising approach in understanding the complex urban processes, such as urban land use changes since it accounts the social, infrastructural and other human based aspects [23]. Objective of current analysis is to model urban growth pattern of 4 major cities of India using Agent Based Modeling.

II. Study Area

Rapidly growing tire 1 cities, namely Ahmedabad, Bhopal, Kolkata and Hyderabad were considered for the current study. Administrative boundary of the cities along with 10 km buffer regions were considered under the study. Figure 1 depicts the locations of the select cities in India. Currently Ahmedabad and Bhopal are selected under smart city planning (http://www.smartcitieschallenge.in).

Ahmedabad locally known as Amdavad, 14^{th} largest by area and 6^{th} largest by population and 3^{rd} fastest growing city of India is located along the banks of river Sabarmati of Gujarat. City has a population of 5.5 million people (2011 census), having spatial extent of $466km^2$, with a population density of 11,946 persons per square kilometer. It is the financial and economic hub of Gujarat dominated by textile industries, also known as the 'Manchester of India'. The growth rate has led to a GDP of 64 billion USD in 2012

Bhopal is the Capital of Madhya Pradesh State; the city is also known as City of Lakes for its various natural as well as artificial lakes and is also one of the greenest cities in India. Bhopal is 15^{th} largest city by area and 16^{th} largest by Population of 1.9 million people.

Kolkata, capital of West Bengal state, is located along the banks of river Hooghly. Wetlands (Ramsar sites) are present to the eastern part of the city. Being one of the principal commercial, cultural, and educational centre, Kolkata City has a population of 4496694 people, being the 7^{nd} largest city in India. Considering the urban agglomerations, population of Kolkata urban agglomeration exceeds over 14.1 Million, the third largest after Delhi and Mumbai. GDP has reached over 102 Billion USD (2008).

Hyderabad is a capital of Telangana state and Andhra Pradesh (after partition in 2014). The city is located along the banks of river Musi. The city has a population of 7.74 Million people in 2011. The current area under the HUDA is over $7100km^2$. City in the recent past has found its place in the IT sector leading to rapid urbanization, with the current growth rate, Hyderabad is in the verge of being Mega city.

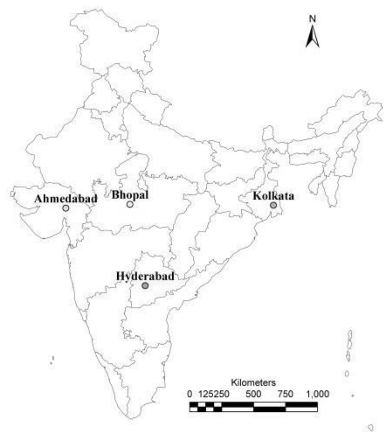

Fig. 1. Study sites

III. Data and Method

Three phase process involved in simulating the landscape transitions are depicted in Figure 2, which include i) Data Acquisition and Feature Extraction, ii) Land use analysis, iii) Land scape modeling and visualization.

Data acquisition involves acquiring Optical (Landsat series from USGS, http://www.usgs.gov and IRS series, http://www.nrsc.gov.in) and Radar (SRTM DEM from USGS) satellite data, the Survey of India (http://survayofindia.gov.in) Topographical maps (1:50000 and 1:250000 scale), Field data using pre calibrated GPS, City maps, Cities Comprehensive development plans (CDP), and other supporting secondary data such as online spatial portals - Google Earth (http://earth.google.com), Bhuvan (http://bhuvan.nrsc.gov.in) and ancillary databases. Optical satellite data is subjected to radiometric enhancements and geometric corrections with help of secondary data, Field data and Topographic maps. Whereas the radar data is used to extract maps such as DEM, Slope and Drainage networks which play a crucial role in modeling. City administrative boundary is extracted using Topographic maps and supporting datasets. Based on the city boundary, 10 km buffer zone (circular) is delineated. Factors supporting the growth namely road network, bus stops, railway stations, educational institutes, industries and other important socio economic places, using Google earth. Constraints for growth are derived from the CDP maps which include Protected regions (Reserve forests, valley zones, parks…. Etc.) and defense establishments. Both factors and constraints for development for the study sites are presented in the annexures (annexure 1-4).

Land use analysis was carried out using the supervised classifier - Gaussian Maximum Likelihood Classifier (GMLC). The process involved, i) Preparation of False Colour Composites to locate heterogeneous patches, ii) Collection of training data sets (based on heterogeneous patches in FCC) from field using GPS supplemented by Google Earth and Bhuvan virtual spatial databases, covering at least 15% of the study area, iii) GMLC was used to for classification, where in 60% of the training data are used for land use analysis and 40% of the training data are used for accuracy assessment. The land use data of various time frames were used to understand future landscapes based on the current dynamics.

Landscape prediction model was built by integrating various concepts namely Markov chains, Fuzzy logic, Analytical hierarchical process, Multi criteria evaluation and Cellular automata. Markov chains were used to understand the transition of various landscapes between two time periods with respect to which future land use transition areas and probabilities are calculated. Effect up to which factor can contribute to dynamics was determined and normalized between 0 to 255 using the fuzzy approach considering sigmoidal increase or decrease function with respect to land use category. Analytical hierarchical process with the help of expert's opinion was used to understand the importance of one factor over the other and to derive weightage of each factor that contributes to the dynamics. Calibrations of weights were based on the consistency ratio. Model with lower consistency ratio i.e., less than 0.1 was considered to be consistent and used for further processes. Site suitability maps were developed using multi criteria evaluation techniques based on weighted linear combination of weights for each of the factors derived from AHP process and constraints derived as Boolean (0 – no alterations, 1- can alter). Site suitability maps along with the Markov transition areas are used in combination to simulate the land use using Cellular automata. Cellular automata consider neighboring pixels and transition areas to predict/simulate land use of the next time period. The simulated output along with the land use for the simulated year is compared and validated. Based on the accuracy of the model, the model is subjected to calibration and further Predictions area carried out up to the year 2030 with suitable time steps.

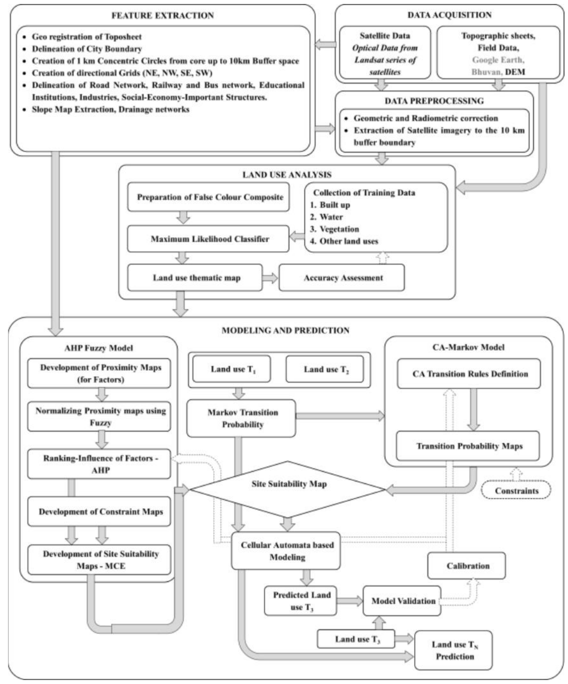

Fig. 2. Method involved

IV. Results and Discussions

Landscape dynamics modeling and simulation up to 2030 was carried out by combining cellular automata with other factor based models. The predicted outcome of the model is presented in Figures 2 to Figures 6 and the statistics are provided in Table 1 to table 4. The predicted results show that Ahmedabad will grow about 38.3% (by 2030), Bhopal 56.2%, Kolkata 51.27% and Hyderabad by 64.6%. It was observed that cities grow over 2 times the current state by 2030. In all the cases, urbanisation was primarily due to infilling, followed by ribbon development along the highways and arteries roads. Major divers of land use change were observed to be industries followed by roads, educational institutes and transportation sector.

Table.1. Predicted Landscape dynamics for Ahmedabad

Year	Builtup	Water	Vegetation	Others
2020	23.7%	2.3%	6.8%	67.2%
2030	38.3%	2.3%	3.0%	56.4%

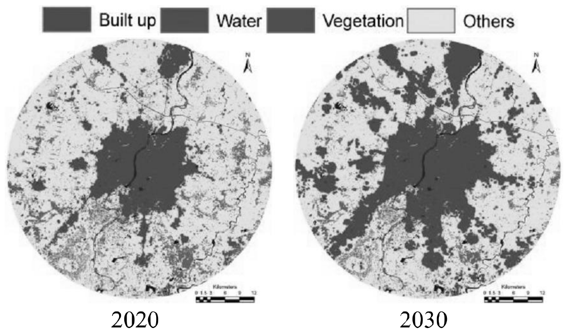

Fig. 3. Predicted Landscape dynamics for Ahmedabad

Table. 2. Predicted Landscape dynamics for Bhopal

Year	Built up	Water	Vegetation	Others
2018	11.51%	2.41%	11.10%	74.99%
2022	25.09%	2.12%	4.71%	68.09%
2026	43.77%	2.12%	4.10%	50.00%
2030	56.20%	2.12%	4.10%	37.58%

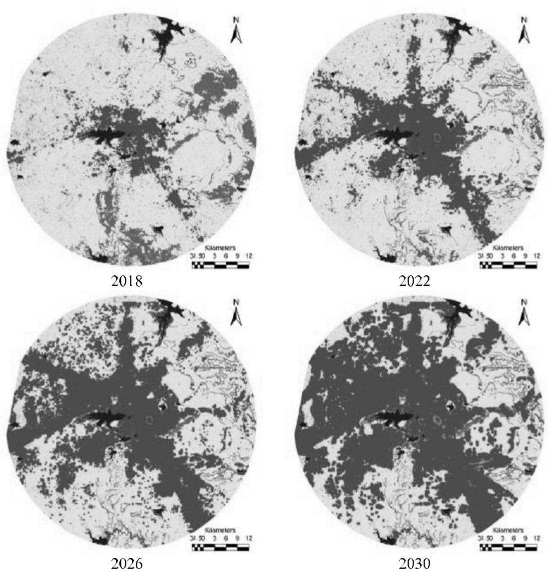

Fig. 4. Predicted Landscape dynamics for Bhopal

Table. 3. Predicted Landscape dynamics for Kolkata

Year	Built up	Water	Vegetation	Others
2020	29.54%	5.68%	8.31%	56.47%
2025	41.88%	5.68%	5.14%	47.30%
2030	51.27%	5.68%	3.37%	39.68%

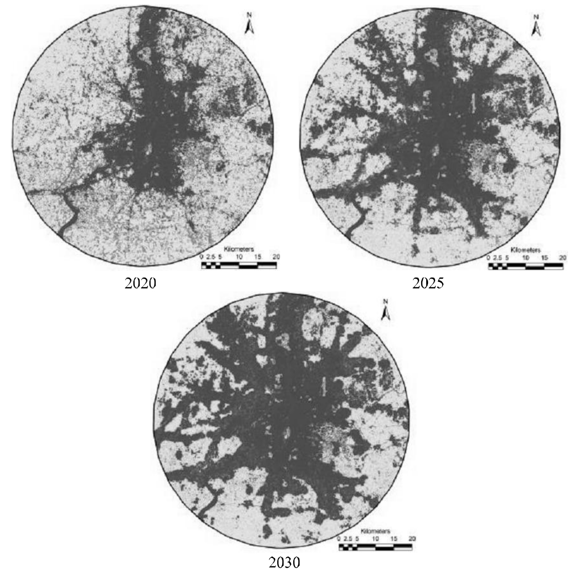

Fig. 5. Predicted Landscape dynamics for Kolkata

Table. 4. Predicted Landscape dynamics for Hyderabad

Year	Built up	Vegetation	Water	Others
2019	35.18	3.03	1.84	59.93
2024	51.25	2.67	1.84	44.23
2029	64.6	2.55	1.84	30.92

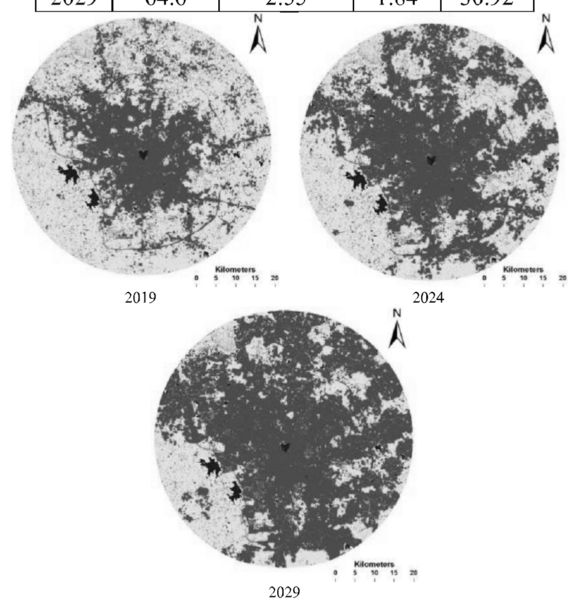

Fig. 6. Predicted Landscape dynamics for Hyderabad

V. CONCLUSIONS

Indian cities are growing at a higher rate due to higher inflow and investments from the industrial hubs. Populations in the cities are growing at a very high rate due which the cities with tie tend to become Tire 1 city or Mega city. Modeling considering various factors and constraints of development helps in identifying the regions of growth. The current demonstrates modeling of urban growth using historical remote sensing data and visualization of future landscape dynamics. Agent based models consider various factors contributing to the growth and provided valuable insights to landscape dynamics. The predictions shows higher tendency of urbanization along the arterial roads, and industries, followed by major amenities such as transport sectors and educational institutions. The outcome of these models helps the city planners to plan the city for providing basic amenities including proper infrastructure, making city in to a livable/smart city.

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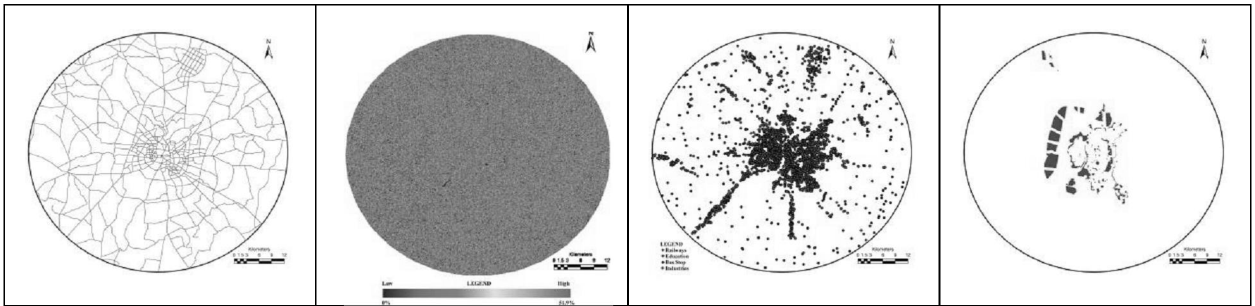
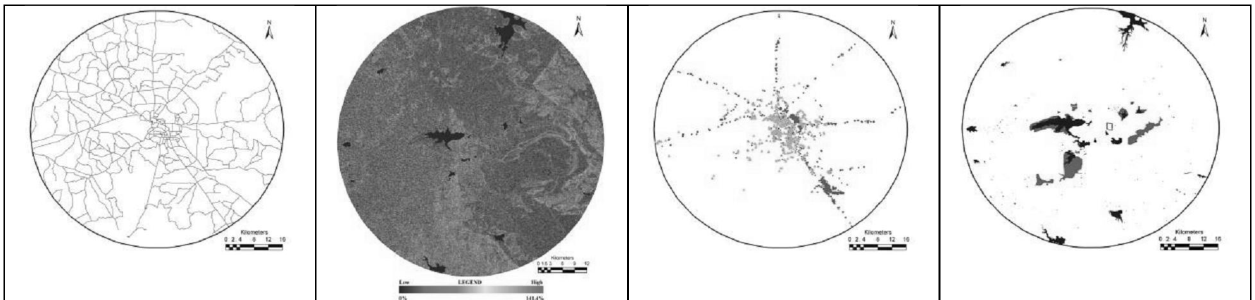
ANNEXURE



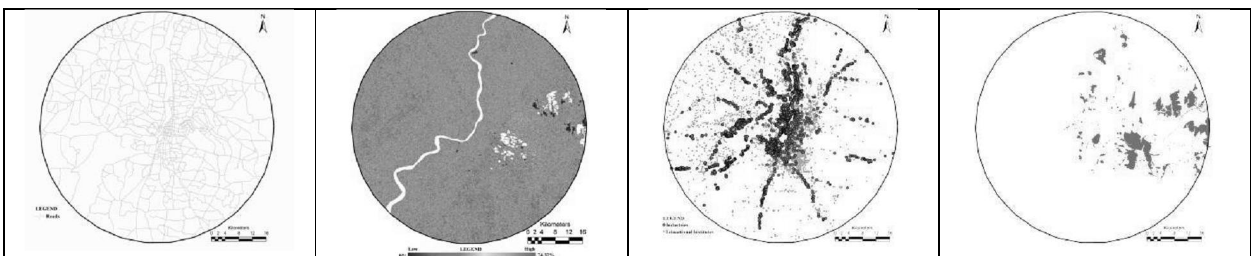
Roads	Slope	Amenities	Protected Area

Annexure. 1. Factors and Constraints of Growth for Ahmedabad



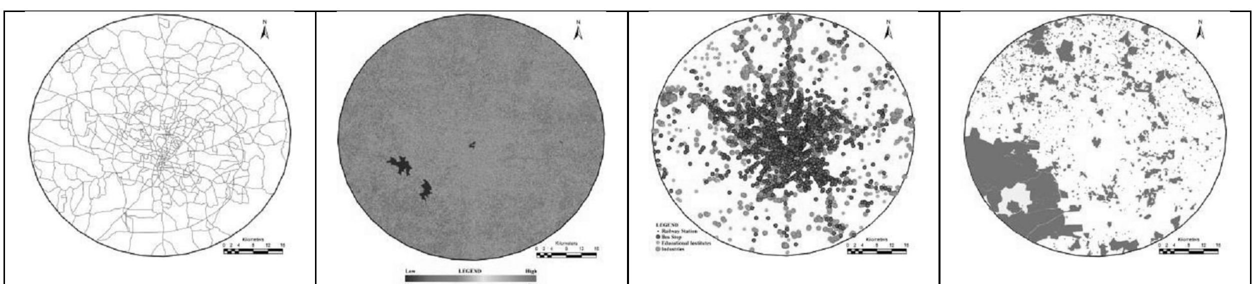
Roads	Slope	Amenities	Protected Area

Annexure. 2. Factors and Constraints of Growth for Bhopal



Roads	Slope	Amenities	Protected Area

Annexure. 3. Factors and Constraints of Growth for Kolkata



Roads	Slope	Amenities	Protected Area

Annexure. 4. Factors and Constraints of Growth for Hyderabad

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PUBLICATIONS

Journals (peer reviewed international journals)		
Theme	*Year*	*Publication*
Environmental Sustainability	2015	Ramachandra, T.V., Bharath H. A., Shreejith, K., 2015. GHG footprint of major cities in India, Renewable and Sustainable Energy Reviews. 44, pp.473-495.
	2015	Ramachandra T.V. and Bharath H. Aithal, 2015. Wetlands: Kidneys of Bangalore's Landscape, National wetlands, 37:12-16
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