Prediction of Spatial Patterns of Urban Dynamics in Pune, India

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***Abstract*-The potential of Markov chain and cellular automata model with help of agents that play a vital role in a cities urbanisation through fuzziness in the data and hierarchal weights (for principal agents) have been used to understand and predict the urban growth for the Pune city, India. The model utilizes temporal land use changes with probable growth agents such as roads drainage networks, railway connectivity, slope, bus network, industrial establishments, educational network etc., to simulate the growth of Pune for 2025 using two scenarios of development – implementation of City Development Plan (CDP) and without CDP. In the study, multi temporal land use datasets, derived from remotely-sensed images of 1992, 2000, 2010 and 2013, were used for simulation and validation. Prediction reveals that future urban expansion would be in northwest and southeast regions with intensification near the central business district. This approach provides insights to urban growth dynamics required for city planning and management.**

Key Words- Urban sprawl, Remote Sensing, Cellular Automata, Markov Chain, Modeling, Pune, AHP, Fuzzy

I. INTRODUCTION

Urbanisation refers to lateral and vertical growth of urban pockets as a result of population growth, industrialization, political, cultural and other socio-economic factors. The process of urbanization is dynamic [1, 2] and leads to centralization of humankind's civilization and wealth [3], large scale land use pattern changes over time [4] which also degrades the environment and natural resources [5, 6, 7]. Lack of planning and uncontrolled urbanisation would lead into unstable, uncontrolled and dispersed development and would also lead to process called urban sprawl. The process of urban sprawl is a very common among the developing countries and in particular the large cities. The dispersed growth can be quantified through mapping of impervious urban surfaces in and around the city. The process of urban sprawl is studied in many developing countries [8, 9, 10, 11, 12, 13] as it leads to drastic change in the landscape. For mapping and monitoring the landscape changes using traditional mapping techniques with increased coat and time, has led to larger interest in research and advancements in modern mapping and modeling techniques through GIS and Remote sensing [14]. Remote sensing technique has advantages over traditional ways of mapping as it is cost effective and time saving [15], since the images from the remotely sensed satellite data has a wide coverage of the earth surface, are multi temporal and are of high spatial and spectral resolutions, based on which the land use can analysed using various classification techniques and monitored are used to map, measure, visualise changes in the land use pattern Mapping using remotely sensed data is important since it has no bias towards human interventions, also apart from mapping the land use change, modelling the future changes is also empirically significant, since it helps in understanding the consequences of such spatial LU change [16]. Models specific to urban growth have been used along with remote sensing data and have proved to be important tools to measure land-use change in peri-urban and rural regions [17, 18, 19]. Torrens [20] suggests use of cellular automata (CA) for urban growth modelling and in simulating land use changes as population migration and evolution can all be modeled as automation, while the pixel and its neighbors can account for various changes such as demographic data etc., neighborhoods as part of the city can be simulated by the cells on the lattice based on predefined site-specific rules that represent the local current transitions that are raster-based for modeling urban expansion for discrete time steps [21]. Further it can be noted that standalone CA models lack the ability to account for the actual amount of change since it cannot account for specific transitions of change in the region. Eastman [22] suggested coupling of Markov chains (MC) and CA. This coupling helps in quantifying future likely changes based on current and past changes which essentially addresses the shortcoming of CA such as spatial allocation and the location of change [16]. Having said this studies have failed to link agents of changes that are main driving forces using this coupling [23, 24]. Further, some studies have used agents or drivers of changes that can be transition potential using multi-criteria evaluation (MCE) techniques. This failed due to shortcoming in calibration techniques (Eastman, 2009). Hence it is necessary to calibrate the model and associate the agents of change and driving forces in order to understand and develop accurate transition potential maps. Fuzzy-AHP technique of obtaining such accurate calibrations [25]. First, fuzzy clustering is used to group the spatial units into clusters. Clustering is based on certain attribute data. With fuzzy clustering, each spatial unit will be assigned a factor of evolution and urbanism. Analytical Hierarchal process (AHP) is then used to assign weights to these spatial units thus based on various inputs.

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The present study was conducted to investigate the previous land use changes and patterns of urban growth of Pune, one of the fastest-growing cities in India [26]. This study merges land use analyses of the period 1992 to 2013 and predicts for 2016, 2019, 2022 and 2025 using Fuzzy –AHP calibrated MC-CA.

II. Study area and data

Pune, earlier known as Poona is the cultural capital of Maharashtra and is also known as “Queen of Deccan”. Pune is located in the western part of Maharashtra state between 18°32′ N and 72° 51′E at a height of 560 m above mean sea level. It lies near the confluence of the Mula-Mutha River. The Pune Municipal Corporation covers an area of 243.84 sq. kms. Population during 1901 to 2011 showing an increase by 347%. Pune being one among incipient mega cities in India has seen the large scale development in recent times. Population of Pune has increased to 9 million (Census 2011) from 7 million in 2001 (Census 2001). Fig. 1 shows the study region.

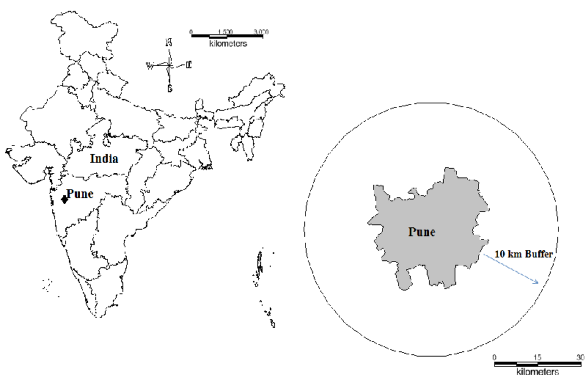

Fig. 1. Study area considered, Pune and 10km buffer.

Pune Municipal Corporation with forty-eight wards is the civic body that is responsible administration and infrastructure development of the city and it is known as the Pune Mahanagar Palika (PMP). The current study has been carried out in a region of 1524.4 sq. km consisting of municipal corporation administrative region with 10 km buffer. Buffer of 10 km is considered to account the growth in the peri-urban regions

Time series spatial data acquired through Landsat Series thematic mapper (30m) and Landsat 8 operational image scanner (30m) sensors for the period 1992 to 2013 were downloaded from a public domain Global Land Cover Facility [27]. Survey of India (SOI) topographic sheets of 1:50000 and 1:250000 scales were used to generate base layers of city boundary, training sites, generation of polygons for attribute data, drivers of change etc.

III. Method

Spatial pattern of urbanisation is assessed using temporal remote sensing data of 1992 to 2013. Data analyses include:

Pre-processing: Remote sensing data (Landsat series) for Pune, acquired for different time periods, were geo-corrected and cropped pertaining to the study area. Geo-registration of remote sensing data (Landsat data) has been done using ground control points collected from the field using pre calibrated GPS (Global Positioning System) and also from known points (such as road intersections, etc.) collected from geo-referenced topographic maps of the Survey of India.

Land use analysis: This involves i) generation of False Color Composite (FCC) of remote sensing data (bands – green, red and NIR). This helped in locating heterogeneous patches in the landscape ii) selection of training polygons (these correspond to heterogeneous patches in FCC) iii) loading these training polygons co-ordinates into pre-calibrated GPS, iv) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, v) supplementing this information with Google Earth, vi) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment.

Land use analysis was carried out using supervised pattern classifier -Gaussian Maximum Likelihood Classifier (GMLC) algorithm using various classification decisions based on probability and cost functions [28, 29, 30]. Remote sensing data was classified using training data of all land use types as as Urban (includes all impervious urban structures), Water, Vegetation (Trees, standing vegetation cover) and others. Mean and covariance matrix are computed using estimate of maximum likelihood estimator. Land use was computed using the temporal data through the open source program GRASS - Geographic Resource Analysis Support System.

Statistical assessment of classifier performance based on the performance of spectral classification considering reference pixels is done which include computation of kappa (κ) statistics and overall (producer's and user's) accuracies [31, 32].

Modelling urban dynamics using fuzzy-AHP-MC-CA: Standardization of agents and process using fuzzy charecteristics and Weighted principal agents using AHP

In order to determine the influence of the factors affect land use transition probabilities agents were selected based on preliminary studies e.g., [25, 33], were employed within an AHP framework. The relative influence of each factors are determined by fuzziness using sigmoidal increasing and decreasing functions based on each factor combinations.

For example, the areas with slopes less than 20% are probable candidates for urban growth. This is modeled as a sigmoidal decreasing function in which suitability starts at zero and levels off at 20%. It may be noted that choosing the type of fuzzy membership function and corresponding control points is prone to subjectivity. Further, importance of each factors was determined by AHP. Further, logical consistency of determined weights was verified using consistency ratio. The

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value of 0.03, which is below the critical value of 0.1. The individual weights for urban is as determined are listed in Table 1. Factors with higher weights are considered to be statistically more effective.

Factor	Weightage
Industry	0.385
Road	0.2665
Bus stops and Railway stations	0.1566
Education	0.0806
Socio-economic	0.0486
Religious	0.0398
Crematorium	0.023

Table 1: example of weightage generated for each factor

Once weights are determined MCE was used to determine the site suitability considering two scenarios i). Restrictions based on City Development Plan (CDP); ii)). as usual scenario without CDP. These suitability change maps were considered in the MC-CA model.

Modelling using MC-CA model: Considering land use of 1992-2000 and 2000 - 2010, transition potentials were computed using a Markovian process (table 2). For calibration purposes, CA first input the transition probabilities for the years 2000-2010 and the suitability map to project the previously known built-up areas for 2013. Using and hexagonal CA Filter of 5 x 5 neighborhood with variable iteration at every step until a threshold is reached. Careful model validation through kappa statistics was conducted to assure accuracy in prediction and simulation. Built-up areas were predicted for 2013 were cross-compared with the actual amount of built-up areas in 2013 using classified data. The kappa index of 81.5% and accuracy of 82.2% shows a good agreement accuracy of the model. Accordingly, the model was refitted with similar parameter settings Using the land use data from 2010 to 2013, the transition probabilities from 2010 to 2013, and the identical suitability map. The future patterns of urban expansion were then simulated for the years 2016, 2019, 2022, 2025.

	Probability of changing to				
Given Land use	Land Use	Urban	Water	Vegetation	Others
	Urban	0.8453	0.1547	0	0
	Water	0.0338	0.8363	0.0793	0.0506
	Vegetation	0.0327	0.0056	0.3517	0.61
	Others	0.1446	0.0029	0.2008	0.6517

Table 2: Markov transition potential

III. RESULTS

Land Use Analysis: fig. 2 and table 3 depicts the land use dynamics from 1992 till 2013, accuracy over 80% and kappa over 0.75 (table 4) indicated good relation with the classified satellite information and the true information. Land use classification showed that the built up area has increased from 7.64% (in 1992) to 29.73% (2013) at the cost of other land uses, while the water bodies remained constant.

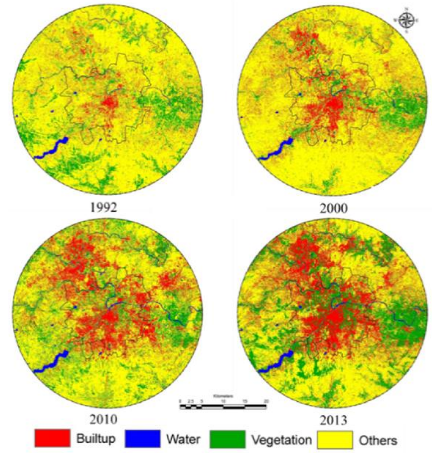


Fig.2. Land use analysed for study region

Model Calibration and Simulation:

The model was designed in order to simulate the land use for the year 2013 based on the knowledge of historical data such as 1992 to 2010. Different factors that either restrict or support urbanization were normalized using binary (constraints) or fuzzy logic (supporting factors), where in the distance up to which the effect of each factor would take place was considered. Weightages were calculated in order to prioritize the normalised factors of growth using the analytical hierarchical process, these weights plays a crucial role in calibrating the model for higher accuracy and precision. For each of the land use, using various constraints and factors of growth, site suitability maps (Fig. 3a, Fig. 3b) were developed based on multi criteria evaluation process for the year 2010 and 2013 which were used further in simulation and prediction of land use respectively, of all the factors roads, industries, bus and railway stations and educational institutes had higher impact on the process of simulating the land use dynamics. It can be observed that the effect of CDP has higher impact towards the core of the city, restricting the growth of urbanization, but promoting towards the peripheries, whereas in the absence of CDP, the core is more susceptible to the increasing urbanization, where as in the absence of CPD, the core allows built-up growth to a higher extent at the cost of protected features such as drainages, defense establishments, parks, etc. Vegetation has higher tendency to sustain where the slopes are high and away from the factors those support the expansion of built up areas. Based on the ancillary data of the year 2000 and 2010, Markov assessment was carried out in order to quantify the probable land use change at 2013. Markov probability, along with the probable transition areas (site suitability maps) were used in order to simulate for the year 2013. The simulated results are as presented in fig. 4 and table 4, both of the calibrated models had accuracy over 83% and agreement of over 0.8 which indicate that the model could further be used for predicting the land use.

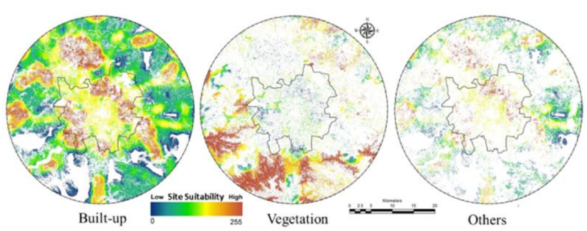
Land Use	1992 [%]	2000 [%]
Built-up	7.64	14.83
Water	1.28	0.86
Vegetation	13.78	8.85
Others	77.29	75.46
Land Use	**2010 [%]**	**2013 [%]**
Built-up	24.27	29.73
Water	1.42	1.75
Vegetation	23.85	16.67
Others	50.46	51.85

Table 2: Land use analysed

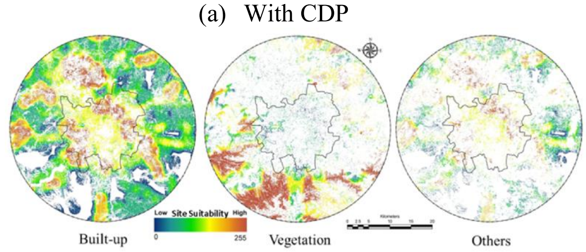
1992		2000		2010		2013	
OA	κ	OA	κ	OA	κ	OA	κ
91.2	0.9	93.1	0.9	94.4	0.92	94.6	0.91

Table 3: Accuracy assessment and kappa

Prediction of future land use: In order to predict the land use dynamics in the future, two different scenarios were adopted i.e., considering effect of presence and absence CDP. In order to predict the land use, Markov chains were run across equal time intervals i.e., using 2010 and 2013, predicting 2016; using 2013 and predicted 2016, predicting 2019 and so on up to 2025. Fig. 5, Fig. 6 and table 5 depicts the probable land use. It could be attributed to the implementation of the CDP that, the land use being converted from other land use classes to built-up is high across the peripheries since the restriction on using defence, recreation, and 30 m buffer across drain lines at the core. In case if CDP is not implemented, the restrictions holds only on existing built-up area, water bodies and slope only, the defence, recreation areas, drainages would be outgrown by the urbanization process, hence the core getting clumpy and saturated, rather than peripheries.



(a) With CDP



(b) Without CDP

Fig. 3. example of site suitability maps

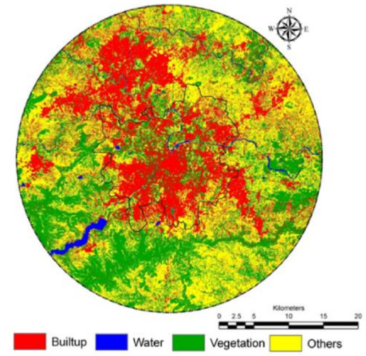


Fig. 4. Simulated Land use year 2013

Land Use	[%]
Built-up	28.07
Water	1.29
Vegetation	29.40
Others	41.24
Accuracy	82.2 %
Kappa Location	0.8159
Kappa Standard	0.7354

Table 4: Simulated Land use 2013

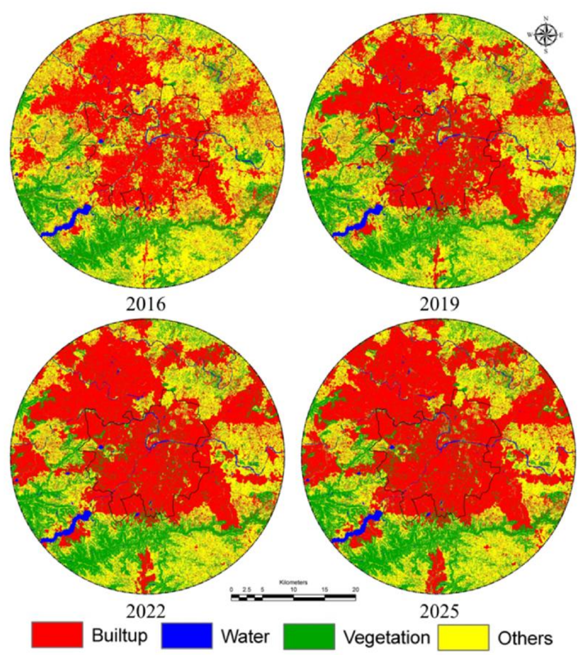


Fig. 5. Simulated land use with CDP

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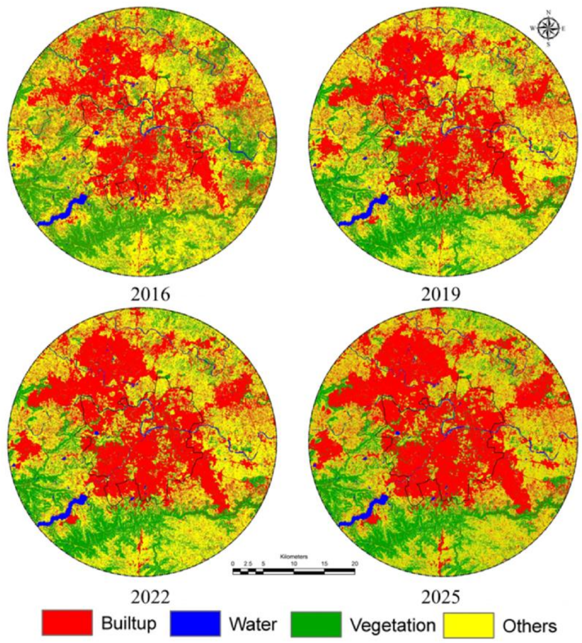

Fig. 6. Simulated land use without CDP

Year	Land Use	with CDP % Area	no CDP % Area
2016	Built up	37.78	33.48
	Water	1.75	1.75
	Vegetation	16.37	22.21
	Others	44.11	42.56
2019	Built up	41.64	36.47
	Water	1.75	1.75
	Vegetation	20.16	18.44
	Others	36.45	43.35
2022	Built up	47.89	38.86
	Water	1.75	1.75
	Vegetation	20.16	18.41
	Others	30.20	40.98
2025	Built up	50.02	41.12
	Water	1.75	1.75
	Vegetation	20.16	18.40
	Others	28.06	38.73

Table 5: Predicted land use

IV. CONCLUSION

Pune is one of the fastest-growing urban regions with effects of sprawl and influx of population in the region as established. Given prevailing high urban dynamics would require modelling and remote sensing to understand the future growth. This proposed approach would help in understanding specific regions and pockets if growth and would help in sustainable planning. In this context, our analysis contributes significantly by having demonstrated that urban growth models, by means of fuzzy-AHP- MC-CA, which in turn provided important and crucial information regarding urban growth pattern in and around Pune till 2025. The results show clear urban expansion and demonstrate that urban growth dynamics are strongly linked to population dynamics. The temporal mapping of land use and further urban growth simulations for the next decade indicate that the predicted urban expansion will happen along the major transport network such as Mumbai –Pune corridor etc., and existing built-up areas, among other physical factors. The main contribution of change in land use would occur in form of other category conversion.

More importantly, the MC-CA could model the with help of factors and maps generated using Fuzzy –AHP and MCE, which exhibit that same trend will continue through 2025, that would resulting in a mixture of different growth patterns in the buffer region and clumped urban centric growth in the city with loss of other land use. This Model also shows that new urban nuclei might emerge in next decade such as Pimpri Chinchwad and Yerawada and Nagar regions, Moreover, several notable smaller in-fill developments could be easily seen. These relevant findings would help policy makers, urban planners, to understand the further expansions of the city and to plan the resource and basic amenities with sustainable policy interventions.

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