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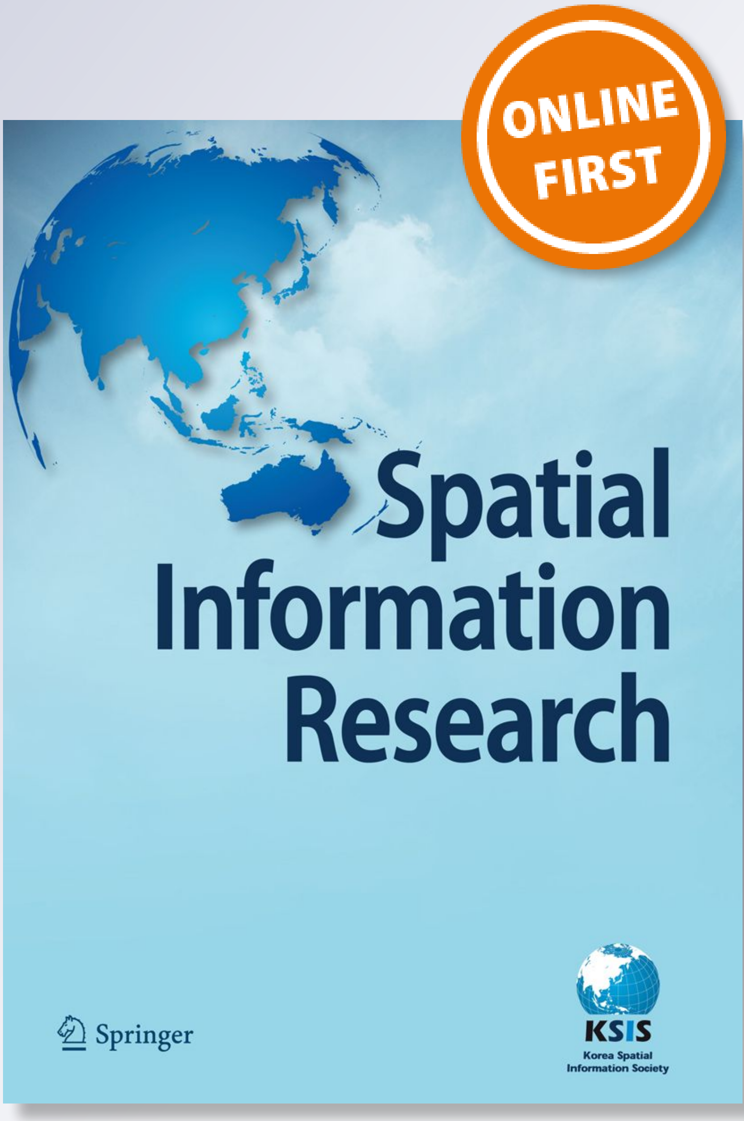

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Modeling urban dynamics along two major industrial corridors in India

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Abstract Rapid urban growth and consequent sprawl have been a major concern in urban planning towards the provision of basic amenities and infrastructure. The current research was undertaken as per the recommendations of brainstorming session involving stakeholders from academia, government agencies and industry. The outcome of this study is expected to provide the vital inputs to the federal government to provision basic amenities and smart infrastructure, to boost the industrial growth, while maintaining the local ecology and environment and support local livelihood. Spatial patterns of land use dynamics have been analysed in two major corridors (with 10 km buffer on either side). During the past two decades, the urban growth is about 441% along Mumbai–Pune Industrial corridor and 276% along Chennai–Bangalore–Mangalore corridor. The prediction of likely growth has been done using Markov-cellular automation model, accounting fuzzy behavior of agents. Spatial metrics confirm that the core urban areas of major cities have concentrated growth and sprawl at the outskirts. Prediction model estimates that urban area would increase to 47.1% by 2027 in Mumbai–Pune corridor and to 35.4% in 2029 in Chennai–Mangalore corridor. This study aids in pre-visualising the urban growth to evolve appropriate management strategies to mitigate environmental impacts.

Keywords Cellular automata · Chennai–Bangalore · Fuzzy · Markov chains · Mumbai–Pune

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1 Introduction

Urbanisation refers to the shift of population into a particular region in search of job and livelihood prospects. This leads to a gradual increase in population of a region. Unplanned urbanisation fuels the expansion of human populations away from central urban areas into low-density and usually mobility dependent communities, in a process called urban sprawl. Normally, the sprawl regions are devoid of basic amenities and infrastructure due to lack of planning as the planners were unable to visulise the likely growth. Thus, urbanisation is a result of concentration and diversion of resources to urban areas, extensive developments, population migration in search of employment form rural to urban areas, etc. [1] leading to alterations in land use patterns, unsustainable developments, socio-economic, water and environmental related problems [2]. According to World Urbanisation Prospects [3], increasing connectivity has increased the urban population from 30% in 1950 to 54% in 2014 that is projected to grow to 66% by 2050.

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China, India and Nigeria is estimated to account for 37% of the population. India currently with about 16.6% of the total world population, has the distinction of being the second most populous country in the world. As per Census of India [4] and Planning Commission of India [5], urban population in India has increased from 28% in 2001 to 31.7% in 2011. Number of urban areas in India increased by 44.5% between 2001 (6498) and 2011(9391) and expected to reach 60% by 2050.

Globalization and consequent opening of Indian Markets during the early ninety's has led to the rapid urbanisation of landscape. Economic transformations coupled with infrastructure improvements in the last decade have opened up plenty of opportunities for improving basic necessities with the planned implementation in many Indian cities. Infrastructure development, fundamental to the overall development of human needs is a crucial and deciding factor for quality of life and also aids in deciding new factors for improvement and urban growth. There has been severe under investment in infrastructure development in developing world that most of the cities have an unplanned development in its periphery and the adjoining regions of the city. India has witnessed large-scale urbanisation in cities and towns since 1990's as a result of industrialization, political, cultural and other socio-economic factors neglecting the necessary infrastructural reforms along with provision of basic amenities to the citizens in planned phased manner The recent thrust in development of infrastructure across India connecting cities, is through the development of industrial corridors linking two or more major cities and few hundred town(s), providing necessary connectivity in the last decade. This is expected to enhance the economic activities between cities and the government has started large scale funding towards the infrastructural reforms.

The industrial corridors have initiated a new era of urban growth connecting towns to cities. Industrial corridors are along the specific routes between geographical limits enabling faster movement of goods from source to destination i.e., efficient supply chain management. The corridors are generally planned along existing road network, train routes to stimulate industrial development through available human resources, reduced transport time and cost, quicker supply, etc. Globally, industrial corridor were designed with "world class infrastructure such as high-speed transportation (rail, road) network, ports with state-of-the-art cargo handling equipment, modern airports, special economic regions/industrial areas, logistic parks/transshipment hubs, knowledge parks etc. focused on feeding industrial needs, complementary infrastructure such as townships/real estate, and other urban infrastructure" [6]. However, this would lead to the large scale land cover changes, which would pose a new web of challenges to the decision makers that includes meeting the needs of the rapidly growing population; catering to the increasing expectations for improved quality; range and access to services; utilizing human resource to improve socio-economic development and education. This necessitates prior visualisation of spatial growth to mitigate the environmental and ecological impacts associated with the land use land cover [LULC] changes.

The Government of India [7], in recent times has initiated ambitious novel programmes such as Make in India, Skill India, Smart Cities, Industrial Corridors, Digital India, etc. The purpose of these programs was to enhance the job opportunities and boost countries economy with planned capabilities through global competitive methods. Industrial corridors are one such initiative under the vision of development in various states of India linking major cities, that aid as transport routes connecting various economic centres and industries [8]. These corridors would play an important role in connecting regional economies while boosting the local economy towards regional or global development [8]. In India, industrial corridors with improved connectivity, energy distribution systems, piped network, etc. would focus on cluster development approaches. This would expand manufacturing and services base, develop as a Global Manufacturing and Trading Hub [9], expand domestic markets, integrate domestic companies with global market, that reduces the regional inequalities [10]. The Government of India has launched 5 major industrial corridor projects under the National Industrial Corridor Development and Implementation Trust [11] in 2014–2015, which include Delhi Mumbai Industrial corridor, Bangalore–Mumbai Industrial corridor, Chennai–Bangalore Industrial corridor, Chennai–Vizag Industrial corridor, Amritsar–Kolkata corridor. These identified projects are expected to be the key economic driver for increasing share of manufacturing in India's GDP from 15 to 16 to 25% by 2022.

Academia and industries have been the pivotal pillars of economy and the regional prosperity. A robust collaboration among the academia, government and industry gives impetus to the planned urbanisation with innovations towards provisioning smart infrastructure, basic amenities, quality education system, while producing an employment-ready workforce.

2 Review of related studies

Urban research during the last decade has made considerable efforts in bringing into focus urbanizing pattern of cities and challenges [12]. Studies have also focused on peripheral areas emerging as employment centers and transforming the immediate rural neighbourhood [13].

However, earlier research focus were mainly into urban core and urban–rural neighbourhood and not much emphasis given to the corridors that connect two major urban centers. The corridors have always been attributed to improved functional properties of a growing city, however very minimal attention has been provided especially the land use change dynamics and associated environmental impacts. Hence, more often industrial corridors exhibit or develop a tendency to represent fragmented urban growth connected to cities with extremely poor environmental conditions.

Spatial analyses for inventorying, mapping and monitoring land cover using remote sensing data acquired through space borne sensors have been proved to be the quickest and economical technique for mapping large areas. The multi-resolution (spatial, spectral and temporal) data and robust classification algorithms with the best accuracy are useful in land use mapping and to understand landscape dynamics. Now, Earth-observation-based monitoring of urban growth has been widely accepted and implemented by local, regional and national governments [14]. Satellite technology helps urban mapping at finer scales and thereby making it easier for policy makers and planners to understand the growth dynamics and sprawl [15]. GIS (Geographic information system) with facilities to capture, manage, store, retrieve, analyze and display geo-spatial data on a real-time basis, has entered the majority of the service sectors. Further strength to GIS comes from a built-in database, decision support system and application-specific plugins, which makes GIS a more reliable tool for urban studies [16]. Studies in India [10, 12, 13, 17] and worldwide by researchers [2, 6, 14, 18], mainly address land cover changes and its implications. Assessment of spatial patterns of land use dynamics and identification of agents is a prerequisite to understanding urban growth dynamics and modelling the urbanisation process. Further, this will aid in understanding and visualizing the specific pockets of growth and influence of urban corridors in the buffer regions. There has been extensive research in urban modelling in recent years. Urban modelling is the process of identifying a theory which could be translated into a mathematical model as well as developing a specific computer-aided programs to feed the model with data so as to calibrate, validate, verify and predict future urban trends [19]. During the past four decades, there have been significant contributions to urban growth models and visualization with a common goal to study land use dynamics and simulate urban growth using geospatial techniques [20]. Theoretical assumptions, the method followed, spatial, temporal aspects and geographical extents might vary with each model types, but the final outcome of these models is to understand the complex interrelationships between natural ecosystem and urban environment by observing irreversible heterogeneous spatial patterns of changes [21]. Cellular automata (CA) based modelling framework has been one of the widely accepted technique of urban simulation and modelling due to its simplicity, flexibility and intuitiveness [22]. CA models were gradually improved on the aspects of increasing complexity of transition rules [23]. Despite all these, CA models do not consider the change probability. This opens up an opportunity to couple Markov Chains (MC) and CA providing a potent modelling structure. The CA–Markov develops based on time series and spatial predictions of the Markov and CA, making it possible for Spatial–Temporal simulation. Modelling based on CA depends on five elements namely, the spatial arrangement, states, neighbourhood, rules of transition, temporal scale of cells [24]. Among other approaches, regression modelling has been effectively applied in urban research [25]. These models are extremely useful in knowledge development if integrated with the process of physical and socioeconomic patterns. These socio-economic drivers are called 'Agents of Development' and modelling approaches are referred to as 'Agent Based Modelling (ABM)'. ABM has proved to be reliable, individual decision-making tool to capture spatial dynamics by incorporating socio-economic and environmental factors [26]. Potential usage of ABM in research areas like LULCC (land use land cover changes) simulation, design, development and implementation has been explored earlier [27]. Over the last two decades, ABM has evolved with various factors and understanding interactions contributing to urban growth and has proved to be superior over conventional modeling techniques [28]. ABM is evolving and flexible, considers bottom-up approaches studying behavior of factors in urban evolution, while allowing complex, heterogeneous nonlinear interactions. ABM exhibit an extensive knowledge base on how the agents of changes interact with each other to be responsible for the social and physical environment of urban areas and their immediate vicinity. Numerous ABM techniques have been used to understand/predict urban sprawl/land use changes in a region such as Sleuth, SLUCE/Some, Land Change Molder (LCM), Artificial Neural Networks, Dynamic Urban Evolution Model, Multi Regression, CLUES, Dyna-CLUES, CAPRI-Spat, Fuzzy-AHP-CA etc. [27].

Evaluation of a process was earlier restricted to precise values [29], and the process of using fuzzy logic has freed the boundary conditions by a range of values [30]. Integration of Fuzzy into the modelling allows the decision maker to compare two variables (pair wise comparison) which allows accessing the relative importance of one variable over the other in AHP—analytical hierarchical process [31]. Analytical hierarchical process formulates and analyses the decisions made individually or as a group

[32]. AHP with multi-criteria evaluation approach has been useful in evaluating the site suitability for landscape development [33]. Thus, this integrated agent-based approach would help in visualizing development scenarios aimed at decision making for a sustainable development goal [23]. The current study analyses landscape dynamics using temporal remote sensing data, identifies agents of local growth poles and analyse spatial patterns using spatial metrics through segment (zones) approaches and predict future land uses using ABM in the two major Industrial corridors in India.

The paper is organized in five sections: Sect. 1 brief introduction of urban growth. Section 2 reviews the related studies, Sect. 3 details out the study area considered for the analysis, and explains the method and data used in the analysis. This is followed by the Sect. 4 explaining the results. Section 5 presents the outcome of the research with suggestions.

3 Materials and methods

3.1 Study area

Assessment of land use dynamics and prediction of likely land uses in the future based on agent-based modelling has been carried out in the major industrial corridors connecting two metropolitan cities of India—Mumbai–Pune Industrial (MPI) corridor known as Yashwantrao Chavan Mumbai–Pune expressway and Chennai–Bangalore–Mangalore Industrial (CBMI) corridor.

MPI corridor (Fig. 1a) is India's first six-lane high-speed toll express highway extending over a distance of Ninety-three kilometres connecting Mumbai, also known as "Business Capital of India" and Pune "Industrial and Educational Hub" and also known as "Manchester of India".

CBMI corridor extends along the National Highway (NH 48 and NH4) covering a distance of 630 km (Fig. 1b). The Government of India extended Chennai–Bangalore industrial corridor to Mangalore in order to connect east and west ports. The industrial corridor connects the major Tier I cities such as Chennai and Bangalore and Tier II city Mangalore.

The buffer of 10 km on either side was considered to understand the effects of the industrial corridor in its immediate neighbourhood. The study region of MPI is about 3022 sq km covering districts of Mumbai, Raigarh, Thane and Pune. The CBMI study region is about 13,572.37 km^2 and the industrial corridor passes through 15 districts including Chennai, Chittoor, Dharmapuri, Kancheepuram, Thiruvallur, Vellore, Thiruvannamalai,

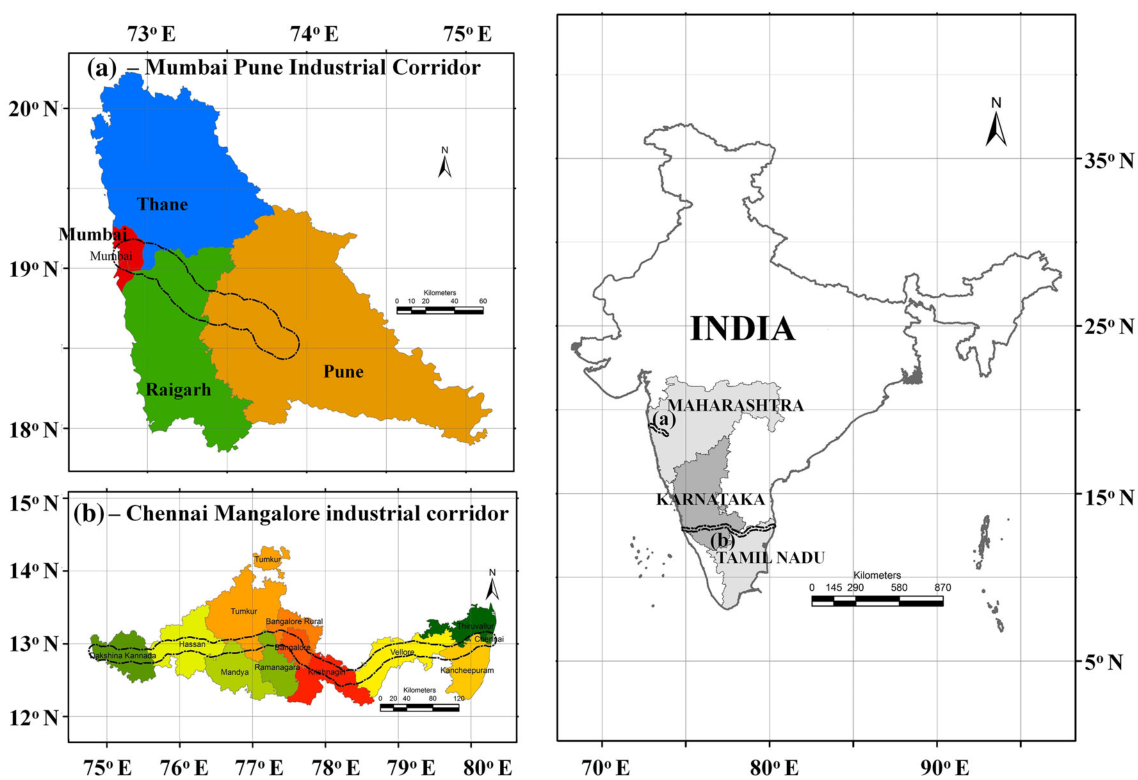

Fig. 1 Study area major industrial corridors in India. **a** Mumbai–Pune Industrial (MPI) corridor; **b** Chennai–Bangalore–Mangalore Industrial (CBMI) corridor

Bangalore, Bangalore Rural, Hassan, Mandya, Tumkur, Dakshina Kannada and Kasargod.

3.2 Data and method

Figure 2 outlines the method which includes three-step framework. The first step includes data acquisition, pre-processing and land use land cover change analysis (LULCC). Data acquisition involves the collection of Primary data and Secondary data. Primary data includes remote sensing data for the period between 1997 and 2015 [34]. Table 1 lists the data obtained from various sources. Secondary data were used to support primary data for geometric corrections and land use classification, which includes historical land use maps, the Survey of India Topographic maps [35], information from virtual earth database viz., Google Earth [36] and Bhuvan [37]. Ground control points were collected with hand held pre-calibrated GPS (Global Positioning System).

The remote sensing data was preprocessed for geometric/positional errors and geometric correction was carried out using GCPs for inaccurate datasets. Radiometric corrections were carried out to enhance spectral properties of the chosen scene. All data were resampled to common spatial resolution i.e., 30 × 30 m to maintain uniformity across the temporal data. The study region (25 km length corridor with 10 km buffer on either side of the corridor) was delineated/cropped from the respective scene

The land cover analysis was performed using Normalised difference vegetation index (NDVI) to understand the spatial extent of region under vegetation and non-vegetation. NDVI values ranges between − 1 (non-vegetation) and + 1 (vegetation). Remote sensing data was classified considering supervised classifier based on Gaussian maximum likelihood algorithm. This included the creation of false colour composite (FCC), which aided in identifying heterogeneous features, training polygons were chosen from these representative heterogeneous features. These training polygons with geo co-ordinates were loaded in pre-calibrated (error < 1 m) GPS and the corresponding attribute data for the training polygons were collected from the field. These data were then used to classify remote sensing data into four classes (Table 2) using a supervised classifier based on the Gaussian maximum likelihood algorithm and this technique was found superior in terms of classification accuracies [38]. Validation of remote sensing data classification is done through accuracy assessment using overall accuracy and kappa statistics [39].

The study region (respective industrial corridor with 10 km buffer on either side) was segmented into 25 km zones to understand the pattern and process of urbanisation in the neighbourhood. Initially, the region was segmented at every 5 km interval, 10 km, 25 km and 50 km and spatial indices were computed. It was found that 25 km was optimal to understand the spatial patterns of landscape dynamics using metrics.

Then, modelling of likely growth was simulated using CA-Markov integrated with Fuzzy ABM framework. Figure 2 explains the entire process of analysis and visualization based on fuzzy logic with AHP, MCE and CA.

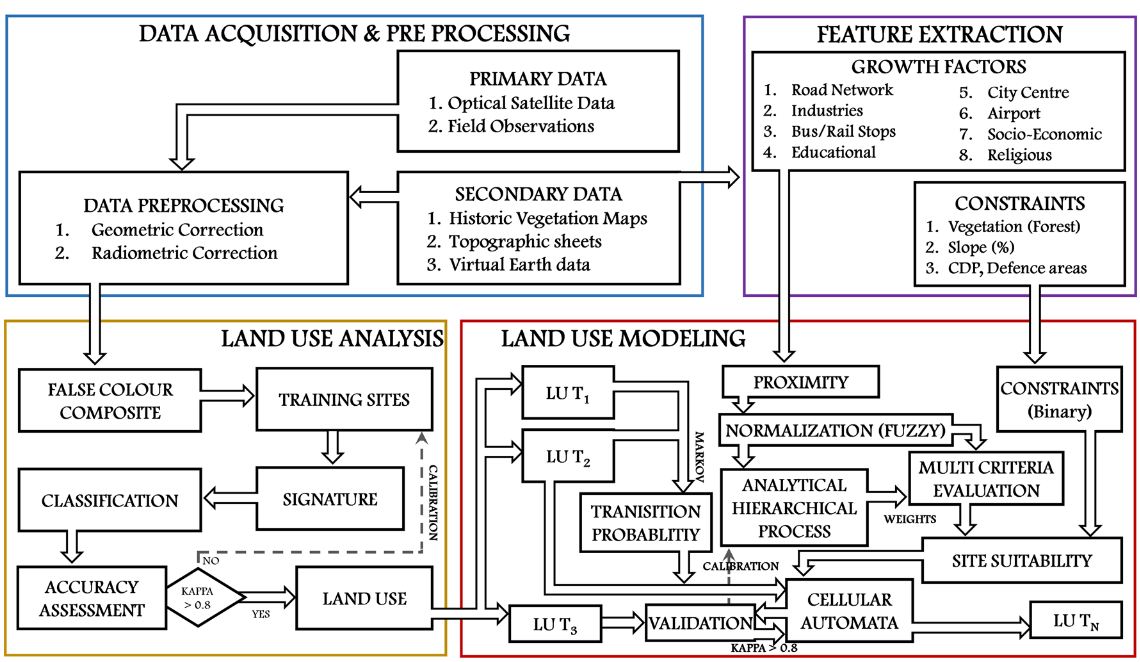

Fig. 2 Method for assessing landscape dynamics and visualisation of likely growth based on ABM

Table 1 Optical satellite data sources

Year	Mumbai Pune	Year	Chennai Mangalore
1997	Landsat Thematic Mapper (30 m)	1997	Landsat Thematic Mapper (30 m)
2003	Landsat Enhanced Thematic Mapper Plus (30 m)	2004	Landsat Thematic Mapper (30 m), Landsat Enhanced Thematic Mapper Plus (30 m)
2009	Landsat Thematic Mapper (30 m)	2009	Landsat Thematic Mapper (30 m), IRS LISS 3 (28.5 m)
2015	Landsat Optical Land Imager (30 m)	2014	Landsat Optical Land Imager (30 m)

Table 2 Land use classes and associated features

S. no.	Class	Features
1	Built up	Residential Area, Industrial Area, Paved surfaces, mixed pixels with built-up area
2	Water	Tanks, Lakes, Reservoirs, Drainages, Oceans, Water logged areas, etc.
3	Vegetation	Forest, Plantations, Horticulture, Current Sown farmlands, Grass lands with vegetation, etc.
4	Others	Quarry pits, Open areas, Unpaved roads, Current fallow farmlands, Bare lands, Wastelands, etc.

Fuzzy Logic helped in understanding the behaviour of agents, the Analytical Hierarchical Process (AHP) aided in assessing the role of each agent. This was combined with the already proven technique of Multi-Criteria Evaluation (MCE), Markov chains and Cellular Automata (CA) to model and visualize the urban growth. Agents that facilitate the urban growth process are roads, industries, educational institutions, bus stands, railway stations, metro, population, etc. Ecosystems (such as water bodies) that are to be conserved for the sustenance of natural resources are considered as constraints. Validation of the simulated growth was performed with the actual growth (2014/2015) through kappa indices, as a measure of agreement. Once these data and agents are trained and validated, data is used to model and simulate for future trends (10 years) with definite time steps.

Anthropogenic and topographic parameters were used to evaluate the probability of each pixel converting to urban in the study area using the fuzzy AHP method. AHP was computed as per Saaty 2011 [40]. The weight of the effective factors was estimated based on fuzzy AHP with the creation of 25 different judgment scenarios. Each scenario had six pairwise matrices (agents) including the development of sub-matrices (sub agents). Variables were developed similar to fuzzy triangular numbers and mean was considered based on fuzzy extent analysis [41] to get the weights of each agent that included fuzzy comparison and then fuzzy arithmetic mean, development of degree of possibility and developing priority vector. The consistency ratio (CR) was calculated to evaluate the accuracy of the derived weights.

Classified land uses were verified by comparing the predicted land use with the actual land uses. Suppose, 3 years y_0, y_1 and y_2 land uses are computed through supervised classifier, first, two land uses of y_0, and y_1 were used to train, calibrate and predict the land use for the year y_3. These predicted values were compared with the actual land use as per the classified information of y_3. The accuracy of prediction is assessed using Kappa statistics as a measure of agreement between predicted y_3 and actual y_3 (classified).

4 Results and discussions

Industrial corridors have been planned and promoted by the Government of India as effective instruments for achieving accelerated industrial growth by integrating industry and infrastructure with the available local resources based on cluster-based developmental path, to attain accelerated development and regional industry agglomeration. In this regard, the academia, government and industry collaboration would aid in the planned urbanisation with innovations.

NDVI [42] aided as prelude knowledge for LU analysis and field data collection. Details of land cover analysis are summarized in Table 3 and is presented in Fig. 3. Vegetation cover has declined during the last three decades from 40.55 to 23.99% in the Mumbai–Pune (MPI) corridor. Chennai–Bangalore–Mangalore (CBM) recorded a decrease from 44.08 to 37.29%.

Spatial patterns of land uses were analysed using remote sensing data through supervised classifier and are depicted

Table 3 Land cover statistics along the industrial corridors

Mumbai–Pune			Chennai–Mangalore		
Year	Vegetation (%)	Non vegetation (%)	Year	Vegetation (%)	Non vegetation (%)
1997	40.55	59.56	1997	44.08	55.91
2003	36.42	63.69	2004	41.52	58.45
2009	33.9	65.7	2009	40.39	59.63
2015	23.99	76.09	2014	37.29	62.65

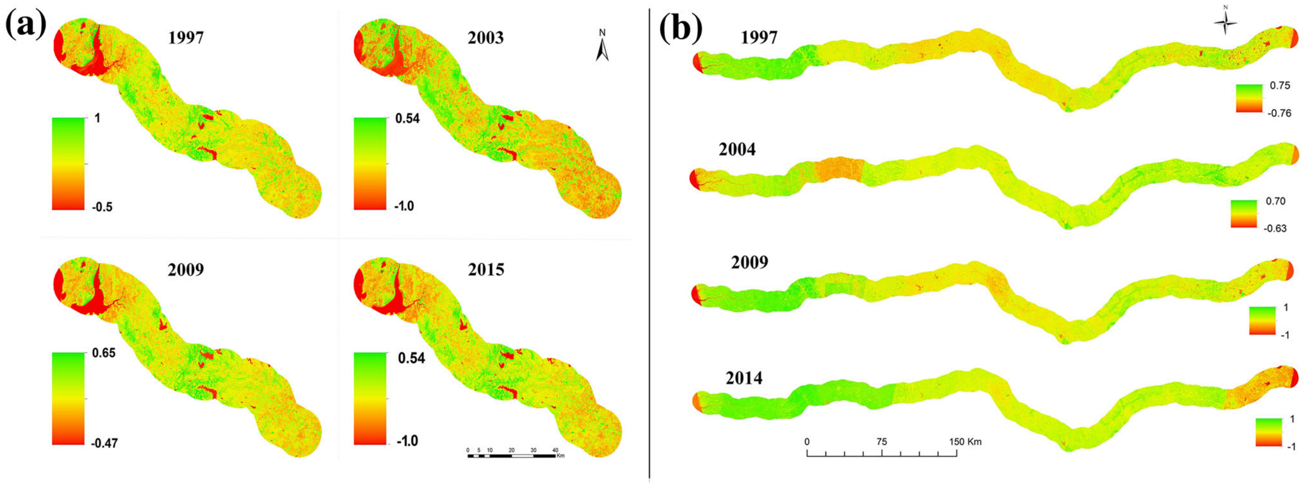

Fig. 3 Land Cover dynamics along the corridors. **a** MPI corridor, **b** CBMI corridor

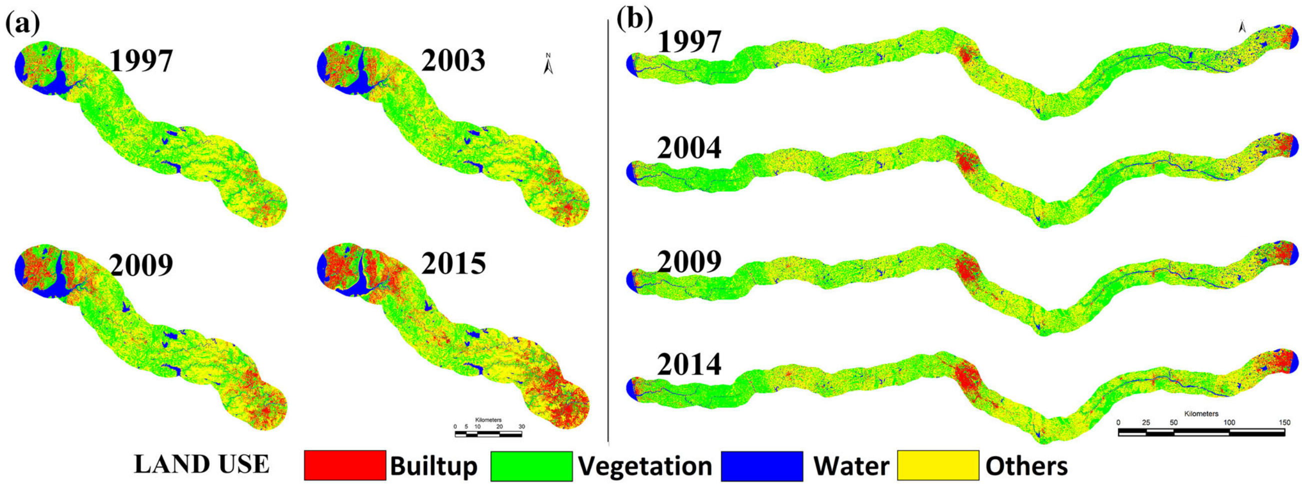

Fig. 4 Land use dynamics along the corridors. **a** MPI corridor, **b** CBMI corridor

in Fig. 4, which highlights that built-up area has increased by about four times during the past three decades in both corridors. Built-up area or paved surface has increased from 3.66% (in 1997) to 19.81% (in 2015) along MPI corridor, with the reduction in vegetation from 41.27 to 24.64% (Table 4). MPI corridor is located in one of the global biodiversity hotspots of India, which also witnessed severe erosion in vegetation cover with the opening up of the corridor for transportation in 2000. Land use analysis in MPI corridor shows that Mumbai, Navi-Mumbai, and Pune city regions are witnessing intense urbanization process with both outward and inward growth such as ribbon development, sprawling and infilling. Lonavala region located between these major cities has witnessed sprawl (from both cities) to form intense development.

Similarly, along the CBMI corridor, built-up area has increased from 2.27% (in 1997) to 8.54% (2014). Bangalore and Chennai area urbansising at higher stride

Table 4 Land use statistics along the corridor

Year	Water (%)	Vegetation (%)	Built up (%)	Others (%)
Mumbai–Pune Industrial corridor				
1997	7.30	41.27	3.66	47.77
2003	7.12	36.64	7.04	49.21
2009	7.77	32.33	11.47	48.42
2015	7.06	24.64	19.81	48.5
Chennai–Mangalore Industrial corridor				
1997	5.37	44.51	2.27	47.95
2004	4.62	44.03	4.07	47.41
2009	4.41	42.60	5.88	47.17
2014	3.64	40.89	8.54	47.05

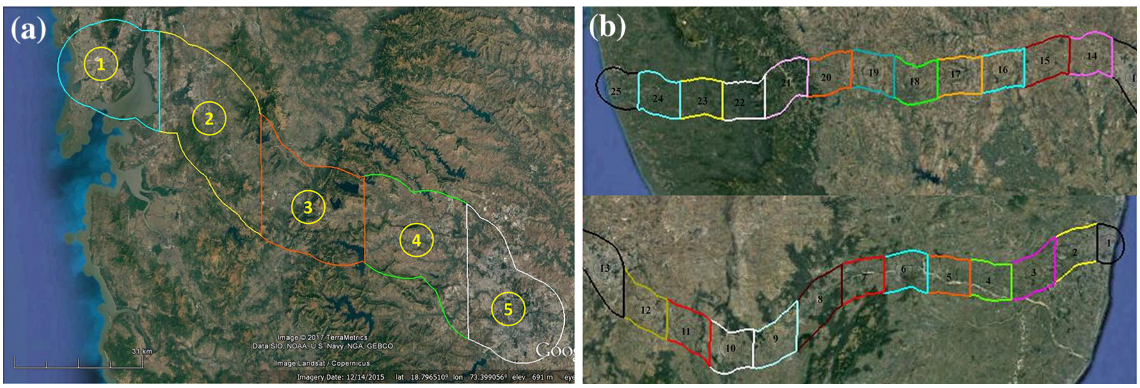

Fig. 5 Segments along the corridor. **a** MPI corridor, **b** CBMI corridor

compared to other cities/towns such as Mangalore, Vellore, Hosur, Kancheepuram, Kunigal, Hassan, etc. Water bodies in and around Bangalore and Chennai are also undergoing stress with the unplanned urbanisation.

Spatial patterns of landscape dynamics are assessed in each segment using landscape metrics for both the study regions. MPI corridor regions consists of five segments (Fig. 5a), while CBMI corridor region consists of 25 segments (Fig. 5b). Modelling was performed considering the neighborhood, constraints in the neighborhood and other factors.

Land use modelling was carried out using CA-Markov integrated with Fuzzy ABM framework. The behaviour of agents was captured through Fuzzy (similar to human thinking) with rule-bound and context-specific formulation of rules and the urbanisation data of the existing Mumbai Pune express highway (operational since 2002), that improved the connectivity while reducing fright time of goods and services. This has led to an escalation of industrial activities with job opportunities along the corridor closer to Mumbai and Pune cities. Population dynamics along the corridor between 2001 and 2011 indicated rampant growth at outskirts of Mumbai and Pune indicting high development in these regions. This highlights the role of the corridor in urbanisation with agents such as population followed by other agents of change (road networks, bus stops/railway stations, Schools and Other educational

Table 5 Markov transition probability "Mumbai Pune Industrial corridor" 2003–2009 to 2015

Year	Year	2015			
	Land use	Water	Vegetation	Built up	Others
2009	Water	0.85	0.05	0.05	0.05
	Vegetation	0.00	0.65	0.05	0.30
	Built up	0.05	0.05	0.85	0.05
	Others	0.00	0.00	0.28	0.72

Table 6 Markov transition probability "Chennai Mangalore Industrial corridor" 2004–2009 to 2014

Year	Year	2014			
	Land use	Water	Vegetation	Built up	Others
2009	Water	0.85	0.05	0.05	0.05
	Vegetation	0.00	0.646	0.023	0.331
	Built up	0.05	0.05	0.85	0.05
	Others	0.00	0.00	0.192	0.808

Table 7 Actual versus simulated land uses

	Water (%)	Vegetation (%)	Built-up (%)	Others (%)
Mumbai Pune Industrial corridor				
Actual 2015	8.18	24.63	19.7	47.45
Predicted 2015	8.18	24.59	21.2	46.01
Chennai Mangalore Industrial corridor				
Actual 2014	3.64	40.89	8.54	47.05
Predicted 2014	3.39	39.6	12.42	44.08

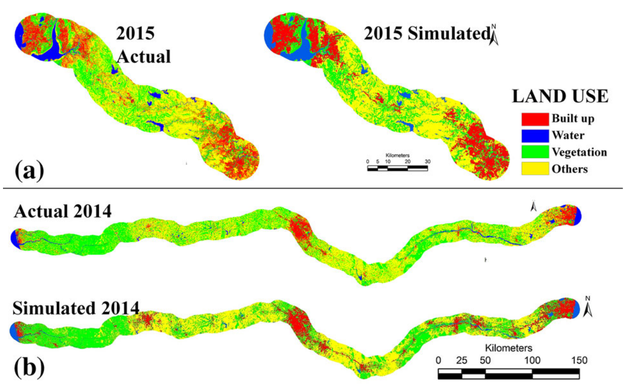

Fig. 6 Simulated land use versus actual land use. **a** MPI corridor, **b** CBMI corridor

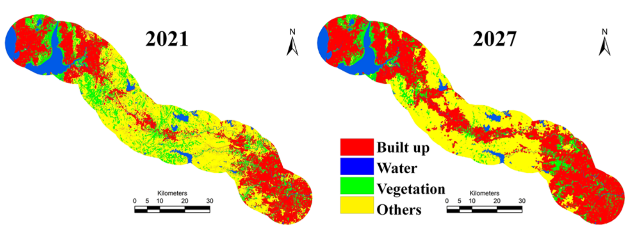

Fig. 7 Predicted land uses in MPI corridor for 2021, 2027

institutes, industries, Places Social-Cultural importance, distance to CBD, connectivity through airports etc.). This assists AHP in the numerical computation to achieve influential pattern around each agents and objective behavioral influences in each pattern. Fuzzy-AHP is used to include the effects of the agent-based influence on the land use. Markov chains are used to understand the change probability of each land use between t_1 and t_2. Markov transition probability matrix for Mumbai–Pune and Chennai Mangalore area as shown on Tables 5 and 6 respectively. CA-Markov is then used do the space–time

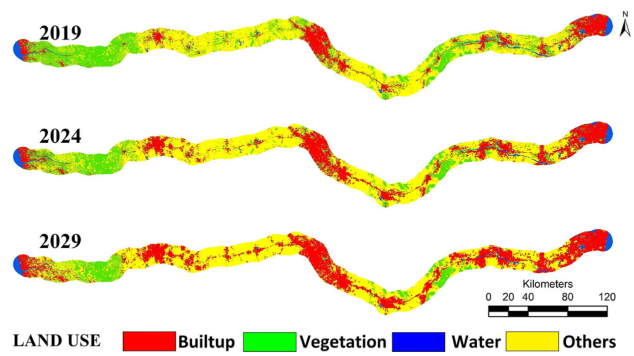

Fig. 8 Predicted land uses in CBMI corridor for 2019, 2024 and 2029

allocation with probability changes using defined rules and neighborhood criteria of each cell. The integration of agents to CA Markov is then used to simulate the likely changes in the two industrial corridors.

During 2009–2015, other land use category has a probability of 28% to change to built-up and vegetation has a probability of 30% to change to other land use category (Table 5) in MPI corridor.

Similarly, in CBMI corridor, during 2009 to 2014, other land use category has a probability of 19.2% to change to built-up whereas and vegetation has a probability of 33% to change to other land use category (Table 6).

Validation of the simulated land uses reveals of higher accuracies for CBMI (overall accuracy of 92.5%, kappa of 0.93) and for MPI (overall accuracy of 89.63%, kappa of 0.87). Simulated results of land uses are listed in Table 7 and are presented in Fig. 6a, b for MPI and CBMI respectively. As the accuracy of simulation was good, land uses for 2021 and 2027 are predicted with the constant time scale for MPI corridor, which are presented in Fig. 7 and details of the likely land uses are listed in Table 8. Urban growth along the corridor is predicted to increase from 19.81% (in 2015) to 47.12% (by 2027). Pune, Mumbai and

Table 8 Predicted land use 2021, 2027 Mumbai Pune Industrial corridor

Land use	Urban		Vegetation		Water		Others	
Year	Ha	%	Ha	%	Ha	%	Ha	%
2021	97,343	32.16	51,442	17.00	24,761	8.18	129,110	42.66
2027	142,621	47.12	33,593	11.10	24,761	8.18	101,680	33.60

Table 9 Predicted LU statistics Chennai Mangalore Industrial corridor

Land use	Water		Vegetation		Urban		Others	
Year	Ha	%	Ha	%	Ha	%	Ha	%
2019	50,643	3.7	382,628	28.2	237,929	17.5	687,119	50.6
2024	45,570	3.4	243,573	17.9	359,935	26.5	709,435	52.5
2029	41,659	3.1	14,390	10.6	480,692	35.4	692,209	51.0

Navi Mumbai would be saturated by 2021 and outward concentrated growth would continue. High urban growths can be observed in close proximity to industries along the corridor. Vegetation is expected to reduce from 24.6% (in 2015) to 11.1% (in 2027). Ambivali, Panvel, Chinchwali, Khopli, Dehu showed rampant growth which can be attributed to the connectivity and proximity of the corridor.

Similarly, land uses for 2019, 2024 and 2029 are predicted of CBMI corridor, which are presented in Fig. 8 and likely land uses statistics are listed in Table 9. Urban growth in CBMI region is predicted to increase from 8.54% (in 2014) to 35.4% (by 2029). Bangalore and Chennai cities would be saturated by 2024 and would witness concentrated growth in peri-urban regions. High urban growths can be observed in close proximity to industries and CBDs along the corridor namely Mangalore, Hassan, Kunigal, Vellore, Kancheepuram, Hosur. Vegetation is expected to reduce from 40.8% (in 2014) to 10.6% (in 2027).

5 Conclusion

Temporal land use analysis of Mumbai–Pune Industrial (MPI) corridor region reveals a steady urban growth of 3.38% along the corridor during 1997–2003, which accelerated to 8.34% during 2009–2015 with the implementation of PMI corridor. Spatial metrics confirm that the segments with core urban areas of Mumbai and Pune have concentrated growth between 1997 and 2015 and sprawl is being experienced to the outskirts of the metropolitan area. Prediction of likely changes indicates that the urban area would increase to 33.7% by 2021 and 47.1% by 2027.

Spatio-temporal land use analysis Chennai–Bangalore–Mangalore Industrial (CBMI) corridor reveals that urban area has increased from 2.27% (in 1997) to 8.54% (in 2014), with urban sprawl occurring near the vicinity of the existing urban areas and along the outskirts. Spatial patterns of urbanisation have been assessed using landscape metrics, which highlight that urban patches are becoming more dispersed along the corridor and compact concentrated growth is observed in Chennai and Bangalore and surroundings. The high rate of urban sprawl is observed in Chennai and Bangalore followed by Mangalore. Prediction result shows that urban area would be increased from 2.27% (in 1997) to 35.4% (in 2029). The spurt in the urbanisation process along the industrial corridors are due to the industries and improved infrastructure networks. The current trend of land use indicates that the natural vegetation cover, agriculture lands would be affected along the highways and surrounding of the CBD's. This necessitates evolving appropriate policy plans towards the prudent use of natural resources while providing livelihood to the local people.

The spatial patterns of landscape dynamics provide vital inputs to the regional decision makers to mitigate the environmental impacts with urbanisation due to the implementation of industrial corridor. This research is an outcome of the recommendations of stakeholder interactions between academia, government agencies and industry. Prediction and visualisation of spatial patterns of likely land use changes with the implementation of the industrial corridors, would aid in smart decision making to evolve appropriate planning strategies to provide basic amenities and adequate infrastructure with the mitigation of environmental degradation. Provision of basic amenities and smart infrastructure would boost the industrial growth while supporting the local livelihood and preservation of the local fragile ecology and environment. This entails Strategic Environmental Assessment (SEA) for each corridor by a reputed academic institution or the organization accredited by the Quality Council of India, implementation of environmental management plans (EMP) and environment monitoring with the regular auditing involving local engineering and technological institutions during the post project period.

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