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著者	Chandan Mysore Chandrashekar, Bharath H. Aithal
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Impact assessment of Corridor Oriented development

A case of urban agglomerations of India

Chandan Mysore Chandrashekar [1,2] and Bharath H. Aithal [1*]
1 RCG School of Infrastructure Design and Management, Indian Institute of Technology Kharagpur
2 *Department of Civil Engineering, The National Institute of Engineering, Mysore*
** Corresponding Author, Email: bharath@infra.iitkgp.ac.in*

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Abstract: Rapid urbanisation has been a factor affecting cities negatively and irreversibly in developing countries like India, adversely leading to depleting natural resources and promoting unbalanced and uneven urbanism. To handle the influx of population into core urban regions and to promote holistic, sustainable development, government and planning agencies are now looking upon regional development. Developing countries like India has laid plans for future urban corridor-oriented development. This study aims to understand the urban growth of two major developing cities influenced by transport corridor through a methodological approach using multi-temporal satellite data and its position in India's network of cities. Land use analysis was validated with the aid of measures such as overall accuracy and kappa statistics, with good values of more than 85% and 0.75 respectively were achieved. The hierarchical network analysis indicated five different clusters based on the urban growth rate. Among these clusters, Bangalore, Ahmedabad and Pune cluster was further shortlisted for analysis based on the urban transport corridor affecting the growth of these cities. Cellular automata-based SLEUTH model was adopted in this work to carefully observe sub-division level details of the region under the influence of the corridor. Exhaustive calibration, with three phases of coarse, fine and final, validation procedure along with statistical fit measures reveal urban expansion for Ahmedabad region has witnessed an increase from 497.50 km^2 (2017) to 826.24 km^2 (2025) while Pune region has experienced tremendous urban area transformation of 901.11 km^2 in the year 2025 against 497.27 km^2 in 2017. Results of this analysis would help policymakers and planners to inculcate decisions concerning future urban trends accommodating safer, healthier, sustainable and liveable urban ecosystem.

1. INTRODUCTION

1.1 General understanding of Urban growth and corridors

Urban areas can no longer be considered as monocentric economic-based core regions. On the other hand, development is treated to occur holistically en-route two urban centers, including their suburban areas or transitional areas. Aerial visualisation of such cities reveals continuous paved surface patches. Classical concepts of urban expansion, for instance, urban sprawl is defined based on physical parameters such as sparsely distributed settlements, that were previously monocentric and eventually got converted into dispersed or scattered development on fringes of a city.

Urban sprawl can be classified into three significant categories: Low-density sprawl, Ribbon development and Leapfrog sprawl (Harvey & Clark, 1971; Taubenbock et al., 2009a). On the contrary, modern concepts of urban expansion, for example, Functional urban region, Megacity, Megalopolis, Megapolitan, Megaregion and Urban corridors (Catalan et al., 2008; Fang & Yu, 2017; Georg et al., 2018; Piacentini & Rosina, 2012) have common traits of extended limits of city growth beyond its administrative boundaries forming gigantic regions around the core city. By definition, an urban corridor is developed with several polycentric city clusters linked with transport routes (Georg et al., 2016b; Li and Cao, 2005). The idea of urban corridors is also associated with economic growth as the central idea to improve national and international trade. Policymakers have always focused on concepts such as satellite towns and connected cities to plan an efficient utilisation of exiting resource and to decongest the core regions. Literature suggests the idea of the urban corridor is still a trending research area and there exists no clear definition of corridors (Florida, 2006; Li & Cao, 2005; Priemus & Zonneveld, 2003; Whebell, 1969). Across the globe, three prominent urban special interest corridors have already emerged: (i) BOSWASH in the United States of America, starting from Boston, New York, Philadelphia, Baltimore and Washington; (ii) Blue Banana in Europe, from North Wales, London, Rhineland, Alsace, Switzerland and Northern part of Italy encompassing a population of approximately 110 million (Hospers, 2003) and (iii) BESETO or Beijing-Seoul-Tokyo urban corridor in east Asia (Choe, 1998; Keiner et al., 2016). However, Urban corridors are directly dependent on connecting cities and its global position in a network of cities, based on various factors influencing changes in urban land use. Analysis of intercity networks has drawn sufficient interest in the research community to portray world cities as nodal points facilitating and controlling the global economy. New York, Tokyo, London, Hong Kong, Paris, Beijing are among the top cities in a hierarchy that have been identified as dominant nodes in commanding World capital economy (Choi, Barnett, & Chon, 2006; Sassen, 2000; Wei & Yu, 2006)

1.2 City network analysis: Position of a city in the global economic system and its influence on emerging land-use dynamics

The world has seen tremendous change during the last five decades in terms of city development. Cities rely on economy and population. Post globalisation researchers have tried to address the role of cities, ties with other cities, and the position of a city in the international system (Taylor, et al., 2006). Authors argue that globalisation has lead to a divide between developed countries and underdeveloped countries, giving rise to world cities or global cities (Alderson & Beckfield, 2004; Friedmann, 1986; Sassen, 1994). These cities command or dominate over other metropolitan regions in a system controlled by the economy. To better recognise the role of a city in a system, it is necessary to understand its relations and patterns with other cities.

A social network is one such analysis which includes a set of nodes (or cities) tied to one-another with multiple relationships (Wasserman & Faust, 1994). It essentially comprises identification of nodes or actors, relationships and interaction between nodes - indicated using edges or connector or ties. Remarkable research in the field of city network analysis, often called as "World city network" has been carried out by numerous investigators to identify a city's importance in the context of globalisation, its position and role in the world economy (Beaverstock et al., 2000; Choi et al., 2006; Hennemann and Derudder, 2014; Hennemann et al., 2015). City growth in India is associated directly with the economic policy at both state and central level. With opening up of global markets, implementation of foreign direct investment (FDI), schemes boosting agriculture, engineering, infrastructure and industry sectors such as digital India, make in India, dedicated freight corridors and industrial corridor (Mukhopadhaya, 2017; Paul & Mas, 2016) have picked up pace in the last decade. This has led the country to attain top rank positions in ease of doing business index (63rd rank as of May 2019), global competitiveness index stabilising the economy and thus projecting Indian cities as potential world cities (World Bank, 2020).

1.3 Urban corridors in India

The concept of urban corridors in the Indian context has emerged since the last decade with the central aim to connect megacities along with industrial hubs and major ports across the nation. Most important Indian urban corridors include Delhi National Capital Region (NCR), Delhi Mumbai Industrial Corridor (DMIC), Mumbai–Pune Infrastructure Corridor, Chennai–Bangalore–Mumbai Industrial Corridor (CBMIC), Bangalore–Mysore Infrastructure Corridor (BMIC), defunct and currently being updated as Bangalore – Mysore expressway or NH275, monitored by National Highway Authority of India (NHAI), Mumbai– Jalgaon, Hyderabad–Vijayawada (Georg et al., 2016a). Of these, DMIC is of particular interest since it connects country's capital (Delhi) with financial capital (Mumbai) of India, with a total dedicated length of over 1483 km (Jain et al., 2014) and later dedicated freight corridor (DFC) was formulated, Ministry of Commerce and Industries took no time to realise the importance of DMIC, in alignment with DFC to improve regional economic development. The DMIC region extends over seven Indian states and two union territories. Important cities falling under the influence of DMIC includes Delhi, Ahmedabad, Vadodara and Mumbai (*Figure 1*). Reason for choosing these particular areas is because these areas have excellent connectivity to major ports, national highway, railway routes, several existing and proposed investment zones (Pangotra & Shukla, 2012). Development strategy of DMIC regions consists of manufacturing, industrial areas, special economic zones (SEZ), agriculture products and processing zone, port development, skill development cities, logistic park, augmentation of airports, IT hubs, feeder routes (both road and rail) etc. totalling investment of 90 Billion US dollars with huge scope of land development over several thousand hectares (DMICDC Ltd, 2009).

Therefore, DMIC has a direct impact on transportation, freight movement in significant states of India and hence an impact on surrounding land-use changes. Projects like DMIC often face criticism with respect to topics such as sustainability and resource consumption. While the project is committed to low carbon development, unaddressed challenges, for instance, balancing available natural resources with present and future demand, water scarcity, pollution levels and health quality residing near corridors, impacts on local and therefore global climate change etc. needs to be assessed. Government of

India (GOI) is further planning (by 2030) to achieve universal access of reliable energy services that are modernised, expand amenities through infrastructure development and upgrade technology for the supply of sustainable energy, building resilient infrastructure to improve the integrated human settlement, rural-urban transport and therefore promote the economy. GOI has reported these goals to United Nations distinguished political meeting on sustainable development emphasising the implementation of SDG's (Voluntary National Review Report GOI, 2017). Therefore, predicting urban growth for the year 2025 helps in formulating comprehensive strategies and policy revisions in combating rapid growth to achieve harmony between development and surrounding natural ecosystem.

1.4 Role of satellite data and models in assessing city dynamics

Area serving under various national level projects of cities is vast. Conventional mapping, monitoring, and quantifying changes prove tedious. Remotely sensed data along with Geographical Information Systems (GIS) had played a significant role in identifying historical land-use change and prediction of future development (Bharath et al., 2018; Nimish et al., 2017; Schneider et al., 2003; Seto et al., 2000). It is evident from the literature that rapid urban expansion can have a substantial effect on the environment both at local and global scales (Cui, Ren, & Sun, 2015; Grimm et al., 2008; Patra et al., 2018; Ramachandra, Aithal, & Beas, 2014; Tan et al., 2005). Urban researchers have studied various modelling techniques to estimate future urban growth, policy implementations and planning aspects to combat adverse effects on the environment. These techniques include cellular automata (CA) models (Sante et al., 2010), agent-based models (QuanLi et al., 2015), artificial neural network models (Yatoo et al., 2020), fuzzy and analytical hierarchical process (AHP) based model (Parry et al., 2018), and SLEUTH-UGM (Bharath et al., 2019; Chaudhuri and Clarke, 2019; Jafarnezhad et al., 2016; Wu et al., 2009). To predict land change, the preliminary step is to acknowledge the status of Spatio-temporal dynamics. s

While CA can capture and control the spatial dynamics aspects, Markov chain integrated with CA controls temporal dynamics of a region. However, SLEUTH has the capability of considering the spatial and temporal characteristics of urban expansion to predict urban growth. The SLEUTH model runs on C language with a standard GNU C compiler (GCC). (Chandan, Nimish, & Bharath, 2019; Rafiee et al., 2009). Building blocks of the model consists of a Moore neighbourhood lattice of identical cells, with urban (1) and any other category (0) cell states, and parameters such as diffusion, road gravity, slope resistance, breed and spread governing the nature of urban expansion (Silva & Clarke, 2005). Several studies in the Indian context have been conducted individually on cities (Taubenbock et al., 2009b). However, in this paper, we present a novel approach to identify the city's dominance and role-based on its ranking using network analysis. This paper aims to (a) Understand city's relative position in the hierarchy through network analysis, (b) Understand the changes in land use influenced by an urban corridor in two major cities, (c) Analyse multi-temporal patterns of urban growth, (d) Model urban region of influence for two major metropolis of India using SLEUTH.

Further, research questions of this paper are formulated as Among emerging Indian cities, in which position does a city stand with reference to several urban growth-related factors? How the positions of cities are placed, and its positions in hierarchical order? Which cluster of cities needs immediate attention based on present corridor status or planning scenario? What are the critical and effective measures to be considered to address near-future sustainable urban growth aspects of these clustered cities?

2. STUDY AREA SELECTION

Literature suggests a city can grow and attain the status of the urban field, metropolitan area, conurbation, megacity or megalopolis, depending upon the size, shape, housing population, extent, to name a few. These transformations can be visualised and modelled by understanding the present urban extents. Keeping the above factor intact, two urban agglomerations, Ahmedabad and Pune, falling under the influence of proposed DMIC corridor and Mumbai - Pune expressway were chosen for analysis. The study has been carried out by considering administrative boundaries with 10 km buffer around the city to understand urban dynamics in future (*Figure 1*). A rural area comprising of small towns and villages showcase extremely vulnerable trend to undergo rapid urban transformation (Antrop & Van Eetvelde, 2000), especially in case of DMIC region, the rapid land-use transition is expected due to substantial investments on industries and economic zones. Therefore, consideration of 10 km buffer is justified to account for spatial changes occurring in these hinterlands or peri-urban areas and visualisation of these regions in the next decade.

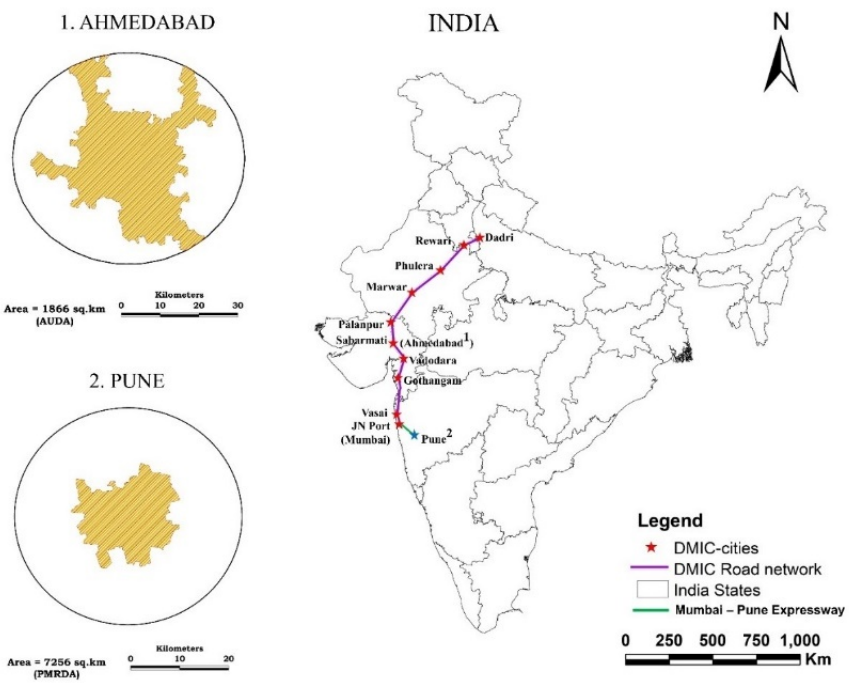

Figure 1. Location map of urban agglomerations along DMIC. Land use analysis of Pune and Ahmedabad have been considered in this analysis

Ahmedabad lies on the bank of river Sabarmati in the northern part of Gujarat state at an elevation of 53 m above MSL. The city is one among the largest metropolitan cities of India with a national ranking of seventh, and a population of 6.3 million in 2011 in comparison with 4.5 million during 2001 (Census of India, 2011). Majorly dominated by Textile Industry, it is the financial and economic hub of Gujarat, and often is referred to the "Manchester of India". In 2010, Gujarat had a GDP of 160 billion USD as a result of substantial growth of the city's economy. The last two decades saw the city attracting many foreign investments making Gujarat one of the few economically developed Indian states. Ahmedabad Municipal Corporation controls the administration of Ahmedabad whereas Ahmedabad Urban Development Authority (AUDA) monitors development in the periphery. Dholera-Ahmedabad investment region is envisioned in the DMIC master plan with an intent to transform Dholera into a prominent industrial cum residential hub. Gujrat state has an area of total 196024 km^2 of which 120706 km^2 falls under DMIC influence area, that is approximately 62% of the state will be subjected to rapid infrastructure growth in the next decade.

Pune, popularly recognised as "Queen of Deccan" is located in Maharashtra, in South-East direction to the capital city of Mumbai on the Western part of the state. The city lies close to Mula-Mutha River confluence at the height of 560 m above MSL. The Pune Mahanagar Palika (PMP) governs an area of 243.84 km^2, is the controlling authority of administration and economic development of the city, whereas regional development is in the hands of Pune metropolitan region development authority (PMRDA) with a total area of 7256 km^2. Pune is emerging as a prominent place for IT hubs and manufacturing industries.

3. METHOD

An integrated method of network analysis, pre-processing, land use analysis and modelling adopted to assess impacts on land use is depicted in *Figure 2*. Dataset for the network analysis was collected during the year 2016-17 (except population) and included a binary matrix of 10 x 10 comprising of socio-economic, industrial and urban growth aspects. For base land use map generation, Landsat series satellite images were obtained from from USGS GloVis database during the time frame 1990-2017 for study regions. Pre-processing of data involved geo-rectification and geo-registration of satellite data using GPS point data. Further, roads, excluded areas from future urbanisation, buffer and city administrative boundaries were digitised using survey of India (SOI) Toposheets, Google earth and city development plans. Layers required for SLEUTH model, its source and description are listed in section 3.4.

3.1 Network Analysis

Network analysis aims to identify structures in systems with respect to important nodes, its relations and influence among other components and ranking in the entire form.

To answer research questions related to a city's position in the network, we employ the concept of centrality. It is one such measurement technique used under three different ideas: degree, closeness and betweenness. To recognise the difference among these centrality measures, we consider an example of two networks in the shape of a star and circle, as illustrated in *Figure 3* involving an exchange of petroleum between cities. Here, nodes refer to cities that is from A to G; ties refer to the relationship within cities. After probing the star network, we can infer that city A is regarded as the most affirmative spot compared with all other cities. Meanwhile, in the case of a circular structure, it is evident that all cities are equally convenient or inconvenient. Freeman explains why city A has a more significant advantage in star network using centrality measures (Freeman, 1978).

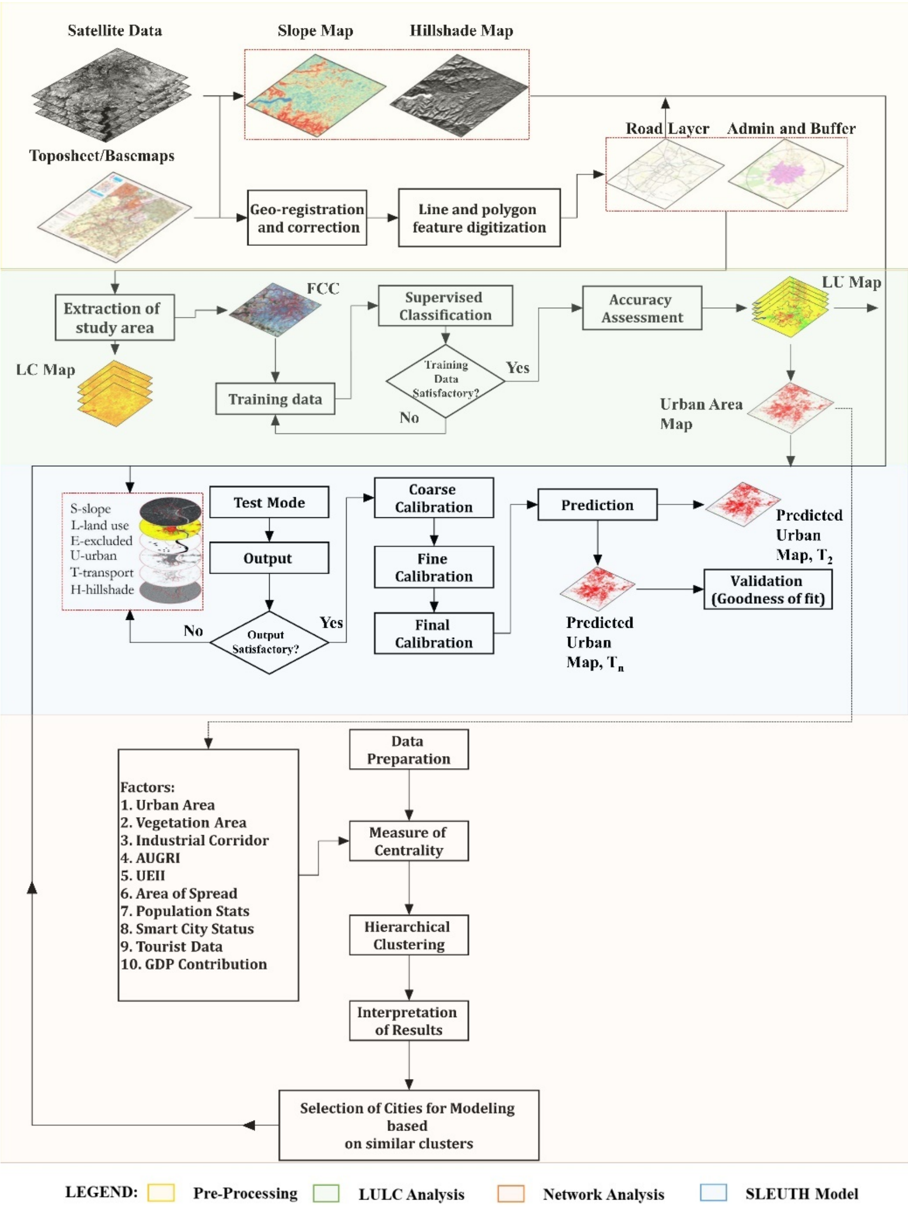

Figure 2. Integrated approach to assess impacts on land use, network analysis and modelling

Degree centrality: Degree indicates the connectivity of nodes and its position in the entire network. City A in star network has more advantage over other cities since it is more active and has other alternatives. For instance, if city D refuses to provide petroleum to A, alternatively A can rely upon E, F, G, and so on. Meanwhile, on the contrary, cities other than A are isolated, and if they want to trade, it has to be through A, making it more powerful. In the case of a circular network, all cities are connected in a particular direction, and therefore, they have an equal chance of advantages or disadvantages. Degree centrality has two broad categories: a) Outdegree (ties sent from a node to another) b) Indegree (ties received from other nodes).

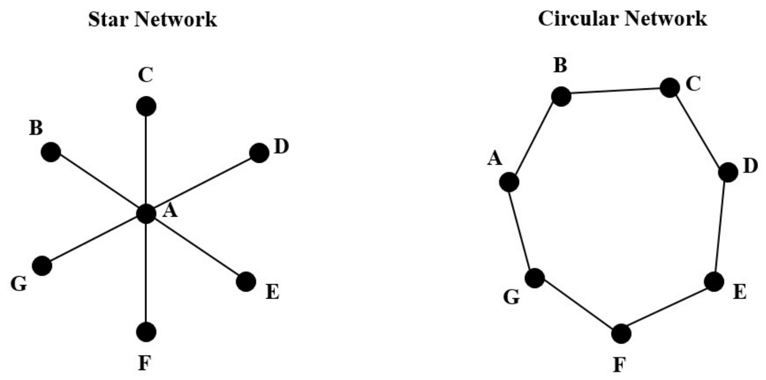

Figure 3. Examples of the network to define centrality measures (Modified from Alderson, Beckfield, & Sprague-Jones, 2010)

Closeness centrality: Closeness gives the shortest geodetic path between two nodes, and it also indicates the node's potential to impact various elements within the network. In the above example, city A has more advantage since it is closer to more cities than others. Network closeness is measured as:

$$\text{Closeness} = \frac{\sum_{i=1}^{n}(\text{Cmax} - \text{c (vi)})}{Mpc} \quad (1)$$

Where, C_{max} represents maximum closeness centrality, $v_1 \ldots. v_n$ represents vertices of a given network, $c(v_i)$ represents closeness centrality of vertex v_i and Mpc represents maximum closeness value possible.

Betweenness centrality: Calculates the betweenness and normalised betweenness centrality of each vertex and gives the overall network betweenness centralisation. It also signifies vertices which have a high possibility of appearing on a randomly selected shortest path between two vertices. Betweenness centrality is expressed as:

$$\text{Betweenness} = \frac{\sum_{i=1}^{n}(\text{Bmax} - \text{b (vi)})}{Mpb} \quad (2)$$

Where, B_{max} represents maximum betweenness centrality, $v_1 \ldots. v_n$ represents vertices of a given network, $b(v_i)$ represents betweenness centrality of vertex v_i and Mpb represents maximum betweenness value possible. City A in star network is much better than any other cities in terms of betweenness since it acts as a connecting agent between any other cities to trade.

Eigenvector centrality: Includes calculation of the eigenvector of the largest positive eigenvalue as a measure of centrality.

To address which emerging city in India can be considered for investigation in terms of corridor oriented urban growth, it is necessary to primarily rank cities with the aid of above network centrality measures. Further, to examine the city's relative position in the hierarchy, clustering analysis was performed along with the help of dendrogram to represent the relationship among similar cities. The process is essentially a bottom-up approach shows step by step pairing of existing sub-clusters and finally to obtain a single merged cluster at the top of the dendrogram. In a dendrogram, individual branches are labelled as clade, terminal node is labelled as leaf. Horizontal distance between individual branch signifies distance between clades. The decision of merging two clusters depends upon the closeness, and it can be calculated using distance measuring algorithms such as Euclidean distance, Manhattan distance, Mahalanobis distance etc. (Noiva et al., 2016).

3.1.1 Network construction and calculation

To categorise network of cities into a group of similar cities and thereby assessing potential city in terms of urban growth and corridor-oriented development, a network analysis was carried out for ten major cities of India. The network was constructed using nodes (n = 10) and vertices. Here, ten cities considered for the analysis were treated as nodes and ten factors were chosen based on expert opinion were selected as vertices. Network density was calculated to measure how well the network is connected (Wasserman & Faust, 1994). Network construction was based on binary data to describe ties among network members. In a binary data, 0 indicates no tie and 1 indicates existing tie. Therefore, network density is expressed as the ratio of existing ties in the network to a total number of possible ties. Overall network analysis and its visualisation were performed using UCINET 6.668 software (Borgatti, Everett, & Freeman, 2002). Obtained network with nodes, vertices and ties between these was later modified considering ten cities as a background map. Factors considered for preparation of 10 x 10 binary matrix was: Urban area greater than 20% of the total area of administrative/buffer boundary of a city; Vegetation area less than 10% of the total area; Presence of industrial corridor within the city or anywhere in the buffer of 50 km; Annual urban growth rate index (AUGRI) greater than 5%; Urban expansion intensity index (UEII) more than 1; Area of spread greater than 1000 km^2; Population residing within the administrative boundary greater than 8 million; Smart city status as per Government of India's smart city programme; Number of tourists arriving annually greater than 2.5 million; Gross Domestic Product contributed by city greater than \$100 billion. Based on the above dataset, a measure of centrality analysis and hierarchical clustering or dendrogram analysis were performed.

3.2 Land use classification

Land use maps derived from satellite data serves as base layers and helps in the visualisation of urban pockets. Training polygon belonging to heterogeneous patches were created on false colour composite (FCC) with ground truth points collected using GPS during the field survey and Google earth was used as ancillary data wherever data collection was restricted either due to topographical hindrance or privacy and security policies. Land use categories considered for the study included urban, vegetation, water, others and corresponding training polygons were delineated such that they were uniformly allocated throughout the observed region. A supervised technique named maximum likelihood classifier was employed to perform land use classification based on Gaussian distribution function.

3.3 Land use validation

Verification of a land use map was performed by generating a confusion matrix using reference points of known land cover types. Kappa statistic (Cohen, 1960) and overall accuracy (producer's and users) were assessed statistically to ensure classifier satisfactory performance, land use map fitness for further modelling purpose.

$$\text{Kappa coefficient} = \frac{observed\ accuracy - chance\ agreement}{1 - chance\ agreement} \quad (3)$$

$$\text{Overall accuracy} = \frac{Sum\ of\ correctly\ classified\ pixels}{Total\ number\ of\ reference\ pixels} \quad (4)$$

Overall accuracy provides statistical accuracy only based on diagonal elements in an error matrix and do not consider omission and commission errors. However, Kappa statistic considers the entire matrix to indicate the accuracy of analysis performed (Lillesand et al., 2015).

3.4 Future land-use transitions and estimation

Input layers used for SLEUTH model such as slope and hillshade maps (raster) were obtained from digital elevation model (DEM); land use and urban maps (raster) were classified as explained in section 3.2.; Excluded map or a restricted layer was obtained from city development plan (CDP, originally vector, converted to raster) Transportation layer or road layer was digitised from open street maps, Bhuvan and Google earth virtual repositories (originally vector, converted to raster).

The aforementioned layers were compiled according to the specifications provided by Dietzel & Clarke (2004). Layers were exported greyscale images with various spatial resolutions: 120m for coarse phase, 60m for fine phase and 30m for full phase calibration (Chandan et al., 2019). Obtained layers were named according to specified format to ensure data compatibility during the model calibration process.

Details of SLEUTH workflow is illustrated in *Figure 2*. 30m data was used for test phase. Coefficient values will be set as default to test the data compatibility with the model. Monte Carlo (MC) iterations are fixed to 4, and the test phase is run. Calibration phase entails several iterations to slender down the variety of most favourable and top of the line coefficient values required to match the expected city growth. During coarse calibration, coefficient values for all factors can be explored over the entire dynamic range of 0-100 at a time step of 25. This wide range (25 units) needs to be filtered further for achieving better results. Fine calibration phase involves coefficient values being explored within a fixed range such as 0-25; 25-50; 50-75 or 75-100 at a time step of 5. The final calibration mode has a full-size resolution. Based on the goodness of fit statistic, five unique coefficient values shall be picked, and correspondingly the scenario file will be modified to simulate urban expansion.

4. RESULT

4.1 Network analysis

The network was constructed using cities as nodes and ties between cities and factors (n = 20), as illustrated in *Figure 4*. The cities were marked with red dots and elements marked in blue squares for easy identification. Ties between cities and corresponding factors were labelled using light grey colour; the arrows specify the direction of a connection between city and factor. Relationship of a city with the factor was decided with respect to number of ties. For instance, Bangalore city has link with 9 out of 10 factors, similarly tier two city Ahmedabad has link with 4 factors. In the obtained network, 10 cities share 43 ties/linkages with factors of a possible 380 linkages. This resulted in a network density of 0.1131 or 11.31% of all possible ties are represented. Of the total ten cities, three were considered to be Megacities, with a population greater than 10 million, they were Delhi UA, Kolkata UA and Mumbai UA. Remaining seven were Metropolitan/tier two cities, namely Ahmedabad, Bangalore, Bhopal, Chennai, Coimbatore, Hyderabad and Pune. Each city's centrality score, i.e., degree, closeness, betweenness and Eigen vector centrality, were calculated separately to establish the position of the city in the whole network in terms of various factors considered.

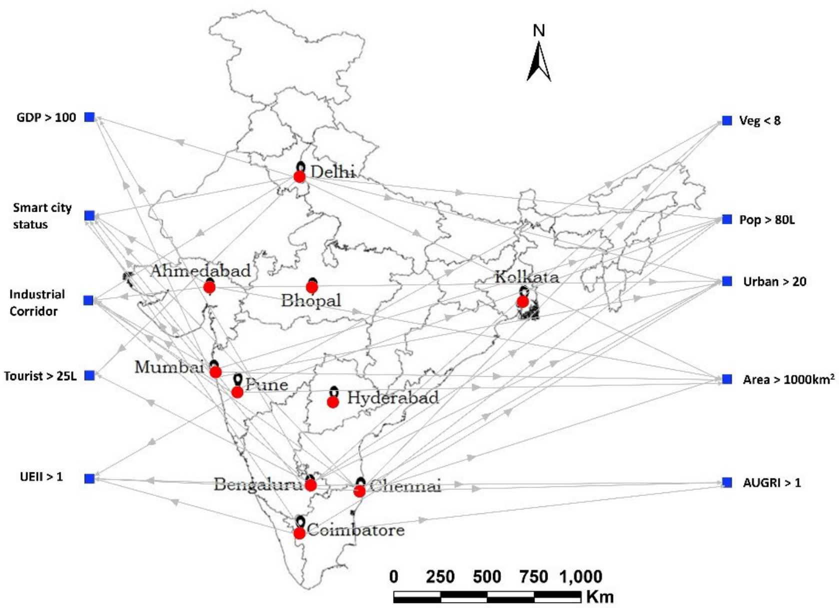

Figure 4. Network analysis depicting major Indian cities

Major Indian metropolitan and tier two cities were ranked based on centrality measures. *Table 1* presents basic score numbers. Mumbai and Delhi have consistently stood in the top ranks of all the centrality measures indicating stability. Other major metro cities like Chennai, Kolkata, Bangalore and Hyderabad hovers between rank 3 to 6 indicating its importance in the network of cities. Tier two or upcoming metro cities such as Ahmedabad, Pune, Bhopal and Coimbatore and their corresponding centrality score suggests they are not only close to top metropolitan city score, but also have a potential to overtake these cities shortly. In terms of degree and closeness centrality, it is very important to note that Bangalore has obtained rank 4, Ahmedabad with rank 7 and Pune with rank 8 suggesting its excellent network and has direct ties with other cities. After evaluation based on national city network, this study focuses on Ahmedabad and Pune considering these as the potential to emerge and most favourable metropolitan cities of India.

Table 1. Centrality scores for top 10 cities of India

Rank	nDegree	nCloseness	nBetweenness	Eigen vector
1	0.778 (Mum)	90 (Mum)	9.25 (Mum)	0.4 (Chn)
2	0.744 (Del)	86 (Del)	9.23 (Del)	0.359 (Del)
3	0.726 (Chn)	81 (Chn)	7.96 (Hyd)	0.357 (Blr)
4	0.71 (Blr)	78 (Blr)	7.87 (Chn)	0.332 (Hyd)
5	0.702 (Kol)	76 (Kol)	7.5 (Kol)	0.327 (Mum)
6	0.681 (Hyd)	75 (Hyd)	6.36 (Pun)	0.32 (Kol)
7	0.622 (Ahm)	74 (Ahm)	6.3 (Blr)	0.317 (Ahm)
8	0.551 (Pun)	68 (Pun)	5.9 (Ahm)	0.291 (Bho)
9	0.501 (Bho)	66 (Bho)	5.22 (Bho)	0.289 (Pun)
10	0.486 (Com)	65 (Com)	2.52 (Com)	0.247 (Com)

City City (CODE): Ahmedabad (AHM), Bangalore (BLR), Bhopal (BHO), Chennai (CHN), Coimbatore (COM), Delhi (DEL), Hyderabad (HYD), Kolkata (KOL), Mumbai (MUM), Pune (PUN).

Figure 5 shows the hierarchical cluster analysis performed for Indian cities. Cities are coloured based on cluster types. Clearly, there are no isolated groups. This suggests inter-relationship between cities has been well established considering transport, social and economic factors. Two nearest clusters are merged into the same cluster in the next level (on distance axis), merging continues until there is only one cluster left in the hierarchy. The distance at which two clusters are merged designates the distance between two clusters in data space. Shorter the bracket, stronger the relationship between cities. However, there are four different clusters, indicated in different colours in *Figure 5*, were based on city's position: Mumbai, Delhi and Kolkata (strong network) forms a cluster, Chennai and Hyderabad stands alone, Bangalore, Ahmedabad and Pune (strong network) forms another cluster followed by Bhopal and Coimbatore cluster. These clusters show the strongest bond between cities based on various factors, as discussed in section 3.1. Among the Bangalore, Ahmedabad and Pune cluster, we further shortlisted two cities for analysis based on the urban transport corridor affecting growth of these cities. Ahmedabad and Pune are directly influenced by Delhi Mumbai Industrial Corridor and Mumbai–Pune Infrastructure Corridor. However, Bangalore is influenced by Chennai–Bangalore–Mumbai Industrial Corridor only. Pune is such a city that is affected by all of these three-corridor development and Ahmedabad can be treated as the city with highest influence from DMIC and industry-oriented progressive plans, hence reason for selecting Pune and Ahmedabad city for further modelling is justified.

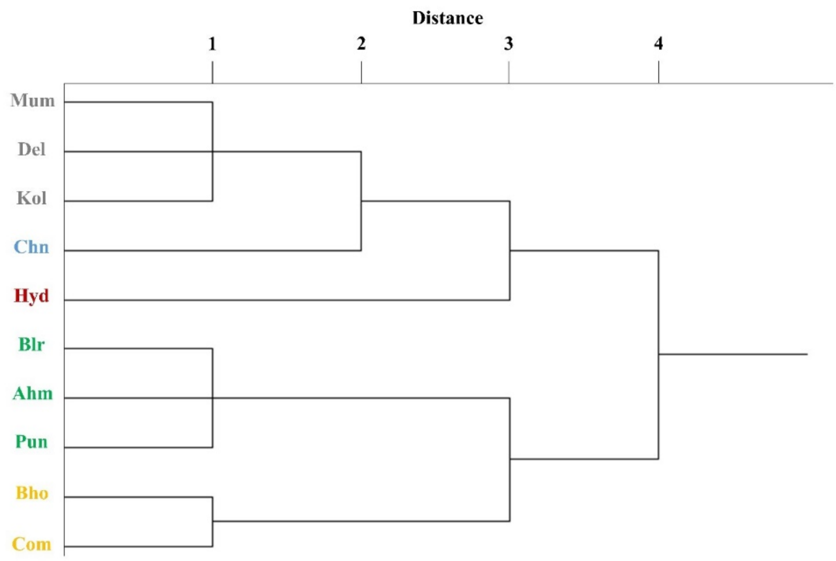

Figure 5. Dendrogram for the hierarchical clustering of cities

4.2 Land use classification

Ahmedabad - Significant change in the built-up area, as well as vegetation, has been observed from 1990 to 2017. Urban settlements have been increased from 7.03% to 21.36% while vegetation category has recorded continuous dip from 36.63% in 1990 to 19.74%. Rapid transition is apparent during 1990-2010 in areas such as Gandhinagar, Chandlodia, Makarba, Odhav etc. mainly due to housing and industrial policy revision. It is also evident from the results that other land-use classes such as barren area, open fields, agricultural fields have also lost and converted to built-up surface over the years. Water category, including open water body, river, lake etc. has also recorded a drop to a mere 0.72% in 2017, sends out an alarming message to conserve water for the sustainable urban ecosystem. Land use statistics are depicted in *Table 2* and visualisation in *Figure 6*.

Pune- *Table 3* gives the statistical results of land-use change for Pune region. Comparison of land use from the year 1992 to the year 2017 indicates rise in the urban area of over 366% in just two and a half decades. This rapid change is attributed mainly due to the expansion of information technology sector, particularly "Info-Tech park" in Hinjewadi and other areas like Pimpri-Chinchwad, Talawade, Kharadi and Hadapsar regions having special economic, industrial zone status. Companies like Infosys, Wipro, Patni, IBM etc. have chosen Pune as their business administration headquarter, gives a new name to the region as "IT city" attracting a large number of migrants from surrounding cities. It is observed that vegetation has decreased to 8.34% from 23.85% within seven years, mainly due to the loss of agricultural land and loss in secondary forest areas. Water class remained reasonably constant throughout the study period. *Figure 6* provides a visual representation of these statistics.

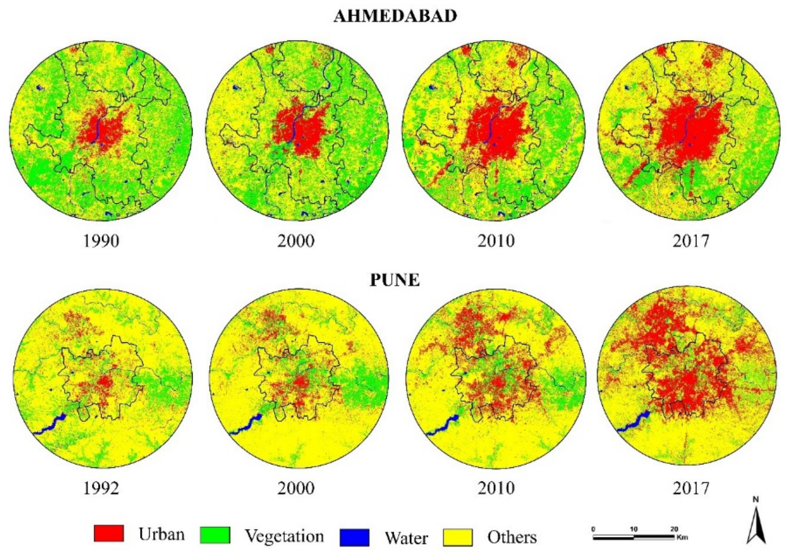

Figure 6. Temporal land-use changes of Ahmedabad and Pune region

4.3 Land use validation using error matrix

Overall accuracy and Kappa statistics estimated for both cities were greater than 85% and 0.75 respectively, as depicted in *Table 2* and *Table 3*. Overall accuracy considers only the correctly classified pixels. Kappa statistic considers not only diagonal elements, but it also accounts for non-diagonal elements describing the categorical error. Obtained results indicate classified images are in excellent agreement with the ground truth conditions.

Table 2. Land use and accuracy statistics for Ahmedabad region

Year	Urban (%)	Vegetation (%)	Water (%)	Others (%)	Overall Accuracy (%)	Kappa
1990	7.03	36.63	2.33	54.01	92	0.84
2000	11.64	30.93	3.22	54.20	94	0.8
2010	17.85	23.47	2.28	56.39	86	0.78
2017	21.36	19.74	0.72	58.18	93	0.87

Table 3. Land use and accuracy statistics for\ Pune region

Year	Urban (%)	Vegetation (%)	Water (%)	Others (%)	Overall Accuracy (%)	Kappa
1990	7.64	13.78	1.28	77.3	91	0.9
2000	14.83	8.85	0.86	75.46	93	0.9
2010	24.27	23.85	1.42	50.46	94	0.92
2017	32.62	8.34	1.5	57.54	93	0.85

4.4 Future land use transitions and estimation

Ahmedabad- The results of the calibration phase and the corresponding values for Ahmedabad is listed in *Table 4*. The city showed very fewer coefficient values (based on average log statistics and Lee-Salee value) for diffusion (1 and 6) indicating the low possibility of overall depressiveness of urban settlements at the outskirts of Ahmedabad urban development authority (AUDA) boundary. These low values were further justified by breed coefficient (4 and 6) suggesting very minimal chances of newly occurring detached type of urban patches. An inference drawn from slope coefficient (20 and 1) shows the region has lesser slope resistance to development, meaning the area is generally flat. Medium range of spread coefficient (25 and 71) specifies that existing urban pockets can influence in radiating new settlements attached to them. High values of road gravity coefficient (76 and 67) show the importance of urban growth along major roads and highways. Ahmedabad has excellent road connectivity (*Figure 8*) within the city and also inter-city. For instance, Narol-Naroda road to the east of Sabarmati river and 132 feet ring road along with dedicated bus rapid transit system (BRTS) to the west of river forms partial ring road system to connect major district and sub-atrial roads within 5 km buffer from the central business district. Important road list also includes Sardar Patel outer ring road (76 km length), national highway (NH) -8C connecting to Gandhinagar, NH-8A connecting to Rajkot, Ahmedabad-Vadodara expressway or national expressway one via Nadiad and Anand city (total length 93 km), state highway (SH) -3 to Nadiad, NH-59, NH-8, NH-228, NH-947, SH-17, SH-68, SH-71 and SH-142 among others proposed.

DMIC consist of Ahmedabad-Dholera Investment Region (Node #12) via Bavla (NH-8A) and Dholka (SH-142), giving impetus to growth in these routes. As far as the model fit functions are considered (*Figure 7*), population, edges, clusters and cluster size have shown satisfactorily good results. Statistics such as compare and population emphasises on present and predicted urban growth similarity. Cluster and size of cluster metrics were close to 1, depicts promising results of modelled urban clustering versus known recent urban clustering derived from control years. Model results have been shown in *Figure 10*.

Table 4. Parameter values of prediction for Ahmedabad and Pune

City	**Ahmedabad**	**Pune**
Parameters	**Prediction values based on Lee-Salee**	
Diffusion	1	1
Breed	21	1
Spread	80	40
Slope	14	1
Road gravity	43	94
Monte carlo iterations	100	100

Pune- Highly accurate values were obtained for all the 13 goodness of fit metrics for all three phases of calibration, and six of the metrics are depicted in *Figure 7*. These statistics indicate the success of imitating land-use change in Pune region based on historical urban growth trends. Diffusion, breed and slope resistance parameters showed minimum values, whereas spread showed medium weight (40) and road gravity showed the highest weight of coefficient (94). Low diffusion value suggested the lowest possibility of new centre establishment through spontaneous growth. Low weight of slope also indicates that resistance for growth very minimal, since landforms in and around Pune region is flat and it can be clearly visualised from slope and hillshade map (*Figure 9*). Future prediction map of 2025 can be visualised in *Figure 10*. Results show the maximum potential of growth in Pimpri-Chinchwad, Hinjewadi and Kamblewada region. These new developments are of spreading type, leading to a discontinuous pattern of landscape development while the core city continues to grow compactly with a threat to other land use categories. Pune urban area recorded a maximum of 901.11 km^2 in the year 2025 against 497.27 km^2 in 2017.

5. DISCUSSION AND CONCLUSION

Scholars in the last decade have done extensive studies on urban growth and urbanisation process. Studies about the urban corridor and related development, its effect on land use is still an emerging research area, especially in developing country like India, where planning for the next decade is in full swing. Improved visualisation and understanding of effects of development on the urban ecosystem is the need of the hour to guide the planning of cities, corridors and land use-related changes in existing policies. Research in this direction to comprehend the changing aspects of landscape changes and future urban growth using state of the art geospatial technology can also contribute to several unanswered issues.

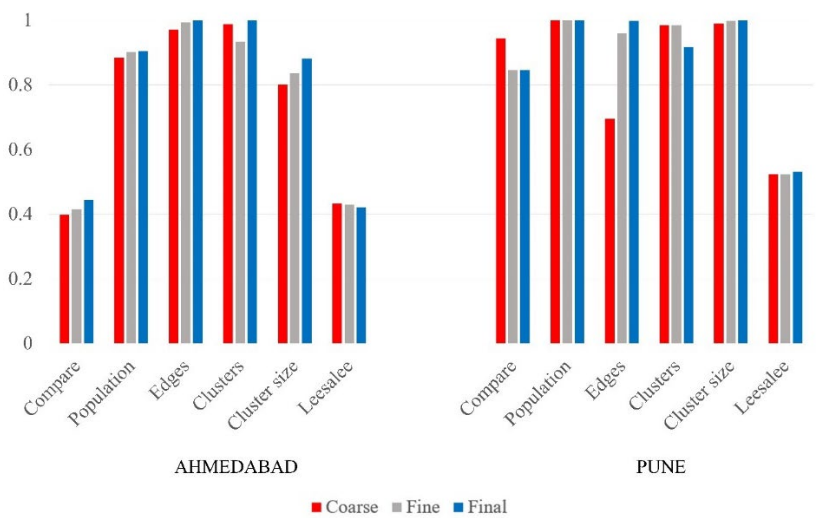

Figure 7. Graphical representation of model fit statistics for Ahmedabad and Pune

This research communication adopts a novel method of integrating city network analysis, land use assessment and modelling to achieve sustainable development goals. We also quantified Spatio-temporal land-use transition of two major agglomerations of India, falling under the influence of DMIC, a 90 billion USD industrial corridor development project. Results of network analysis helped in assessing positions of cities based on various centrality scores. Mumbai, Delhi, Chennai, Bangalore and Hyderabad were among the top-ranked cities with highest centrality scores of degree, closeness, betweenness and Eigen vector. This answers the first research question concerning the position of a city.

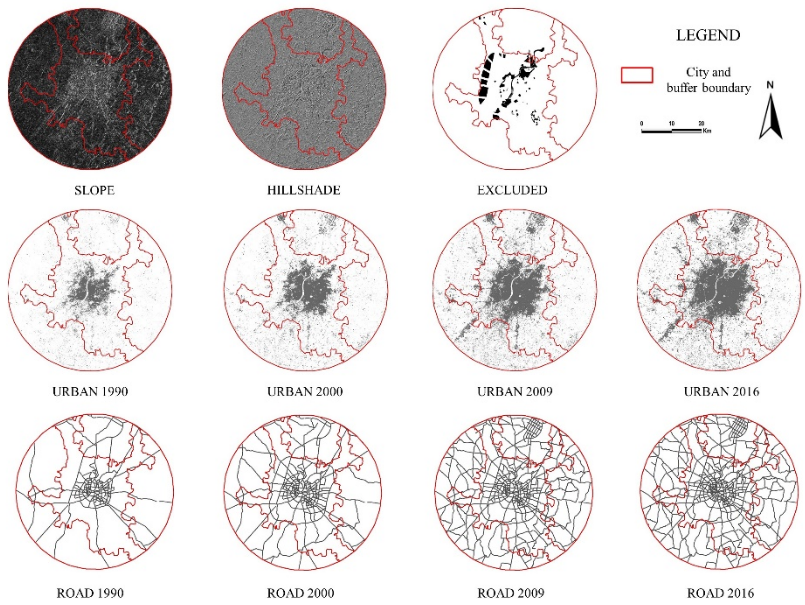

Figure 8. Input data set used for modelling Ahmedabad region

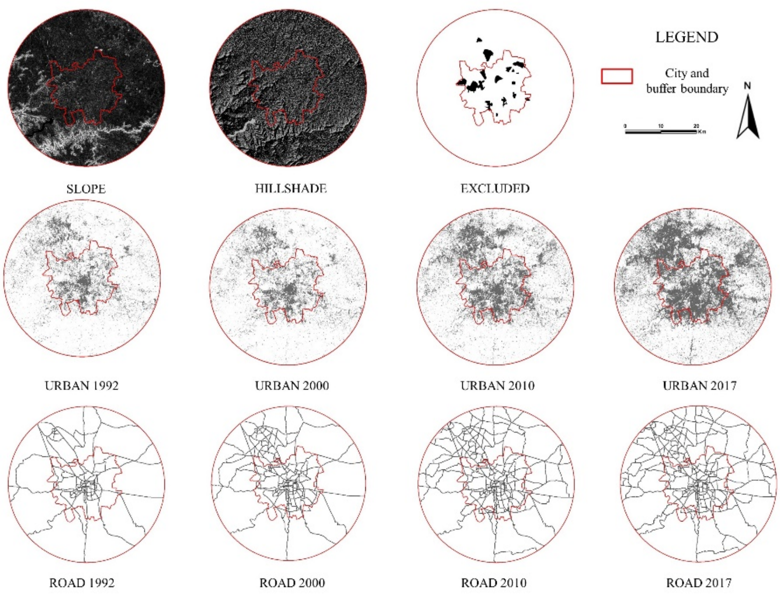

Figure 9. Input data set used for modelling Pune region

Hierarchical clustering analysis or the dendrogram aided in answering second research question, How the positions of cities are placed and what are the positions in a hierarchical order? We found that there are two similar clusters: a) Mumbai-Delhi-Kolkata, which are already existing metropolitan cities of India, are exhausted or saturated in terms of urbanisation and utilisation of natural resources; b) Bangalore-Ahmedabad-Pune, are emerging metropolitan cities and have huge scope of urban development. This lead us to conduct an in-depth study of Ahmedabad and Pune considering one of the Mega urban corridor projects of India connecting Ahmedabad and Mumbai, i.e., DMIC, subsequently answering third research question stating cities which needs immediate attention based on present land use and corridor status, growth projection and planning scenario.

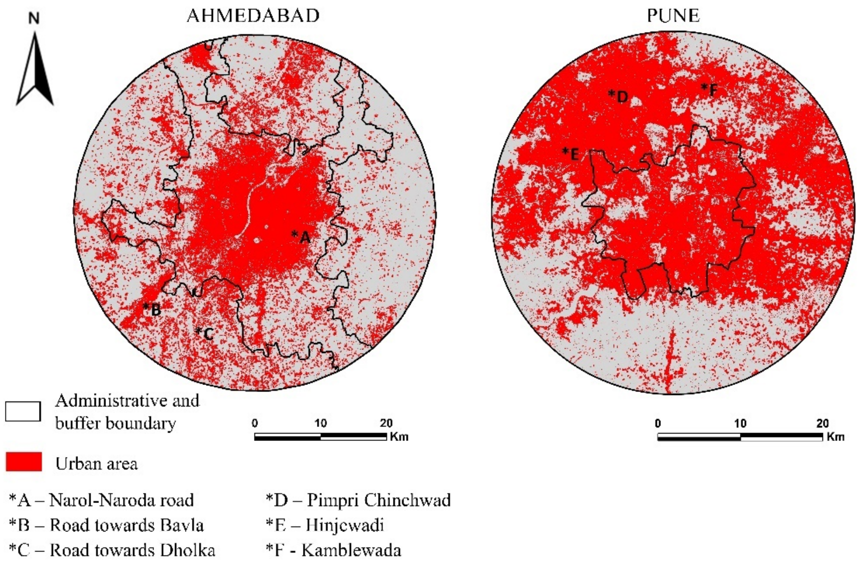

Figure 10. Modelled output for Ahmedabad and Pune region for the year 2025

Detailed land use analysis with 10 km buffer boundary of these two cities was conducted. Acceptable accuracy reported expanding the historical urban footprint of 203.84% in Ahmedabad and 326.96% in Pune within two and a half decades. Further SLEUTH model was adopted to predict future land-use change for the year 2025. Test phase and three-step calibration phase was successfully conducted to obtain the best fit and optimum parameters for prediction. Six different model fit statistics chosen based on literature study showed satisfactory results suggesting modelled urban growth are in exceptional agreement with actual urban growth for the control years (Asgarian et al., 2018; Dezhkam et al., 2014; Dietzel & Clarke, 2007; Sakieh & Salmanmahiny, 2016).

Predicted maps depict areas of growth, for instance, the road leading to Ahmedabad-Dholera Investment Region (Node #12) near Bavla (NH-8A) and Dholka (SH-142) in Ahmedabad region and Pimpri-Chinchwad, Hinjewadi and Kamble Wada in Pune with upcoming government projects. Ahmedabad showed an increase in the built-up category from 497.50 km^2 to 826.24 km^2 while Pune accounts from 497.27 km^2 to 901.11 km^2 during 2017 and 2025 respectively. Visualisation of these results is extremely helpful for various segments of society such as planners, policymakers, government agencies, the general public, academicians, administrators etc. who can be benefitted to draw future action-plans keeping sustainability and habitable aspects as a top priority.

Similar recent global efforts on future land-use change and urban expansion estimation using CA-based model have given the real-time perspective of dynamically changing cities. Xu et al. conducted a study by integrating CA-

Markov Chain with machine learning technique such as an artificial neural network (ANN) to evaluate the success of the model in comparison with routine CA-analytical hierarchical process and logistic regression models (Xu, Gao, & Coco, 2019). Yao et al. developed and optimised algorithm using particle swarm optimisation (PSO) along with CA to simulate urban growth process in a Chinese city, they also compared results with LOGIT-CA and concluded that PSO-CA outperformed LOGIT-CA (Yao et al., 2016). Considering the research above output as a learning lesson, this research can be shaped well in terms of introducing machine learning with existing models based on literature. Researchers have incorporated techniques such as SLEUTH-3r, genetic algorithm- SLEUTH, parallel SLEUTH and distributed SLEUTH to improve computation time and achieve greater accuracy in results (Chaudhuri and Foley, 2019; Clarke-Lauer and Clarke, 2011; Dadashpoor et al., 2019; Guan and Clarke, 2010; Jafarnezhad et al., 2016).

Future scope of this study can be focused on integrating various optimisations with SLEUTH to visualise possible changes of urban expansion in next two decades with precise real-time and using agent based approach also It is also necessary to delineating a fixed buffer zone on each side of the urban corridor connecting Ahmedabad and Pune via financial capital, Mumbai to envision holistic as well as planned self-sustainable development across the landscape. Overall, the proposed modelling approach can be applied to any significant Indian city to foresee transition and therefore, it becomes a pivotal input to policymakers and administrators to design future cities of India systematically. This considerably argues and throws insights on the fourth and last research question concerning critical and effective measures to be considered to address near future sustainable urban growth aspects of the clustered cities.

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