GEOSPATIAL APPROACH TO URBAN SPRAWL AND ENVIRONMENTAL VALUATION: AN ASSESSMENT OF LAND USE POLICY

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DECLARATION

I, Biswajit Mondal, hereby declare that the thesis entitled **"Geospatial Approach to Urban Sprawl and Environmental Valuation: An Assessment of Land Use Policy"** submitted by me for the award of the degree of **DOCTOR OF PHILOSOPHY** is my bonafide work, and it has not been submitted far in part or in full for any degree or diploma of this university and any other university.

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It is hereby recommended that the thesis may be placed before the examiners for evaluation.

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Dedicated to

Maa and Baba

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Preface

Urbanization and loss of natural space is not a new event, it is a known fact spread all over the globe. But, the present intensity and bundles of issues have enticed the researcher to investigate. According to World Urbanization Prospect (2018), almost 68 percent of inhabitants will live in the urban area by 2050. It is expected that Asia and Africa will receive the highest growth. India, China, and Nigeria together will experience a projected growth rate of 37 percent. India alone will add 404 million inhabitants by 2050. To accommodate such extensive urban population, we should have arranged the land for future residential use. Otherwise, it will change the LULC structure. Every large city in developing countries will need to accommodate a huge influx of the population. All these large cities need to ensure urban infrastructure, environment, and job for young population.

However, in India after 1991's economic liberalisation, the urbanisation process has unfolded in tandem with large-scale uncontrolled land consumption, also embedded with widespread urban management problems. Assessment of urban environment and its dynamics are found beneficial for policy evaluation, monitoring and to formulate sustainable management directives. Spatial analyses are now heavily used to quantify the local performance of a process and their behaviour. Major advantages of spatial estimations are the ability to identify the problems along with levels of the goodness of fit. However, uncertainties or limitations are the inherent part of the computer-enabled system models. With the help of remote sensing and GIS tools, this study proposed a land use assessment tool called LESS, acronym as land, environment, sprawl and scenarios. This framework is the first step to developed a comprehensive system for national land use policy assessment. This study is an extension of my M.Phil dessertation submitted at Jawaharlal Nehru University. This integrated approach includes four major elements, i.e., land consumption cluster, environmental amenity and residential pattern, sprawl characterization and sprawl modelling, and alternative policy scenario. Proposed framework subdivided into four stages. Initially, we computed land consumption clusters to examine regional potential land fragmentation zones. In the second stage environmental amenity dependent growth was estimation using valuation approach. Next, this framework considered success and flaws of master planning. Third, we considered the cause and consequences of sprawling. Finally, the scenario is prepared to visualize the future urban growth pattern. This research can be able to formulate a resource sensitive urban land use policy, which Indian cities need. This thesis is divided into six chapters. Chapter 1 accounted for issues of land use regulation and present details overview of land use policy-making process across the globe. This section also highlighted the strength and weaknesses of land use policy. Besides, shows the details plan of this study. The idea of national level policy and its assessment framework have been discussed. Research objectives and unique contribution of this study also discussed in this chapter. Chapter 2 focused on unaccounted land consumption process in India. This chapter aims to examine the land consumption clusters based on land use (1999-2016) and socio-demographic situation, land use regulation can be useful to undertake macro-level understanding of urban growth pattern. For this purpose, the present study used newly built GeoSOM data mining methods to extract land consumption clusters. The spatial-temporal LULC assessment shows a significant increase in land consumption in the Western peripheries. Chapter 3 illustrates the importance of environmental amenities. Due to inadequate understanding of the economic and aesthetic value of environmental amenities developers, decision-makers and policymakers ignored its importance, resulting in massive exploitation. This chapter explores the significance of the local association between environmental amenities and residential attractiveness to elicit an urban expansion pattern. The geographically weighted hedonic regression is employed in this section to estimate heterogeneity among local amenities across the planned residential zones. Our estimation shows that in addition to structural attributes, residents are willing to pay for LST, NDVI, air quality, and tree cover, in spite of these services being exceedingly location-specific. Besides, environmentally-rich townships and transport quality too are necessarily associated with housing price. This chapter is already published in Sustainable Cities and Society. Chapter 4 explores urban sprawl and its association with land use containment policies like floor space ratio, zonation and ring road development. It is well accepted that to promote sustainable living in large cities local government must need to focus on present urban expansion pattern. Still, the cause and consequences of residential spill-over and urban fragmentation are overlooked in the developing countries. This chapter examines the factor contributing to urban sprawl pattern. The generalised additive model (GAM) is employed to estimate the individual factor influence on the urban sprawling. Estimation suggests that population density, housing price, transport quality, profitability, health, and institutional accessibility significantly connected with urban sprawling although, these associations are exceedingly location specific. The result shows the cost of urban sprawl is not homogeneous across space. Urban sprawl in around second ring road increases the fuel consumption, indicate auto-oriented sprawling, whereas house price inflation is significant in the inner ring road. Chapter 5 addresses why land uses policy is required to control the urban expansion. Most of the cities in Europe, USA, China have formulated their land use policies. In the case of India, there is a scope to formulate national level land use policy guidelines. This chapter aims to prepare open-ended guidelines for Indian urban planner and decision makers. Our objective is not only propose highlighted a few policy directives but, develop a land use policy estimation framework. This chapter shows the essence of alternatives in the LESS framework. The outcomes show sprawl is not a sustainable solution to the Ahmedabad city. However, in the future environmental situation will further deteriorate if sprawl is not restricted, whereas compact policy shows some internal issues with urban growth control mechanism. It is also observed that urban spillover is dominant in the Western peripheries, where wide range of housing is available along with rich environmental access. In general, to safeguard the natural space and restrict the urban sprawl location specific trade-off mechanism need to be promoted. Finally, Chapter 6 summarizes the findings and justifies the essence of the proposed framework. Survey questioners have been attached, study finding are based on this survey data.

Date: 29.07.2018 Biswajit Mondal

Abbreviations

ABM	Agent Based Model
AHP	Analytical Hierarchical Process
AIC	Akaike Information Criteria
AMC	Ahmedabad Municipal Corporation
AMTS	Ahmedabad Municipal Transport Services
ANN	Artificial Neural Network
AUA	Ahmedabad Urban Agglomeration
AUA	Area Under the Curve
AUC	Area Under the Curve
AUDA	Ahmedabad Urban Development Authority
BAU	Business as usual
BLISA	Bivariate Local Indicators for Spatial Association
BMU	Best Matching unit
BRTS	Bus Rapid Transit System
CA	Cellular Automata
CBD	Central Business District
dB	Decibel
DEC	Deviance Explain Criteria
DN	Digital Number
DP	Development plan
DT	Decision Tree
ED	Edge Density
FAR	Floor Area Ratio
FRAG	Fragmentation Index
FSI	Floor Space Index
GAM	Generalized Additive Model
GC	Growth centre
GCP	Ground Control Point
GCV	Gross Cross Validation
GDP	Gross Domestic Product
GIS	Geographic Information Science
GUDTP	Gujrat Urban Development and Town Planning
GWR	Geographical Weighted Regression
HUDCO	Housing and Urban Development Corporation
IJI	Interspersion-Juxtaposition Index
INR	Indian National Rupees
IQR	Inter Quartile Range
LAC	Land Absorption coefficient
LARR	Land Acquisition Rehabilitation and Resettlement
LCM	Land Change Modeller
LCR	Land consumption rate
LESS	Land consumption, Environment, Sprawl, and Scenario

LPG	Liberalization Privatization Globalization
LPI	Landscape Pattern Index
LSI	Landscape Shape Index
LST	Land Surface Temperature
LULC	Land use land cover
MCE	Multi-Criteria Evaluation
MCE-CA	Multi-Criteria Evaluation Cellular Automata
MER	Main Employment Rate
MLC	Maximum Likelihood Classification
NDVI	Normalized
OLI	Operational Land Imager
OLS	Ordinary Least Square
PCA	Principal Component Analysis
PCO	Percentage of Cropland
PD	Population density
PMW	Percentage of Main Worker
RF	Random Forest
ROC	Relative Operating Characteristics
RS	Remote Sensing
SAR	Spatial Autoregressive
SE	Standard Error
SIR	Special Investment Region
SEZ	Special Economic Zone
SF	Spatial Filtering
SHDI	Shannon Diversity Index
SPAWNN	Spatial Analysis with self-organizing Neural Networks
SVM	Support Vector Machine
TD	Total Density
TE	Total Edge
TOC	Total Operating Characteristics
TOD	Transit Oriented Development
UA	Urban Agglomeration
UGB	Urban Growth Boundary
UHI	Urban Heat Island
UN	United Nation
UNDP	United Nation Development Program
USA	United States of America
USD	United States Dollar
USP	Urban Sprawl Pattern
USPI	Urban Sprawl Pattern Index
VIF	Variable Inflation Factor
VTM	Vehicle Travel Mile

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Chapter 1

Urban Land Use Planning

1.0 Introduction

Across the world, urban land expansion is equal to population growth which is indicative of a more extensive type of horizontal spread of urban area (Seto, 2011). In European cities, population growth rate has declined considerably, but household expansion is still active, indicating the formation of more nuclear family size (Haase et al., 2012). Contrary to this, China is undergoing a stage of massive urbanization. China unleashed a mega urban future combined with a high level of economic development. This new type of urbanization that China has undertaken lays emphasis on "intensive and efficient, people-oriented, ecologically liveable, fair and just inclusive and harmonious environment" (Feng et al., 2015). On the other hand, USA has experienced low density and "auto-oriented" suburban land expansion since the last fifty years (Downs, 1999; Huang et al., 2013). India has encountered six-fold increase in population from 200 million to 1200 million between 1850-2010 along with significant LULC change and economic growth. In India, urban development consumes 0.12 million hectors of forest area and 0.7 million hectors of cropland. The rate of urbanization was relativity slow during 1880-2010 (Tian, Banger, Bo, and Dadhwal, 2014). In the wider Asia-Pacific region, we find Northeast Asia and South Asia consume more land for urban development (Yu, Feng, and Hubacek, 2013). Several studies have also demonstrated that compared to Europe, urban expansion in North America is dictated largely by population growth. GDP is also a strong contender for urban expansion in western cities as well as China. As opposed to the USA and China, urban land consumption in Indian and African cities is primarily the result of increasing population (Seto, Fragkias, Güneralp, and Reilly, 2011). The land use structure of China, India and African countries is severely affected by the intensity of urban expansion. Urban expansion process, in turn, varies widely due to the national functional policies. If we consider China and India's urban population, 50.6% and 31.3% of the total population respectively live in urban areas. Overall, GDP and population are the major functional criteria behind urban land expansion. Some other criteria like infrastructure, environment policy also associated with urban expansion. China and India both have faced excessive migration toward the main cities due to the polarization of functional factors. Despite the decline of population growth, in some cities household growth seems promising (China, USA, and Europe). Additional demand for houses always influences the land consumption rate (Yansui Liu, Fang, and Li, 2014). However, population growth alone does not indicate the urban expansion scenario. Another study by House et al., (2013) suggests that a decline in both, population and demand for houses and emigration are also deeply associated with urban land consumption. Housing demand not always determined by rent, on the other hand, small households consume more land. This kind of phenomena leads to low-density suburbanization. Therefore, the type of housing and quality of life can also explain the growth of the urban land area.

Rapid suburbanization is a worldwide phenomenon, but the sustainability of suburbanization varies considerably from country to country. Land use conversion from green field to crop to built-up is a major threat being presently experienced by India, China, and African cities. Compact model of urban development always restricts environmental fragmentation and also promises an efficient form of urban land expansion and service deliveries. Ulfarsson and Carruthers (2006) mentioned that land fragmentation is the outcome of low-density urban expansion, which discourages a compact form of land expansion. Some key physical problems are visible in the suburbs, i.e. low density, housing pattern, distance from the main centre, and segregation of land use types (Ewing, 1997). Despite the obvious relevance of urban land use to affect the global environment, urban expansion on the world scale has still not been quantified (Seto et al., 2010). Planning 'informality' and fragmented urban form are the major reasons behind urban sprawling. Siedentop and Fina (2012) mentioned that sprawl phenomena could be explained as a complex group of factors, i.e. demographic, physical socio-economic which 'push' or 'pull' to relocate the individual. Indeed, it is observes that 'all cities are unique combinations of social, political and economic configuration.' After the economic reform of 1970 China experienced rapid socio-economic change and urban expansion which resulted in the degradation of environmental values. China continues to face extreme water shortage and land fragmentation (Shi and Yu, 2014). Major cities in India face almost similar kind of problems. Population concentration occurs largely within some pockets. According to Census of India 2011, 2774 new towns were born, and one-third of these new towns were located in close proximity to the million-plus cities (HUDCO, 2016). Hence, the core cities and its hinterlands experience rapid transformation, or we can define it as Indian urbanization. By studying a large number of U.S. cities, Ewing and Hamidi (2015) highlighted the extreme level of negative urban consequences like car induced sprawling and social exclusion due to long distance from the centre to the outer settlement. Previous research on driving factors analysis established that land rent, quality of residents and infrastructure increase land rent, which in turn leads to urban fragmentation (Mondal, Das, and Dolui, 2015) and environmental degradation. This situation may result in both physical and income heterogeneity (Reginster and Goffette-Nagot, 2005). Land rent pattern and amenities show an inverse association, i.e. with the increasing accessibility to amenities land rent increases; this does not indicate high-class residential space are absent in the suburb. It is true that relatively well-off people choose the suburb because of a clean environment and the ability to reduce time-consuming journeys. Suburban land expansion can be a cause of environmental deterioration. Therefore, we need to develop a trade-off between economic benefits and environmental development. While on the one hand, we need residential houses and development of the peripheral area of the cities, on the other, we need to be cautious that this development must encompass the environmental quality. Existing studies show that peripheral satellite town, small township enclave, and small towns contiguous to large town brought environmental degradation which further increases land consumption outside the planning area or better to say rural to central cities interface (Mondal et al., 2015; Bera et al., 2018). Hence, the primary question that needs to be addressed is how can smart growth be achieved, especially when one important aspect such as environmental degradation is induced by large scale sprawling? Forests, wetlands, agricultural ecosystems are directly or indirectly related to urban development agendas. As Faulkner and Gov (2004) stated, with the increase in land consumption rapid assessment of amenity value is needed for better urban management and environmental concern should be included in urban planning agendas. The objective indicators are useful guiding tools in decision making during urban and environmental policy-making, i.e., monetary value can provide the urban planner with a language to a trade-off between environment and urban settlement (Ibarra, et al., 2013). To quantify the monetary value of the environmental services a 'deliberative – participatory' approach should be encouraged (Niemeyer and Spash, 2001). An efficient locally adjusted trade-off mechanism can provide benefits to develop a sustainable social and cultural landscape. Hence, every choice can be explored from multiple viewpoints. Sometimes the participating process can also be biased in the implementation stage. Before applying any policy for the purpose of environmental regulation, monetary value can be a useful tool. By using monetary valuation approach, one can assess the environmental value in economic terms and discover a monetary solution for a socio-political issues. While it is true that these approaches are not errored free, a different approach nevertheless, is essential to establish the suitability of different tools. (Niemeyer and Spash, 2001).

Better knowledge about environmental services can help to assign neighbourhood environment quality in residential choice (Goffette-Nagot et al., 2011). Both monetary and non-monetary approaches have some limitations because environmental degradation may generate cumulative impacts on future generations which are especially difficult to quantify (Bateman, Turner, and Bateman, 1993). Another major problem with these two techniques is a biased trade-off situation. Valuation is quite useful when we consider sprawl as an environmental issue, for example, effects of roads on cropland degradation, urban expansion and its impact on wetlands. Nowadays, however, environmental degradation and natural resource depletion are the results of planned economies. Therefore, economic valuation of natural resources could be a useful tool to restrict the future economic loss. The perception of the local agencies on neighbourhood environment and stringent legislative laws are also responsible for the loss of environmental resources. Valuation of environmental services is a significant step towards obtaining efficient use and distribution (Mol and Opschoor, 1989). A quantitative assessment can help to identify such issues. Also, advance GIS tool can enhance the analytical capacity of decision making on such issues. New GIS-based spatial analysis and advanced methodologies are used to investigate recent urban form, pattern, and its associated problems.

Traditional urban theories consider only such urban growth scenarios, which were based on the advantages that a city achieved (physical, economic, environmental). At the beginning of twentieth-century majority of the urban researchers emphasized on the urban morphological analysis (Burgess, Park, Hoyt, etc.). Later, the focus has been shifted towards urban sprawl and growth dynamics quantification and urban fringe demarcation. With the help of remote sensing and geographic information system, such city specific assessment is cost-effective and time-saving. The RS and GIS-based quantitative data along with socioeconomic data are widely used to developed indicators of urban development. Remote sensing and GIS tools helped to assess environmental quality, impervious surface and urban structure within the ambit of contemporary urban research.

Before setting any goal to assess urban sprawl and its environmental threats by using spatial models a detailed survey of existing academic literature is needed. It is also true that previous literature delivers the direction for future research. In the next several sections we will focus on urban sprawl and the world land consumption scenario. Section 1.1 illustrates the reviews of LULC change and urban modelling. Section 1.2 introduces the new environment sensitive modelling framework. Section 1.3 shows the study area and its relevance. Section 1.4 represents the benefits of the environmental valuation process and focuses on decision support methodologies that help us evaluate development policy and environmental impact. Major aim of this chapter is to conceptualize a land use policy assessment framework, which must be valid for national level.

1.1 Global urban expansion

The high rate of urban expansion is somehow a function of higher population and GDP growth rate. Association between GDP and urban expansion is greater in middle-income countries due to the large land requirement for the manufacturing sector (Seto et al., 2011). Previous studies revealed that in India and China demographic and economic circumstances fuelled urban expansion. However, a long list of factors is an essential requirement to capture urban expansion due to the existence of heterogeneous cities. Several studies have also demonstrated that household size strongly influences land consumption in New Zealand, Italy, Brazil, Indian River countries, China, and the USA. Haase, Haase, and Rink

(2014) show that while European countries face a declining trend of population growth, land consumption has increased due to a rise of household, which is indicative of a reduction of family size. Hence, population reduction does not necessarily lead to lower urban land consumption. Further, one can think that deduction of household number would reduce land consumption. However, the housing market is not the only factor or that households are the major player in land consumption in an urban area. Small households consume more land area on average (Haase et al., 2014). In Europe, small households increased during 1990–2006 and land consumption also increased during this period. Some studies have shown that European cities faced reorganization which was driven by small households (Haase et al., 2012; Westerink et al., 2013). Including GDP, population, and household, some other factors like compact city building plan, urban quality of life, and housing market are primarily involved in urban land consumption (Mondal, Das, and Dolui, 2015). Du et al., (2014) mentioned that China's 'new urban expansion' pattern dominantly depend on an 'intensive and efficient people oriented ecologically viable, fair and just, inclusive homogeneous' environment. According to Seto and Shepherd (2008), urban land consumption across the countries is quite different, and studies on land consumption pattern are quite difficult due to the diverse definition of urban area. Hence, there exists a major gap to ascertain the factors responsible for urban expansion across the globe despite the importance of urban land use. From this above discussion, a crucial question that emanates are; can land consumption pattern across the major cities in the world help to evaluate urban sustainability. LULC change can be used to find the compact urban management pathway through the grassroots level.

1.1.1 Urban land transformation

Information on landscape change in the urban areas using GIS and RS is extremely popular and worthwhile. Until the late 1980s, instead of satellite imagery, aerial photography was widely used to generate LULC information (Wadle and Lindgren, 1987; LaGro and DeGloria, 1992). The utility of aerial photography in LULC information generation has been abridged when high-resolution satellite imagery becomes available easily (Herold, Goldstein, and Clarke, 2003a). This satellite-based data provides large-scale information on spatial LULC structures and also affords access to the large-scale understanding of landscape diversity (Yu et al., 2013). Landscape complexity and diversity are proved to be highly associated with human activities in the form of urbanization. To explore the urbanization effects on landscape patterns, metric-based landscape analysis is highly beneficial in the context of liveability. It is evident that landscape based measures are highly informative to understand the land fragmentation process (Cushman, McGarigal, and Neel, 2008). But the most important aspect is to quantify the urban growth factors which shape urban transformation. Although population, migration, infrastructure, economic activities largely influence the urban land consumption pattern, yet topography and physical environment always play a role in the emergence of the urban pattern (Sabet-Sarvestani, Ibrahim, and Kanaroglou, 2011). A study by Xiao et al., (2006) shows land consumption pattern varied considerably among Chinese cities; few of them shows major roads or corridor development factors which are highly associated with land consumption pattern. On the other hand, geomorphic factor, as well as proximity to central business districts, proved to be highly associated with land consumption rate. Seemingly, availability and accessibility of basic urban services have changed urban land consumption pattern over time. It is observed that most of the 'third world' cities faced a large-scale mismatch between observed land use pattern and implemented planning norms and standards. Most of these problems have emerged due to the imperfect implementation of common planning tools viz., zoning, density, equitable services provision, and alternatives (Kombe, 2005). In the context of these issues, we lack Indian evidence where RS and GIS tools have usually been ignored in the planning process. Numerous studies in the field of urban sprawl get attention for landscape evaluation purpose. In the Iranian context, Sabet-Sarvestani et al., (2011) measured Entropy index using time series data and concluded that built-up growth and population growth do not occur at the same place and that built-up area increased at the cost of vegetation and cropland. So, rather than following any arbitrary zoning, conservation of natural space should be prioritized. The present research largely follows the approaches which help us understand how accountability, urban services, and demography help in the emergence of a new land consumption process. Extensive disperse built-up development render urban sprawling in most of the cities.

Sprawl is a multi-dimensional phenomenon. It is a complex urban land consumption process. Ewing (2007) defines three major characteristics of urban sprawl, (a) leapfrog expansion (b) linear commercial strip, and (c) low density/single family use. According to Chou and Chang (2009), some indicators of fragmented urban land consumption are decentralized land ownership, disparities in the financial strength of local government and institutional failure. Quantification of land consumption rate is a difficult task due to its multi-dimensional character (Johnson, 2001). Sometimes the negative character of sprawl can act as a positive factor to some locations (Burchfield, Overman, Puga, and Turner, 2006). Various alternate strategies of compact land consumption have been undertaken previously such as 'edge cities', 'transit-oriented development', 'urban growth boundaries', 'smart growth', 'sustainable city', 'unlimited low-density', 'limited spread mixed density', 'new greenbelts' and 'bounded high density. All these strategies have encountered several drawbacks. Higher housing price restricts the supply of land for consumption, supersedes local government functions, restrict future growth, and development largely demand subsidies (Johnson, 2001). To test the urban sprawl Pendall (1999) accounted that the percentage of land area under control, farm character, government spending, transport, minority population, and metropolitan fragmentation are the major drivers. Pendell concludes, regulated urban land use system can control municipal land fragmentation, a hike in housing price, small public spending for infrastructure, and simultaneously dependence on property tax is reduced. From this above character Johnson (2001) defined six indicators of land consumption pattern, (a) land use segregation (b) automobile use (c) growth of metropolitan boundary (d) employment and residential density lower in further suburbs (e) homogeneous population in terms of race, ethnicity, class and housing (f) inability of local govt. To effectively manage the urban form and implement policies all these characteristics need to be quantified. According to Schneider and Gil Pontius (2001), spatial modelling is helpful to quantify the land consumption process. However, Cheng and Masser (2003) argued that land consumption process is a data-dependent process which should incorporate all the identified driving factors and its behaviours. Computational techniques can be used as a tool to quantify the land transformation process with the help of socio-economic and demographic parameters. Herold, Scepan, and Clarke (2002) identified structural features of LULC; these were used to quantify land consumption such as housing density, percentage of built-up area, mean structure, and land parcel size. Further, to quantify the landscape structure Herold et al., (2002) emphasised on more integrated modelling environment that must include regional migration and ecological imbalance which is more promising to understand the process.

Advance RS and GIS technique are quite helpful to identify urban form and quantification of land consumption pattern. Only, metrics-based assessment is unable to address planning issues related to urban sprawl. A detailed understanding of regional landscape change and morphology can help identify the urban process and functionality. Shen and Zhang (2007) examine how smart growth initiatives effect land consumption pattern in the United States. By using a logit model, Shen and Feng concluded that control policy in the USA directed urban sprawl in the suburbs and questioned the smart growth strategies. Compact growth policies aim to densify the urban core, which helps to reduce congestion, emission and fuel consumption (Behan, Maoh, and Kanaroglou, 2008). Decentralization and urban decline is an indication of urban sprawl. Socio-spatial structures of cities create challenges to transport planner, greater commuting distance, as well as amplified congestion. Fallah, Partridge, and Olfert (2011) have shown that the degree of urban sprawl and labour productivity are negatively associated. Siedentop and Fina (2012) present empirical evidence of land consumption pattern which is shaped by socio-economic forces. They used density and LULC criteria to estimate the sprawl pattern. It is accounted that the governance system (hierarchy), land use regulation, and housing always play a major role in the fragmented land consumption pattern. The urban growth boundary (UGB) and policy initiatives exert considerable influence on land consumption pattern. UGB can successfully modify the urban development pattern and encourage commercialization in the core area. Compact development policy, multi-storey family housing and redevelopment of the city restrict suburban development (Kim, 2013).

Aurand (2013), however, delivers a contradictory statement on the affordable housing and sprawling behaviour in the cities. Aurand negates sprawl-induced affordable housing for disadvantaged people. Absences of empirical evidence of sprawling and low-income household draw a new direction of land consumption pattern. However, this statement is not representative of the global behaviour of sprawling and affordable housing. However, the spillover effect or containment policy which is always associated with urban exclusion restricts affordable housing. Sprawling has become a worldwide issue with varying characteristics. On the contrary, urban sprawling can also be viewed positively as it indicates a process of rural development and handles ecosystem (agriculture, forest, and wetland) losses. In reality, no single attribute can address this multidimensional issue. Feng et al., (2015) present a decision support system to control urban land consumption depending on the multi-dimensional approach. They show the association between economic, infrastructural development and urban land consumption pattern. The trade-off between the positive and negative impact of sprawl should be a major guideline to control land consumption. To summarize the land consumption literature, the common characters are identified as: low density with fragmented residential enclave, land transition from open land and cropland to urban land (land use segregation), lacks policy enforcement, growth of metropolitan boundary, way of rural development (spillover effect), increase daily travel (periphery to the core). However, the most difficult task is to quantify this character. Quantification of land consumption is always a major dimension of research in urban studies. The characteristics and their forms, functions, effects and drivers are helpful for compact growth policy initiatives. Answering this question would require emphasis on identification of suburbs that are affected by sprawl. Therefore, quantification of land consumption pattern is required to undertake any regional urban policy.

1.1.2 Urban modelling and monitoring

Socio-economic attributes and time series satellite data have been providing us with a new dimension in urban research, specifically in the urban environmental monitoring. Assessment of urban environment and its dynamics have been found to be beneficial for policy evaluation, monitoring and to formulate sustainable management directives. An integrated database system can be noteworthy if it includes socio-economic, demographic and geospatial information to design a hybrid land use model (Kwast et al., 2011). Integrated hybrid models are reliable tools to the planner and policy-makers in the process of urban sustainability. This data-dependent modelling has a long implicational history, and timely modifications by scholars have improved its reliability. New frameworks and techniques have been developed; it starts from land change modelling to simulation-based modelling. Some scholars also emphasize the urban econometric models; they argued that 'spatial interaction models are aggregate and top-down'. The focus was shifted to urban interaction models through which one can detect the information flow between locations. This characteristic is embedded in the urban growth which promotes interaction among different economic and social phenomena. Spatial analyses are now heavily used to quantify the local performance of a process along with their behaviour. Major advantages of spatial estimations are its ability to identify the problems along with levels of the goodness of fit. However, uncertainties or limitations are an inherent part of this computer-enabled system models (Couclelis, 2000; Manson, 2000; Herold, Goldstein, and Clarke, 2003). Li, Li, and Wu (2013) reveal that Agent-based modelling (ABM) is a complex behavioural process-based modelling approach. In the past two decades, the multi-agent system has gained popularity and has gradually come to be accepted by social scientists, specifically in urban and geospatial studies. Spatial models are widely applied to address the causal problems of multi-dimensional and stream dynamic processes. On the other hand, rule-based models emphasised on the interaction among populations and employment situation in urban space and their heterogeneity (Batty and Longley, 1988; Batty, 1997). Bhatta (2010) listed some of the major urban simulation approaches which were used extensively earlier, such as QUEST model to explore potential threats of future urban expansion designed by the Sustainable Development Research Initiative (SDRI) in Vancouver. QUEST permits people to understand 'what if' condition in future urban scenarios. This model aims to examine alternatives for urban ecosystem sustainability. It can work with large data based on a deterministic formula. One can easily examine environmental threats from urban and transportation infrastructure (Waddell, 2007). Urban simulation (URBANSIM) is similarly a CA-based model which incorporates urban land use and transport as well as environmental threats. Currently, URBANSIM model is available in module form called Open Platform for Urban Simulation or OPUS (Noth, Borning, and Waddell, 2003). Dynamic Urban Evolutionary Model (DUEM) is also a CA-based modelling environment useful for urban expansion simulation. CAST is a city simulation tool, complex CA-based model. CAST provides a soft modelling approach; it estimates a range of potential change scenarios. Similarly, SIMLUCIA is also able to estimate the land use transition efficiently (White, Engelen, and Uljee, 1997). Alkheder and Shan (2008) also developed a CA-based simulation for Indianapolis, Indiana to examine the future urban pattern. They had prepared future scenarios based on time series data. To estimate the reliability, the simulated future map was compared with the actual LULC map and reported the average accuracy of over 80 percent. Dietzel and Clarke (2006) proposed a complex temporal urban computational system called SLEUTH which can easily depict complex structures of the events without incorporating a large set of data. SLEUTH model was further re-examined and modified by several authors (Jantz, Goetz, and Shelley, 2004; Dietzel and Clarke, 2006; Jantz, Goetz, Donato, and Claggett, 2010; Clarke-Lauer and Clarke, 2011; Chaudhuri and Clarke, 2013). According to Dietzel and Clarke (2006), SLEUTH can capture the process town coalescence and 'edge city' development with the help of biophysical, socio-economic data. He, Zhao, Tian, and Shi (2013) developed a CA model on the Beijing-Tianjin-Tangshan Megalopolitan cluster to estimate the urban scenario. This study introduced the gravity model to estimate the effect of migration on urban expansion. This model considered the urban landscape as a dynamic system and refined the transition rule accordingly. Megalopolitan landscape dynamic model based future landscape suggests that the growth should be sustained in 2020 in the few major 'hotspot' areas. Allen and Lu (2003) have previously made a binary rule-based CA hybrid logistic model for urban prediction in the Charleston region. With the help of spatial dataset, Cheng and Masser (2003) modelled the major determinants of urban growth. The former is used to analyse the influence of explanatory variable and the latter is used as a confirmatory approach for comparing each variable. Al-Ahmadi, Heppenstall, Hogg, and See (2009) had used fuzzy set theory, CA and remote sensing data for urban growth simulation known as Fuzzy Cellular Automata Urban Growth Model (FCAUGM) to develop future urban potential surface on Riyadh, Saudi Arabia. They claimed that instead of using probability theory, to represent the relational space, fuzzy logic could be useful to understand complex physical and social-economic complexity. Earlier several most cited works on urban growth modeling used some socio-economic and physical predictor variables to simulate urban growth pattern (Pijanowski, Brown, Shellito, and Manik, 2002; Guan et al., 2011; Jokar, Helbich, and Noronha, 2013; He et al., 2013) which is more suitable to simulate and investigate urban growth dynamics. This modelling environment has a special advantage for spatial allocation and improved urban living condition.

To understand the intricate growth process, the modelling urban pattern is an essential task. Weng (2002) finds out the process and direction of land use transformation and urban land parcel development at the cost of cropland using Markov Chain model. Recently, Feng, Liu, Tong, Liu, and Deng, (2011) developed a hybrid rule-based model named Particle Swarm Optimization (PSO) CA model by using environmental and socio-economic data. In the search for potential development sites in the Shanghai municipality, they have considered long urban growth trends, 1992-2008 and show that PSO is better than logistic based CA model. Jokar et al., (2013) adopted a new approach for urban growth modelling agent-based model. In this model social, economic, and biophysical datasets are combined to simulate future land-use change. They also concluded that the main problem with the CA model is the poor integration ability for human, social and economic factors which is the major hindrance to develop a reliable urban simulation system. Jokar et al., (2013) compares the statistical extrapolation and the Markov process to determine the amount of accuracy in the potential urban surface of Tehran. In the understanding of spatial allocation and urban complexity to improve the management practice, the integration of Markov and CA is an important step. Guan et al., (2011) also applied CA Markov for better spatial land management and found that urban centres constantly declined with growth in suburban areas with a significant decrease of forest and cropland and concluded that this is a warning system for sustainable planning initiative to protect current land utilization. Sang, Zhang, Yang, Zhu, and Yun (2011) applied the CA Markov model to simulate land use transition on Fangshan, China and accounted that land use alteration is the function of urban development. Mitsova, Shuster, and Wang (2011) investigate the condition of the environmentally sensitive area and green infrastructure by simulating the urban built-up area and find that CA Markov is a most simple rule-based model for spatial projection and efficient in urban planning and conservation practices. Liu and Phinn (2003) integrate fuzzy membership function with the CA model to address the urban development scenarios in the form of a ‘virtual city’. Kwast, Canters, Karssenberg and Engelen (2011) used satellite data, optimization algorithms and a few land-use change parameters. They rightly pointed out the uncertainties in initial data that are transmitted through the model. Shafizadeh Moghadam and Helbich (2013) applied CA Markov chain model to investigate the Mumbai metropolitan development and accounted that Mumbai metropolitan expansion is in the declining trend but will take several decades to catch its stability. Land expansion trends embody the coherent picture of unceasing declining of cropland and green space in the immediate future. Axial growth and infill growth is the predominant pattern of urban expansion in some portions of Mumbai city. According to Yu, Chen, Wu, and Khan (2011) CA have prompt space structures which are suitable to perform only with demand and supply mechanisms. Such advantages have increased the sphere of applicability. To find out the irrigation suitability and its spatial distribution, this study applied AHP-CA model. Experimental application of these synthetic city models had produced realistic outcomes and proved to be theoretically feasible systems.

A CA structure is highly relevant for the dispensation of information as a rule; neighbourhood, time, and statecraft it highly popular in action (Liu, 2009). A most important aspect of CA is a transition rule which precisely plots fresh urban cell to show the spatial urban expansion pattern (Chen, Gong, He, and Luo, 2002). A Markovian process can generate transition probabilities for two LULC states considering its previous and current situation. It has descriptive, and trend estimate commands regardless of actual trends (Halmy, Gessler, Hicke, and Salem, 2015; Sharma, Chakraborty, and Joshi, 2015), but it has been facing ‘absenteeism of spatial anxiety’. The fundamental spatial criterion that drives the change is proximity. According to Tobler law ‘areas that have high access to urban services will show high possibilities to turn into urban’. These proximity effects can be effectively modelled using CA approach (Eastman, 2012). The CA model is also used for environmental assessment and planning (Mitsova et al., 2011; NRC, 2014; Mondal, Das, and Bhatta, 2016). Multi-criteria CA Markov model provides a land use pattern with better accuracy, but the integration of different types of data remains a major issue. However, in fact, it provides a GIS environment that reinforces spatial analysis and computation capability in the land allocation and demand system development.

Urban environment sensitive planning is a hectic action in developing countries. Use of spatial modelling in the process of planning is not-popular. However, spatial modelling is highly acceptable to the planner, city manager, real estate developer, and business manager for decision-making purposes. But the reliability of the spatial modelling needs to be clarified first to understand the process of environmental change and extract the information to undertake specific goals (Bhatta, 2009). It is rightly accounted that urban growth modelling approaches are highly factual and changes with time due to the complexity in certain policies and availability of universal methods. Due to loopholes in previous spatial models, modification of urban modelling techniques is undertaken continuously. All models have faced a certain unique problem because they accept any one or two dimensions to simulate urban growth. However, the modification is essential to develop a unified urban model which is still under construction to achieve the highest precision level. The unified model should have a wider implication in planning, decision making, and environmental assessment.

Previous researchers on the urban sprawling and environmental threats specifically focused on issues related to land fragmentation, air pollution, degradation of open space, reduction of species diversity, and the destruction of well-established an ecosystem. All these issues directly and sometimes indirectly influence human health. According to Johnson (2001), urban sprawl directly influences human health in the form of toxic hazard. The toxic and non-toxic material also enhanced ecological degradation. However, quantifying this impact is an extremely difficult task. Quantification and proper identification is an essential task to regulate environmental degradation. Hence, local government participation and environmental measures are required on an urgent basis. Although, such a measure is not enough for sustainable city development, yet spatial modelling and environmental valuation can be a possible way to achieve the urban sustainability. In this task, the GIS can provide necessary assistance to the planner to set alternate policy agendas considering the environmental issues. The modelling approach can help to develop resource sensitive land allocation systems and environmental benefits sharing mechanism as well as explore a glimpse of the environmental problem and help to develop a sustainable principle. This section highlights the mathematical, statistical and economic model of urban growth dynamics. From this discussion, we have identified a few driving factors. An environmental assessment should be introduced into the research agendas. Decision making based on spatial models must incorporate constant evolution and prepare an alternative for developing strategies to reduce the risk of any policy initiatives. This study presents a geospatial approach in search of an impending spatial configuration, and it integrates CA transition rule to capture the spatial dynamics.

1.1.3 Environmental valuation

The previous section focused on urban sprawl modelling and monitoring, but the study will be incomplete if we ignore the environmental aspect. Therefore, this study also attempts to examine the influence of environmental services on urban expansion pattern. Theories of value approach considered that natural resource has no exchange value because of their availability. The differential rent approach believes the supply of the natural resource and scarcity allows the planner to understand the future need and use value. Other approaches like 'replacement value' and 'reproduction cost of natural resources' are considered by different scholars for service valuation, but all these approaches consider only the economic aspect (Mol and Opschoor, 1989; Milne, 1991; Haase, Larondelle, et al., 2014). Social norms and values should be included in the service valuation, i.e. the cumulative effect of loss of arable land, human health, wellbeing, etc. Valuation of environmental degradation must be merged with economic-ecological approaches. Zaikov (2016) has emphasised the economic value of the resources and expenditure on damage elimination mitigation. However, their process seems good but act on complexity in the process. Mol and Opschoor (1989) identified two major issues in economic valuation: (i) asymmetry between actual value used in perspective planning and price demarcated in the daily transaction and (ii) absence of proper incentives to regenerate the stock. Hence, this service valuation never takes the effective capacity of physical planning and policy instrument. Jarvis, Stoeckl, and Liu (2017) while criticizing the economic valuation approach showed that a 'monitory solution to eco-social problems could neglect the civic demand'. Inadequate presentation of a social issue in valuation may lead to social exclusion, and counterproductive regulation and policy failure (Ardeshiri, Ardeshiri, Radfar, and Hamidian Shormasty, 2016; Niemeyer and Spash, 2001). A few studies introduce deliberate monitory valuation rather than just monetary valuation or deliberate valuation (Waltert and Schlapfer, 2010; Kong, Yin, and Nakagoshi, 2007; Sander and Haight, 2012; Dupras and Alam, 2015). Separately monetary valuation is useful and efficient but only able to compute the supplementary and informal value of resources, whereas deliberative valuation emphasizes production of environmental good and service valuation. One can also raise a question to this deliberative monitoring approach. Hence, we can consider these approaches according to their availability such as study area, policy initiative by the government, availability of expert opinion, and survey outcomes. Ibera et al. (2013) used a monitory cum contingent valuation method to compute the market value and non-market value of agro-environmental wetland ecosystem services. They believed that economic value could be used as a trade-off between preservation and urban settlement. Non-market value provides decision makers with a comparative figure among the several alternate policies. Shi and Yu (2014) studied Shenzhen, China to show environmental resource obliteration by adopting environmental resource accounting and given ecosystem service value, environmental capacity, water resource value, and land value. Market-based and non-market based approaches are essential for urban sustainable development and planning. Any specific approach may violate the policy initiative and lead to the breakdown of the approach. Hence, we should prefer both these approaches, which are helpful to develop a resource sensitive planning. Considering the application of these theoretical discourses, one can understand the value of such studies. Based on all these widespread debates on valuation we are able to adopt a suitable approach to quantify the environmental services (Bateman et al., 1993).

A wide range of application is available on environmental service valuation, and these are not limited to a few world cities. McLeod (1984) investigated housing demand and proximity to local amenities by using the hedonic price theory which is helpful to explore the implicit price for every service in the house transaction. Mcleod concluded that pricing of parks, roads, water bodies, green space were found to have a significant association with housing. Environmental service valuation is beneficial in the policy-making process, especially to set-up regulatory mechanisms. Existing studies show that environmental quality and local amenities influence the land rent and change land consumption pattern. Hence, the valuation of environmental qualities and amenities is required to restrict the rapid land consumption. Goffette-Nagot et al., (2011) show the effect of the environmental variables on residential choice-making in Belgium cities. This study primarily examines the economy and ecological complexity and concluded that spatial variation in residential neighbourhood quality could significantly alter the urban growth pattern. Environmental amenities mostly influence the residential location in the Belgium cities.

Major causes of environmental problems in western cities during the nineties occurred not only due to urban land consumption but due to the overemphasis on rapid economic growth, rigid large-scale planning systems, oversimplified environmental goals and interests, lack of enforcement of environmental law and a shortage of environmental knowledge and awareness (Mol and Opschoor, 1989). Currently, China and India have been facing similar kinds of problems. According to Mol and Opschoor (1990), land use planning is a stage of rational resource use, and environmental protection and valuation may enhance the effectiveness. Nilsson (2014) considered resource valuation as a necessary step to understand the rational use and regeneration. Service valuation is an effective criterion for environmentally sensitive planning. Recent approaches to economic valuation and environmental degradation are used to undertake environmental policy.

1.1.4 Policy issues and urban scenario planning

Urban land use policy across the globe proclaimed environmental degradation and sustainable future should be the final goal. To explore the existing debate, previous metropolitan planning initiatives and policy agendas are reviewed. Yiftachel and Alexander (1995) show that increasingly, metropolitan planning becomes worthless to restrict uncontrolled urban development. In the planning process, a few actors restrict sustainable urban development such as bureaucracies, local government, public policies, and breakdown of the institution. After 1990, Australia focused on peripheral urban development; adopted a growth linkage model to enhance the role of local government in planning (Jarman and Kouzmin, 1993). A different phase of urban development is observed in Australia which can be summarized as fragmentation of local government, new town development, consolidation of different type of corporate agencies and final stage may denote as multifunctional polis development (Jarman and Kouzmin, 1993; Yiftachel and Alexander, 1995). Booth and Green (1993) recommended integration of policy and programme as the major tool to central urban planning issues. The concept which shaped urban China is centralized planning process, agglomeration of local economics, economic reform, new housing policies, polycentric urban development and change in the urban governance system (Ma, 2002). The urban policy must be reframed to address the interest of its citizens and diversities to encourage more inclusive urban development (Robinson, 2008). Seemingly, the major task of a planner is to design urban development agendas, and it must have the capability to spread effect without sacrificing economic growth. Datta (2012) argued that most of the cities in India prioritized economic development despite acute issues of environmental sustainability. The absence of regulatory mechanism on environmental issues, inactive local authority, and absence of policy enforcement is crucial in India. Hence, India has failed to capitalize the positive effect of urbanization. Banerjee and Schenk (1984) argue that the basic difference between China and India is the planning approach. China strongly focused on rural development which can be called as balanced development and strong institution whereas India still follows unbalanced strategies, i.e., polarization. In fact, we can say, blind belief in the trickle-down approach has failed to redistribute the wealth. At present most of the lower order town and cities are the major contributors to Indian urbanization and spatial development. Underutilized policy and misplaced opportunities lead to only 34% urbanized area whereas China contributes 74% urbanized area. However, both these countries faced rapid environmental degradation, and sustainability is a distant dream. Bulkeley (2006) rightly mentioned that rather than the conceptualizing role of urban sustainability and policy impact, logical understanding of the whole process is essential.

Moreover, long-term dynamic modelling with environmental and economic decisions is useful for land development. In this context, the scenario-based investigation is highly effective in urban planning (Amer et al., 2001; Chermack, 2004, 2005). It is evident that the sets of alternatives are powerful tools to judge the potential effect of policy decisions in the long run (Xiangô and Clarke, 2003; Varum and Melo, 2010). Thapa and Murayama, (2012) mentioned that scenario based investigation could be suitable to enforce urban growth policies and regenerate the potential urban land demand to save the environment. Considering all these previous sources of information, the present study proposed a framework to develop a resource sensitive land use policy with special emphasis on sprawl and environmental services.

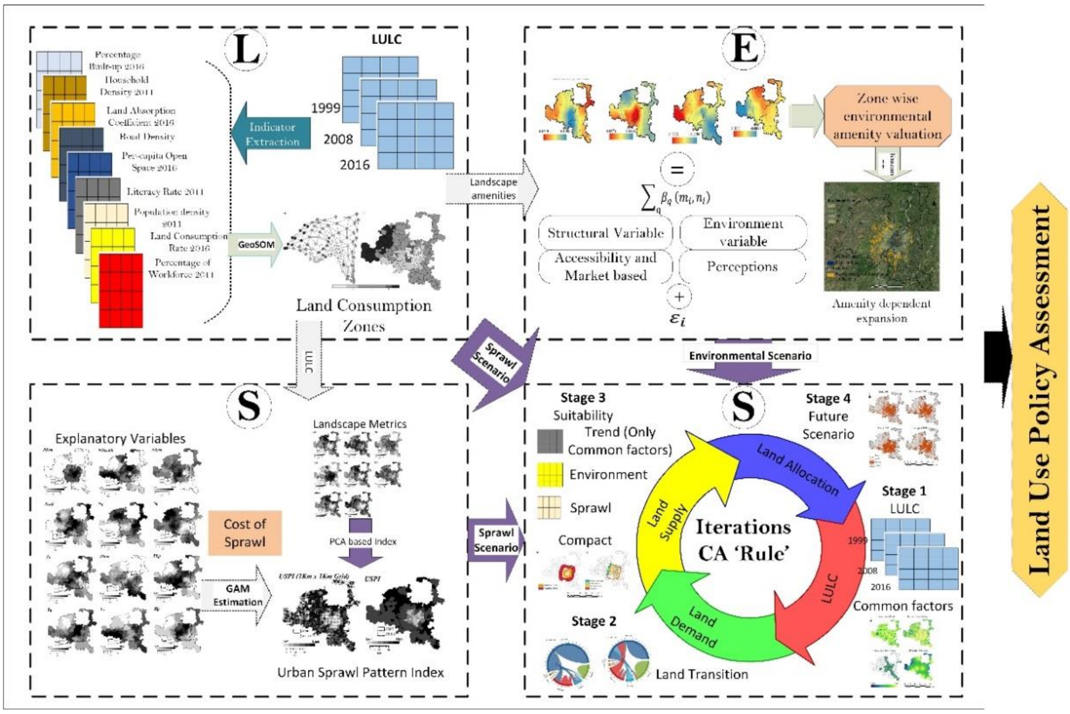

Figure 1.1: Details workflow of the study

1.2 Scope of LESS framework

Considering the issues of policy effectiveness and urban sprawling this study focused on several aspects to capture the complexities inherent in the planning process. Therefore, the major focus of this study is to exhibit a simple, comprehensive methodological tool-set regarding the quantification and characterization of land use issues. Land consumption, environmental valuation, sprawl and scenario (LESS) framework is the first step to develop a comprehensive system for national land use policy assessment. The objective of the LESS framework is not only to simulate future urban scenario but also to examine the interaction among individual forces (environmental, social-geographical factors) that are self-organizing and highly beneficial in the decision-making process. This study is based on an integrated approach of four major elements, i.e., land consumption clusters, environmental amenity and residential pattern, sprawl characterization and sprawl modelling, and alternative policy scenario. The main component of this study is to develop a resource sensitive land use policy assessment framework. The objectives of the present study are: (i) to examine the current trends of land use change, quantify the

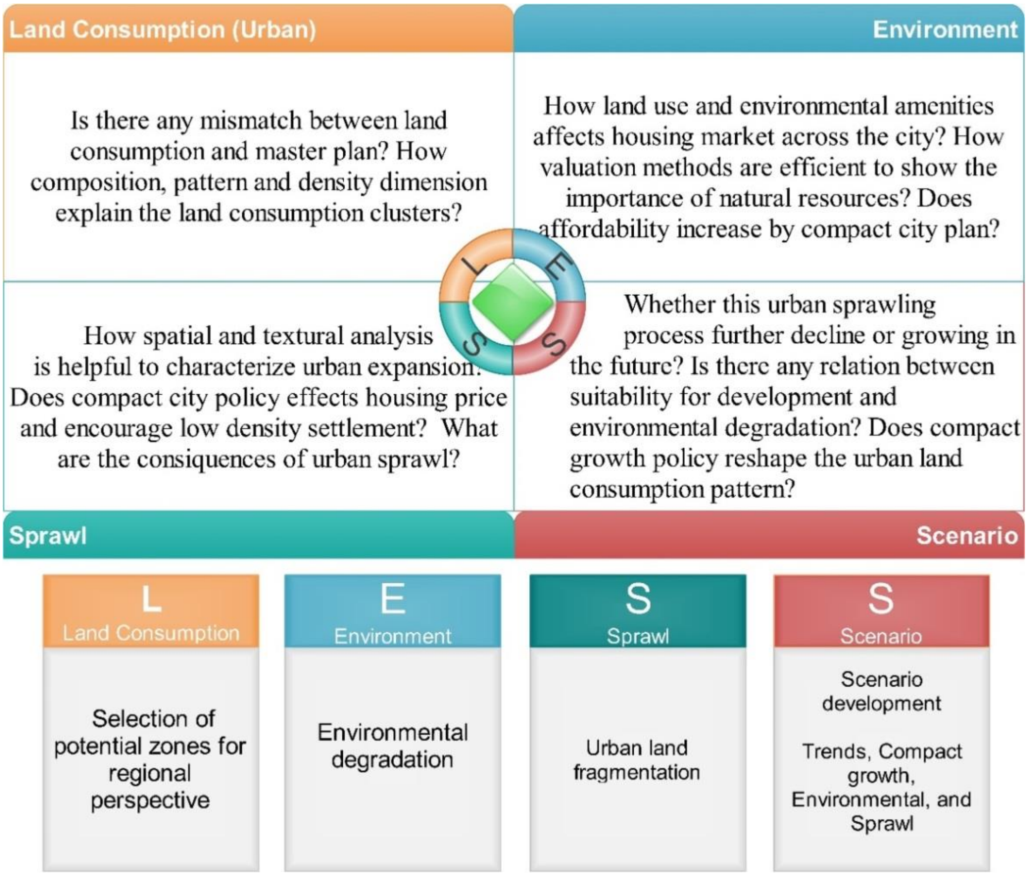

Figure 1.2: LESS framework and its focus to develop an environment sensitive land use policy

land consumption clusters and its associated potential issues, (ii) quantify the services of urban local environmental amenities in association with residential zonation, and environmental amenities dependent residential expansion, (iii) assess the individual factor contribution to urban sprawl considering the compact policy element and its consequences in the context of developing countries and (iv) estimate the trend, effects of sprawling and environmental amenities and containment policy on city visionary plan. Each component of LESS is unavoidable if we try to develop a resource sensitive land use policy. The broader objective of LESS is to reduce unplanned land consumption, loss of environmental amenities, and minimized sprawl with the help of spatial planning environment. Figure 1.1 presents the details workflow of this research. Firstly, the identification of major land consumption zones is useful to understand the regional land utilization system. Secondly, environmental estimation is useful to understand urban sustainability and beneficial to identify a feasible way to benefit from the environment. Third, to what extent containment policy is able to restrict urban sprawling? Finally, this study emphasizes the forces for individual modelling to simulate alternative scenarios. To fulfil the aims, this research focuses particularly on four major groups of questions, which are useful to undertake a national land use policy (see Figure 1.2).

1.2.1 Study area

Urban sprawl is concomitant with suburban development. In India, at present, there are 53 million-plus cities which together with those cities that are on the verge on becoming million plus are extensively reshaped by the sprawling process (Taubenböck et al., 2009). Located in central Gujarat (in the western part of India), the Ahmedabad Urban Agglomeration (AUA) is a major industrial hub that spreads across both the banks of River Sabarmati. Among Indian Class-I (above 0.1 million population), cities the present study considers Ahmedabad – the unique heritage city of Western India. It is the sixth largest urban agglomeration (UA) of India. The Ahmedabad Urban Development Authority (AUDA) is the sole body that undertakes the tasks of planning and decision-making for AUA. The AUDA administrative area covers 1866 km² and is situated between latitudes 23º20′48″ to 22º46′18″ and longitudes 72º11′22″ to 72º51′08″ (Figure 1.3). An area of 450 km² and 118.44 km² each are covered by the Ahmedabad Municipal Corporation (AMC) and five municipalities (Kalol, Sanand, Bareja, Dehgram, and Memdabad) respectively and 169 gamtal (villages). In 2001, the AUDA had 5.24 million inhabitants, and the population increased to 6.3 million in 2011. The administrative setup of the AUDA is based on three segments, viz., AMC, growth centres (consisting of five municipalities), and the rest of the planning area. AUDA has prepared a well-illustrated Development Plan (DP) for 2021. The DP 2021 lays heavy emphasis on land use zoning mechanism under the Gujarat Town Planning and Urban Development Act, 1976. Preliminary assessment of DP shows sharp structural difference regarding morphology, economic activities and demography of eastern and western river bank (Mehta et al., 1987; Nandi and Gamkhar, 2013; Mahadvia et al., 2014; Jain and Pallagst, 2015; Kantakumar et al., 2016). However, the city has a unique planning advantage- Bus Rapid Transit System (BRTS) and Ahmedabad Municipal Transport Service (AMTS) and its containment policies viz., ring roads, land use zones, and floor space index (FSI). Despite these planning advantages, urban sprawling continues to plague the city.

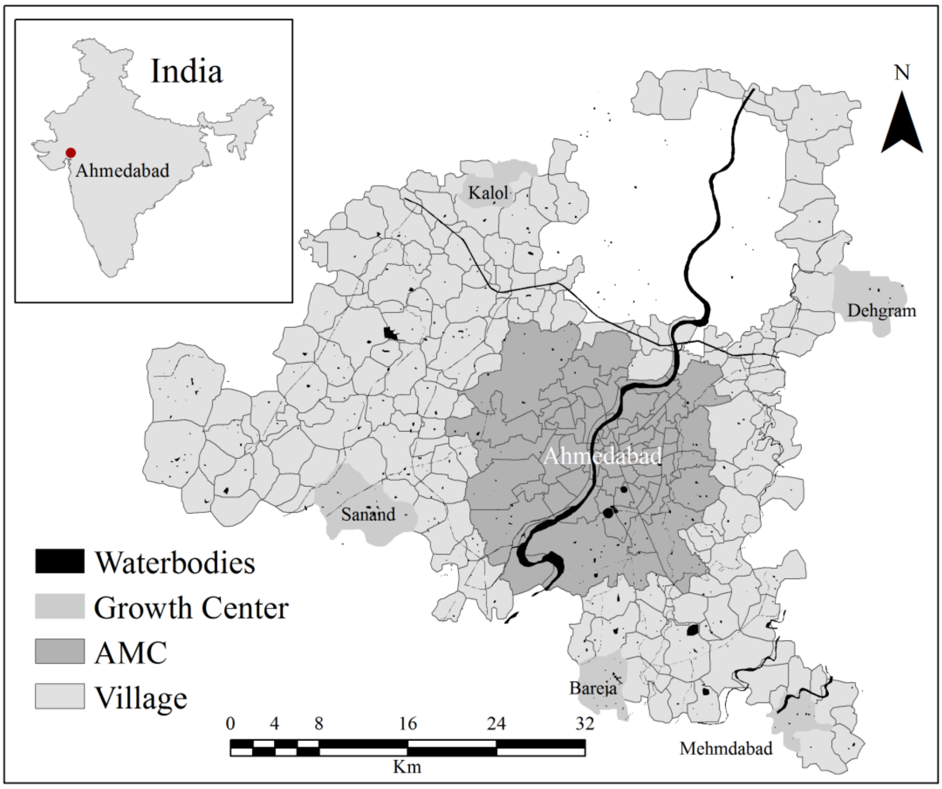

Figure 1.3: Location map of the study area

The regional development of AUDA completely depends on the economic growth of Ahmedabad. The AUDA follows the industrial estate development model (Mehta et al., 1987), which is the sole driver of urban development in the city. The city of Ahmedabad is unique and bears a story of survival and transformation from a traditional industrial city (i.e., textile) to a modern industrial hub. Besides, there are three major reasons for the selection of AUDA: (1) the city has a large industrial base with increasing pressure on natural resources like water bodies, open land and green space, (2) The complex association between urban heat island (UHI) effects and industrial development on both the river banks, and (3) The housing scenario in the city is different from other Indian cities in terms of regional real estate development, under-supplied affordable housing (with optimum luxury housing) and the sharp association between comfortable amenities and peripheral housing stock. Comprehensive AUDA planning mechanism (redevelopment, inclusionary principles, and natural space preservation) make this city a unique space for research on land use policy.

1.2.2 Significance of environmental sensitive planning

Integration of attribute data and GIS is a common tool after technological innovation in the spatial planning. A large number of scholars have been attracted to this technology in order to adopt a new way of expressing and implementing ideas. Although RS and GIS has a wide area of applicability, yet in urban studies this tool induced lots of improvement in theoretical understanding. Approaches are constantly under development. An urban area is a spatial unit where the economy, people, infrastructure are agglomerated and policy structure induced temporal change. To get an idea of this temporal-spatial dimension RS and GIS have gained research attention. The spatial growth of large cities is not confined to its boundary. Most of the Class I cities (> 1 lakh population) have national and international significance, besides large numbers of adjacent towns and villages are depending on their premier central city. Urban growth, form, society, economy and governance issues are the source of attraction to the geographer, planner, economist, sociologist, and scholars from other disciplines. Urban environmental degradation, land alteration process and urban growth always demand a flexible policy, which can evaluate planning practices.

Urban sprawling estimation can investigate land alteration process which has significant implication in land use conservation and protection plans. The LESS framework integrates different policy issues in the planning process. Land use modelling and urban growth modelling have the ability to better urban management. Most of the developed countries have already adopted a spatial modelling approach to preparing sustainable and city plans. China has developed a unique city cluster which brings the city prosperity. It is evident that large-scale investment brings economic boom and integrated planning systems make these cities more equitable and sustainable. However, countries like India have emphasised on smart urban future, but at present most of the Indian cities are growing in an unplanned way and cities become worse in the context of environment and congestion. All major metros have prepared master plans, but timely evaluation and flexibility in planning are absent. In the case of Kolkata, inefficient planning alternatives and monitoring made it unfamiliar to sustained growth. Gradually failed to sustain its national significance, but still, it is a dominant centre of eastern India.

The absence of geospatial investigation raises several questions which urgently need to be addressed. Urban modelling approach enhances local understanding by using mathematical logic. Although modelling approach suffers some major limitations, yet detailed investigation and observation make it more reliable in strategy building. In reality, the modelling approach is sometimes unable to consider the externalities. Therefore, its regular evaluation becomes essential. Socio-economic data increase its reliability and help to produce live information. In this study, urban growth modelling is adopted to simulate trends of growth. The immediate future situation is noteworthy to examine the challenges and strengths of the existing plan. Most importantly, assessment of future land alteration based on past trends is proved to be a useful step to undertake urban policy.

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Chapter 2

LULC and Land Consumption

2.0 Introduction

Cities are recognised as places for bright opportunities, especially after rapid and sustained technological development (Rain et al., 2007; Scott et al., 2013). From the beginning, cities have been considered hubs of education, trade, health, manufacturing, and institutional services. According to the UNDP (2014), the global urban concentration will increase significantly (2.5 billion by 2050). Of this increase, nearly, 90% will be concentrated in Asian and African countries during 2014-2050 (Lu et al., 2014). India, China, and Nigeria together will experience a projected growth rate of 37%. India alone will gain 404 million inhabitants by 2050 (UNDP, 2014). To accommodate such extensive urban population, we should have arranged the land for future residential use, which inevitably changes the land use land cover (LULC) structure. Development of society, health care, economy, culture, and transportation system due to urbanisation further fuelled change of LULC structure (Echenique et al., 2012; Ahmad et al., 2016; Cabral and Costa, 2017). LULC transformation is thus valuable to understand eco-social transformation for urban areas (Sridhar, 2010; Sharma et al., 2013; Bhat et al., 2017). Urbanisation specifies the conversion of non-urban areas to an urban area (Kantakumar et al., 2016; Scharsich et al., 2017; Sreeja et al., 2017). Large-scale urbanisation is not a new event in India. However, the magnitude of recent urbanisation changes the intensity of long-standing problems, i.e. poor housing, quality transportation, poverty, unemployment, congestion and environmental degradation and natural landscape loss. Major urban changes across the world has been encountered dated back to the 1960's which witnessed the first major phase of development (Saleem et al., 2018). China entered into a phase of hyper-urbanisation since the 1980's (Quan et al., 2015; Liu et al., 2018). Recent urbanisation trend shows peri-urban high-density enclave development with large open spaces, whereas small cities are still enclosed with low-density development and absence of effective use of open space (Yaping and Min, 2009). However, in India after 1991's economic liberalisation, the urbanisation process has unfolded in tandem with large-scale uncontrolled land consumption. According to Shaw (2015), metropolitan spill over and its driving factors is almost unformed in most of the countries instead of remarkable variability in the scale and rate of urbanisation. Contemporary urban development and LULC change are one of the most crucial challenges for Indian policymakers, planners and local governments (Kantakumar, Kumar, & Schneider, 2016).

Assessment of LULC change and land consumption pattern started back in mid-twenties. Several land-use models explicitly address the location-based land consumption pattern such as Burges concentrate zone (1925), Hoyt sector model (1939), and Harris and Ullman multiple nuclei theorya (1945). All these basic models are based on static consumption approaches (Adhvaryu, 2010), but one can understand the dynamic process by re-stratifying these three benchmark models as stages of land consumption, for example, stage 1: concentric zone, stage 2: sector theory, stage 3: multiple nuclei theory. These three stages can be useful to evaluate transformation of the single urban centre to multi-centre urban developments. There are more sophisticated theoretical approaches available, i.e. Alanso Land rent theory (1964), land use theories specific to Latin American cities, and urban sprawl. The land rent theory highlighted the influence of land value on the land consumption process. This theory is more efficient to explain why land use pattern varies and how land consumption rate shifted from central city to peripheries. It is evident that three stages of land use theories are closely associated with land rent structure. Although these models are unable to explain the diversity of present consumption pattern yet, they remain an important building block to understanding the land consumption pattern. Recent researches rely on models and techniques (Cellular Automata, Machine Learning, and Optimization) because they are conducive to handling large datasets (Berling-wolff and Wu, 2004). All the advanced approaches heavily rely on statistical modelling and (Vaz et al., 2017) to develop an effective policy-making system.

Based on a few comprehensive researches conducted in Indian cities we observed two dominant characteristics of LULC change behaviour, (i) conversion of the profession from agriculture to non-agriculture along with land transformation from cropland to open land to the built-up area, i.e., peri-urban transition, (ii) dispersion of urbanisation process induced uncontrolled land consumption, indicating imbalances between urban and population ratio (Kumar et al., 2011; Jain et al., 2013; Gibson et al., 2015). This type of land consumption is a great threat to the natural ecosystem in the suburban areas (Hudalah and Firman, 2012; Gibson et al., 2015). Most of the Indian cities show a strong mismatch between actual population growth and land consumption (Mondal et al., 2016; Sridhar, 2010). Land consumption zones are used to examine the macro homogeneous region beyond the planned residential zones. These land consumption zones are also used to restrict the uncertainty of rural land conversion (Nandi and Gamkhar, 2013). Most importantly, in India, neither any zone-specific land consumption threshold was applied nor examined to restrict uncontrolled urban growth. Therefore, continuous monitoring of LULC change can be a tool for evidence-based policymaking to confine uncontrolled land consumption. We have explored several studies on urban growth, urbanisation, and spatial modelling (Morshed et al., 2017; Pazúr and Bolliger, 2017) but to our knowledge, not a single study has attempted to estimate the land consumption zones in India. Recently, Hagenauer and Helbich, (2016, 2018) applied a comprehensive spatial modelling approach to explore the land consumption cluster. Such information can prove immensely useful for planners to improve service delivery. Quantification of land use consumption based on current socio-economic situation is beneficial to mitigate the land use issues and promote sustainable urban development. Diverse empirical investigation on urban expansion using remote sensing (RS) and geographic information system (GIS) is increasing significantly (Fukushima et al., 2007; Echenique et al., 2012; Estoque et al., 2018). The simulation-based spatial modelling approach has been proved to be valuable (Dhiman et al., 2018; Hagenauer and Helbich, 2018). Instead of casual spatial models, this chapter is attempted to estimate land use change and land consumption clusters, which is useful to undertake the macro level land consumption control policy. All previous studies have only considered the pattern and causal factors to suggest effective urban development policies. However, consumption-based clustering merely raises the awareness of the undesirable use of land. The present study undertakes a land consumption based assessment of Ahmedabad (Figure 1). To fulfil the first target of LESS framework this chapter designed two objectives, (i) examine the current trends of land use change and to quantify the land consumption rate for 1999-2008 and 2008-2016; (ii) examine the land consumption clusters and associated potential issues.

The article is structured as follow; section 2.1 presents a brief review of the existing literature on land consumption and sustainability. Section 2.2 provides a detail description of the study area. Section 2.3 presents details of applied methods and database. Section 2.4 explains the summary findings. Section 2.5 discusses land consumption process, planning and limitations of the study. Finally, section 2.6 presents the conclusion.

2.1 Land consumption and sustainability

The land is one of the most expensive resources in the peri-urban areas which provides multiple benefits such as ecological, economic, social, and aesthetic (Hymovitz, 1966; Irwin and Bockstael, 2004; Ibarra et al., 2013; Jarvis et al., 2017). Extensive loss of land can create a serious threat to future use. Present land consumption process aggravates the loss of agricultural land. Most of the cities in China, India, Brazil etc. are plagued by land transformation problems which arose primarily after the economic reforms (during 1970-2000's), due to urban growth and economic restructuring. Infrastructure and migration are the secondary drivers of land consumption. UNDP (2014) estimated that one-third of the land surface is now converted to develop land in the form of residential, commercial, and infrastructural use. Besides the obvious loss of cropland, we can find a long list of issues due to this uncontrolled land consumption, i.e. loss of per capita open space, inflation of housing price, urban sprawling, an increase of urban heat island effect, rural livelihood changes and suburban ecosystem loss (Fukushima et al., 2007; Gibson et al., 2015; Joshi et al., 2009; Nandi and Gamkhar, 2013; Kantakumar et al., 2016; Bhat et al., 2017; Morshed et al., 2017; Sreeja et al., 2017). Although a few studies specifically address the issue of land consumption, yet most of this emphasised urban historical trends. Based on previous studies one can easily differentiate the land consumption pattern between developed and developing countries. Grekousis, and Mountrakis (2015) accounted that USA and Europe will double their population between 2000-2030 and that almost 72% of the total world population will reside in urban areas by

2030. According to their findings, between 2000-2030, the USA alone will increase its land surface consumption by 51%. In contrast, China's 'construction land' will add to the massive industrial development activity with its concomitant social changes. In Bangladesh and India, illegal land conversion and sprawling will be the major future issues (Chatterji and Yang, 1997). The problem is not limited to specific regions or countries but is spread across several countries around the world. Despite the pandemic nature of the problem, we are not closer to find any significant universal policy to counteract it. Several empirical studies have been attempted to explain the land consumption patterns based on statistical modelling. For instance, Grekousis and Mountrakis (2015) used ordinary least square (OLS) which ranked countries based on their rural to urban use. Mcdonald et al., (2009) undertook a work on USA metropolitan cities based on metric measurement to explore the rate of open space consumption. He argued that while open space consumption in recent decades reduced significantly, it varies due to historical factors and contemporary development strategy. Contemporary factors like population growth, capital flow, land use policy, informal economy and transportation change the face of the land (Seto et al. 2010). Numerous simulation based LULC models show significant loss of natural spaces. Cellular rule and machine learning mechanism are frequently applied to investigate the land consumption pattern (Hagenauer and Helbich, 2016). Instead of estimating simple urban expansion pattern, numerous studies used robust spatial regression models to estimate land consumption (Hagenauer and Helbich, 2018). Geographically weighted regression (GWR), spatial autoregressive (SAR), generalized linear model (GLM) and spatial filtering (SF) are used extensively. However, all these models are coupled with a few advantages and disadvantages, which is beyond the scope of this article. From the policy point of view, we aim to find a macro level land consumption clusters. Recently, Hagenauer and Helbich, (2018) developed RegioClust model to estimate land consumption clusters. They also developed a machine-learning algorithm SPAWNN to estimate spatial clusters. This study used SPAWNN toolkit based GeoSOM clustering approach to finding out the most potential land consumption zones in Ahmedabad.

2.2 Data and pre-processing

Two different sources of data were used viz., Landsat and Census of India. To ascertain the temporal dynamic and LULC change, multi-temporal dataset were used. Almost 15 years' time-span for land use change and 30 years' time span was considered for socio-demographic data due to the absence of temporal consistency between cloud-free spatial data and census data. This study used Landsat multi-time images for its strong spatial digital archive and accurate temporal information (Saleem et al., 2018). Numerous studies have demonstrated that the spatial resolution of the Landsat imagery is an important parameter to understand the LULC change, specifically urban growth. Landsat images for the year 1999, 2008, and 2016 were downloaded from the United States Geological Survey (https://earthexplorer.usgs.gov/). For each year, two scenes were collected to cover the 1866 Km^2 study area. The ArcGIS data composite tool was used to mosaic the datasets. Since the data quality of satellite imageries are affected by atmospheric conditions and the seasonal change, such data needed a few corrections before the LULC analysis. Regression-based band to band radiometric correction was undertaken to adjust the value of each image (Cabral and Costa, 2017). To reduce the seasonal error, this study used similar season for three dates, i.e. November. Landsat images were acquired from the different sensors, viz., Thematic Mapper (TM; 2008) and Operational Land Imager (OLI; 2016). All the images are corrected geometrically using UTM zone-43 North, datum WGS-84 with resolution 30m x 30m. Toposheet and Google Earth were also used to estimate the accuracy and validity of the processed data. Additionally, AUDA master planning document was used to extract the agglomeration boundary, Administrative units and roads, population density, employment, literacy, and percentage of main workers were processed from the Census of India 2011. A few land use variables were processed to estimate the land consumption clusters, i.e. transport density (TD), added urban area (AUA), land consumption rate (LCR), and Land absorption coefficient (LAC). Most importantly, time-series assessment was restricted due to the ward level boundary declassification. The brief description of the collected data is presented in Table 2.1

Table 2.1: Brief description of the datasets

Data type	Source	Year	Dataset
Satellite image	USGS	November, 1999	LANDSAT-TM (30m x 30m)
		November, 2008	LANDSAT-TM (30m x 30m)
		November, 2016	LANDSAT-OLI (30m x 30m)
Socio-economic data	Census of India	1991, 2001, 2011	Population density, Household density, Main Workforce, Literacy
	Field Survey	August, 2016	Housing price, Land Price
Land Use	Processed	1999, 2008, 2016	Percentage of urban land, open space, land consumption, and land absorption
Urban features	Digitized feature	2016	Transport network, Protected areas, River stream, District boundary, urban Centre

Table 2.2: Brief description of LULC classes

Class	Description
Built-up	The built-up class considers all construction area, industrial site, commercial area and residential area.
Cropland	Cropland class considers only current agricultural land including plantation.
Open land	Open land includes all land that is currently not cultivated (current fellow), landfill site, and hilly areas.
Vegetation	Vegetation class includes parks, garden, forest patch, small fragment tree and scrubs.
Sand	Sandy area is non-cultivable river bed and rocky surface.
Water	Water bodies have considered lakes, reservoir, pond and river in the master planning document.

2.3 Methodology

2.3.1 Image classification

Reliability of the LULC data is essential to investigate the urban growth pattern, environmental monitoring, LULC change (Hassan, 2017). Medium resolution (30 m x 30 m) Landsat data shows extreme heterogeneous landscape structure, which increases the chances of misclassification. The present study follows the Anderson et al., (2001) LULC classification scheme to prepare the LULC data. Several models are available to classify the images to prepare LULC data. Most popular classification scheme are unsupervised and supervised classification. Most of the studies prefer various supervised classification algorithms viz., Random Forest (RF), Decision Tree (DT), Support Vector Machine (SVM), Artificial Neural Network (ANN) and Maximum Likelihood Classifier (MLC), which have demonstrated high accuracy (Saleem et al., 2018; Hassan, 2017). This study, however, used MLC to prepare the LULC data using six spectral classes. MLC is better suited because this study aims to assess urban growth with medium spatial resolution data. To prepare LULC, six classes, i.e., Built-up, Open land, Cropland, Vegetation, Sand, and Water bodies (Table 2.2) were considered using 100 training pixels for each class. To reduce misclassification which was created by extreme class similarities, this study has employed the following auxiliary information: (a) to reduce the salt and pepper effect 3 x 3 moving window was applied on LULC data (Kantakumar et al., 2016), which is useful to remove isolated pixels, and (b) The error of large spectral mix-up observed between built up and open land, and open land and sand was minimised by using careful visual identification and recode module in the Erdas Image 14.

2.3.2 Accuracy assessment and change detection

As this study processed three different Landsat images with almost eight years interval, however, image collection dates are not exactly same although the month is same days, it leads to the creation of spectral mix-up. Consequently, LULC maps contain misclassification issues even after post classification corrections. Such issues are arrested inaccuracy measures. The present study considers Google Earth 2000 and 2008 as a reference image for LULC 1999 and LULC 2008. To check the accuracy of LULC 2016 data, 180 random ground control points (GCP) were collected. GCP were collected in August 2016. Minimum of 50 GCP for each class was collected. Based on the classified and referenced data, overall accuracy, producer accuracy, user accuracy and Kappa coefficient were measured (Congalton, 1991). The accuracy of LULC change estimation depends on the accuracy of LULC map. Lu et al., (2004) mentioned five popular LULC change estimation processes, i.e. algebra, classification, transformation, advanced models, and GIS. The present study preferred classification process. This process creates a 'From to To' transition matrix, which is useful to interpret the process of LULC change. The study also used Land Change Modeller (LCM) module to develop the two transition matrices in the Idrisi Selva software. Additionally, details of built up grain, natural space loss were mapped. Two transition periods, i.e. 1999-2008 and 2008-2016 were produced for change estimation.

2.3.3 Land consumption modelling

TD, PD, AUA, LCR, LAC and main employment rate (MER) were processed from the land use map 2016 and the Census of India 2011. Details of the variables are presented in Table 3. To estimate the land consumption cluster, this study used SPAWNN toolkit based GeoSOM algorithm (Hagenauer and Helbich, 2016). This spatial clustering is based on self-organisation neural network techniques. This model is highly relevant for its information extraction capability from the large spatial dataset and patterns understanding. The SPAWNN toolkit provides a few powerful clustering algorithms. In this study, we preferred GeoSOM Ward's criterion based 'Contiguity- constrained hierarchical clustering' process. GeoSOM training algorithms are used to compute clustering and visualising spatial data. GeoSOM is a two-step process to define Best Matching Unit (BMU). In the first step closest neurons are identified concerning input data. Next, the same identification process is used but within a specified distance. After that, we designed BMU to reduce the spatial dependences; this study uses radius = 1 (Hagenauer & Helbich, 2016). Each input variables and its BMU structure are presented in a hexagonal space.

Table 2.3: Brief description of land consumption parameters

Parameters	Description
NBA	Includes newly added built-up area, indicate the absolute newly consumed area without any areal constant.
Hden	High *Hden* and *Pden* indicate areas that are highly compact. The high compact area invites fewer than the less dense peripheral block. Therefore, we can assume high compact areas shows past consumption and the less dense area can be a better option to capture future land consumption.
PLC	Per-capita land consumption shows availability of urbanised land for each habitat, which can show the intensity of consumption. PLC= urbanized area of a unit/ population of that unit.
PLAND and *LAC*	PLAND shows the proportion of land is developed and LAC shows yet to be developed. LAC is derived from population and urban area change ratio.
PCO	PCO indicate the better environmental situation. But the extreme availability of open space indicates a remote area with land use change (cropland to open land). High PCO near existing built-up indicate future sprawling potentiality.
PLit and PMW	Literacy rate and PMW is computed to understand the influence of education and job market on the LULC pattern.
RDen	*RDen* is a primary driver of urban expansion in the outskirt. Road length density can be a useful amenity, which increases the land consumption rate in the peripheries.

2.4 Result

2.4.1 Accuracy assessment

As the LULC maps are affected by land use heterogeneity, this study examines the reliability of the LULC data. Since we have collected GCP during the field survey, and most of these points are close to the residential and open land, additional random points were used with the help of Google Earth. Class specific accuracy assessment shows large heterogeneity exists in open land, cropland and green spaces. Green spaces, for example, were observed to be highly inconsistent throughout the period. Classification accuracy of green spaces is lowest in 1999 than other LULC class, whereas high classification accuracy (> 80%) is accounted for 2008 and 2016. On the other hand, the most challenging task was to identify the differences between open land and cropland. A significant level of accuracy is observed throughout the period (> 85%) for open land and cropland. Highest accuracy is observed for the built-up area (> 90%). Water and sand covered a tiny proportion of the area given a homogeneous spectral reflection (> 85%). The overall accuracy for the point level ranged between 80%-90%; Kappa coefficient is 79%, 86%, and 88% for 1999, 2008, and 2016 respectively. At regional level post-change, overall accuracy is 82% and 85% for 1999- 2008 and 2008-2016 respectively. Overall error is highest for 1999 LULC map, but the accuracy of 85% looks satisfactory for urban assessment (Anderson et al., 1976). Accuracy estimation demonstrates that LULC data may be deemed satisfactory for further land consumption estimation. However, it is expected that the minor error will not affect the outcomes of the study. Brief details of the accuracy estimation are illustrated in Table 2.4.

Table 2.4: Accuracy assessment of classified LULC maps by Kappa statistics

Classes	**1999 (%)**		**2008 (%)**		**2016 (%)**	
	Producers Accuracy	**Users Accuracy**	**Producers Accuracy**	**Users Accuracy**	**Producers Accuracy**	**Users Accuracy**
Built-up	92.15	80.29	93.15	83.35	90.67	91.67
Cropland	81.00	85.19	78.17	90.89	84.71	84.21
Vegetation	79.23	89.00	81.10	82.08	74.63	85.79
Open land	91.00	92.88	93.00	93.19	93.55	93.33
Sand	100.00	100.00	100.00	100.00	100.00	100.00
Water bodies	100.00	100.00	100.00	100.00	100.00	100.00
	Overall Kappa Statistics = 0.79		*Overall Kappa Statistics = 0.86*		*Overall Kappa Statistics = 0.88*	
	Overall Classification Accuracy =85%		*Overall Classification Accuracy = 87%*		*Overall Classification Accuracy = 90.00%*	

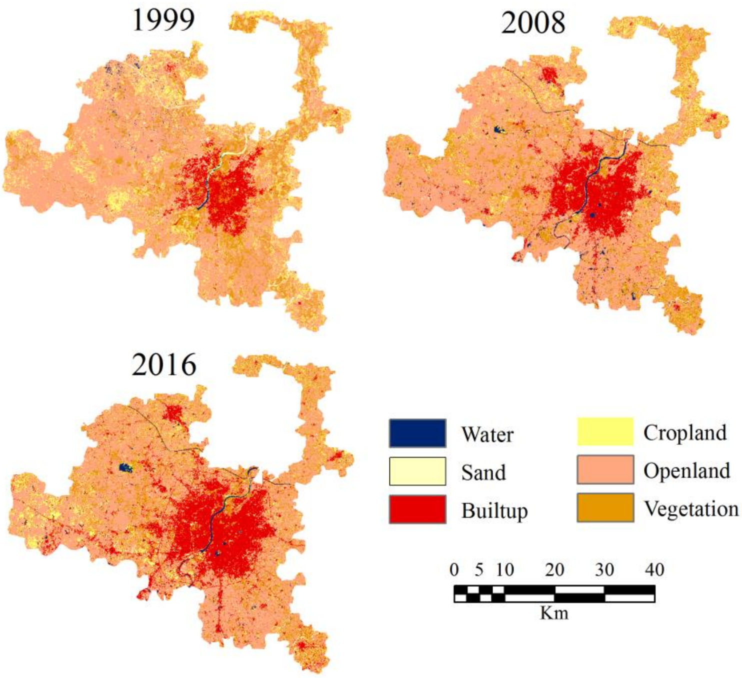

Figure 2.1: LULC map for 1999, 2008, and 2016

Table 2.5: Area of LULC classes for 1999, 2008, and 2016

LULC Class	1999	2008	2016
Built-up area	128.1807	242.89	385.16
Cropland	266.7177	146.24	141.62
Green spaces	280.9467	332.93	318.78
Sand	34.0623	15.46	43.93
Water bodies	11.5803	29.15	23.53
Open land	1170.4437	1125.26	978.91

2.4.2 LULC change

A summary of LULC maps is illustrated in Figure 2.1 and Table 2.5. LULC maps show a spatial pattern of six LULC classes between 1999-2016. Change and persistence estimation show 43% and 42% overall change for two periods viz., 1999-2008 and 2008-2016 respectively. AUDA is dominated by open land and current fallow (OL and CF) area. OL and CF class occupied 62% (1170.44 Km^2) area in 1999, 59% (1125.26 Km^2) in 2008 and 52% (978.91% Km^2) in 2016. The consistent loss of cropland is high in the AUDA area. In 1999, cropland occupied 14% (266.72 Km^2) area but was reduced to 8% (141.62% Km^2) in 2016. Net loss of cropland during 1999-2008 is extremely high (120.48 Km^2) but the loss is reduced (4.62 Km^2) during the 2008-2016, after the AUDA draft plan 2021 was implemented in 2007. In the beginning, green spaces net gain was 51.98 Km^2

areas but has witnessed persistently decline to rest at 14.14 Km^2 areas during 2008-2016. Water bodies were not well maintained before 2008. In 1999, the Sabarmati River almost dried out, following which the local authorities focused their efforts on reclaiming rivers and other water bodies in the AUDA region. Due to these efforts, 17.57 Km^2 water bodies and river area was reclaimed, but between 2008-2016 a net loss of 5.62 Km^2 areas was reported. It was classified that there was no flood/drought effect during 1999-2016. All the LULC maps were prepared for November, which is well beyond the monsoon effects. Despite the overall transformation intensity of LULC loss show a few new insights. Out of 1866 Km^2 area, only 1% (23.53 Km^2) area belongs to water bodies. High fluctuation of water bodies and green spaces occur perhaps due to the dry winter cycle. The high coverage area of open space is an outcome of large-scale land conversion from green space and cropland to open space. The land conversion process is summarized in Table 2.6. Details of LULC conversion (1999-2008), i.e. built up, water bodies, open land, cropland and green space are estimated. The growth of the built-up area occurs at the cost of sand (37%), green space (9%), open land (5.66%), and cropland (3.63%) during 1999-2018. However, during 2008-2016 open space contributed 19.35% area followed by green space (17.77%). Large-scale water bodies increase due to the conversion of the sand area to open land (16.33%). Riverfront development improved the water level in the Sabarmati river. Likewise, almost 68% area that classified as green shrubs is converted to water bodies. Large-scale city beautification projects converted the waste water lake and lake with green shrubs into a decorated lake and pond. Cropland area contributed almost 24.98% are to open land. In all aspects, cropland area is highly affected; almost 15% area converted to green space, 7.55% directly converted to built-up area, 8.68% converted to water bodies, and almost 6% converted to open land. The situation is not consistent in the 2008-2016 period. Conversion of cropland to other classes was restricted (almost 10% area). However, green space is still affected by built-up growth (7.32%). Built-up growth during 2008-2016 occurred due to open land (10.61%), water bodies, green spaces, and sand. It is observed that the process of LULC change is

Table 2.6: Land transition for the period 1999-2016

1999-2008	Built up area (%)	Cropland (%)	Green spaces (%)	Sand (%)	Water bodies (%)	Open land (%)
Built-up area	0	-7.55	-20.87	-9.85	0.51	-51.73
Cropland	3.63	0	15.92	0.26	0.38	24.98
Green spaces	9.52	-15.12	0	0.13	2.8	-15.84
Sand	37.07	-2.03	-1.05	0	16.33	4.3
Water bodies	-5.64	-8.68	-68.04	-48.03	0	-21.33
Open land	5.66	-5.69	3.8	-0.13	0.21	0
2008-2016						
Built-up area	0	-2.44	-17.77	-0.44	-2.27	-119.35
Cropland	2.44	0	-0.32	1.37	-0.6	1.73
Green spaces	17.77	0.32	0	2.67	0.1	-6.72
Sand	0.44	-1.37	-2.67	0	-0.65	-24.22
Water bodies	2.27	0.6	-0.1	0.65	0	2.21
Open land	119.35	-1.73	6.72	24.22	-2.21	0

quite regulated. Uncontrolled conversion of the natural ecosystem to the human-made surface is restricted, but still, green space and croplands are either directly or indirectly converted to built-up. Most of the natural spaces in the vicinity of existing built-up area are converted to built-up. Conversion of cropland to open land to built-up area and cropland to green space to the built-up area are the major pattern of LULC change. The built-up area in the AUDA occupied 128.18 Km^2 (7%), 242.89 Km^2 (13%), and finally 385.16 Km^2 (20%) in 1999, 2008, and 2016 respectively. However, this growth is reduced between 2008 and 2016. Built-up growth mainly occurs in the western river bank during 2008-2016. Extensive fragmented urban development is observed in the western bank since 1999.

During 1999-2016 almost 256.98 Km^2 (13.5%) urban area is expanded. Most of the growth occurs within AMC (Figure 2.2-2.3). Specifically, the peripheral municipal wards experienced high built-up growth. During 1999-2008, Western AMC inner periphery experienced almost 0.41-0.73 Km^2 average growth per annum, whereas Eastern AMC inner peripheral wards experience 0.21-0.41 Km^2 growth per annum. Two growth centres (GC) show potential growth, Sanand (0.25 per annum) and Kalol (0.25-0.30 per annum). These GCs faced extensive urbanisation due to large-scale industrial development. Between 1999 and 2008, almost 21% of the urban expansion was contributed by the western peripheries. Urban expansion share increased in the GCs during 2008-2016. Western AMC shows a consistent influx of urban expansion during

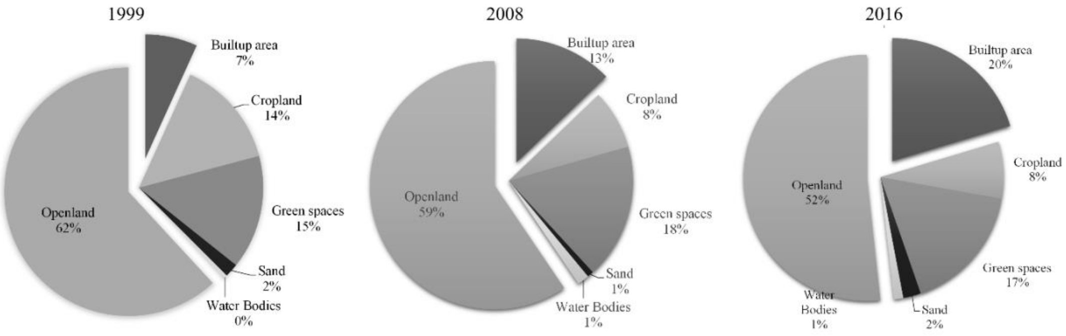

Figure 2.2: Percentage of LULC change for 1999, 2008, and 2016

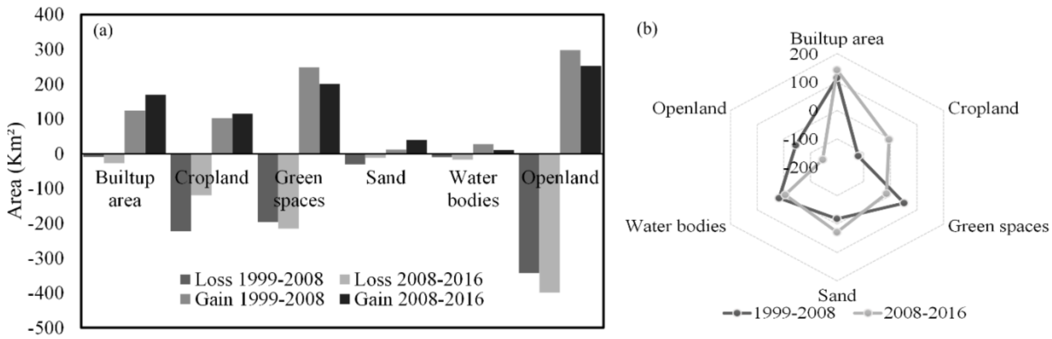

Figure 2.3: (a) LULC loss and gain for two periods (1999-2008 and 2008-2016), (b) Net change faced by the LULC classes for the same periods.

2008-2016. Growth per annum increases extensively in the Sanand (0.59Km^2) area. Western peripheries show almost 0.56-1.51 Km^2 average growth per annum. Central city shows almost zero average growth per annum, sometimes negative. Interestingly, western peripheries indicate a sudden influx of urban expansion, indicating urban sprawling.

2.4.3 Estimation of land consumption

Urban expansion in the immediate periphery of AMC shows extensive land conversion. Although, the AUDA Master Plan 2021 has regulated the land conversion process, yet the rate of urban expansion per annum is increasing. Overall the descriptive summary of urban expansion parameters is shows in Table 2.7. Average NBA during 2008-2016 per administrative unit is 0.6 Km^2 (σ = 1.27), average Pden is quite high (μ= 8297/ km^2, σ =16022.16) and extreme high density is observed in the eastern river bank (almost 81022/ Km^2), whereas high Hden is accounted for in old AMC areas and English Bridge area in the Western bank. Similarly, high road length density is observed in the central city area and GCs (Sanand and Kalol). PCO is declining in the core city (μ = 0.002km^2, σ = 0.02) but available in the remote areas. Literacy rate is high in highly urbanized areas (μ = 32.42, σ = 5.52). Overall, all these urbanisation parameters show land conversion process is significantly active in the western area which is currently experiencing urban growth, along with educationally rich, and employment opportunities. AUDA experienced high urban absorption in peripheries, and in-fill land consumption concentrates on the core city (Figure 2.4).

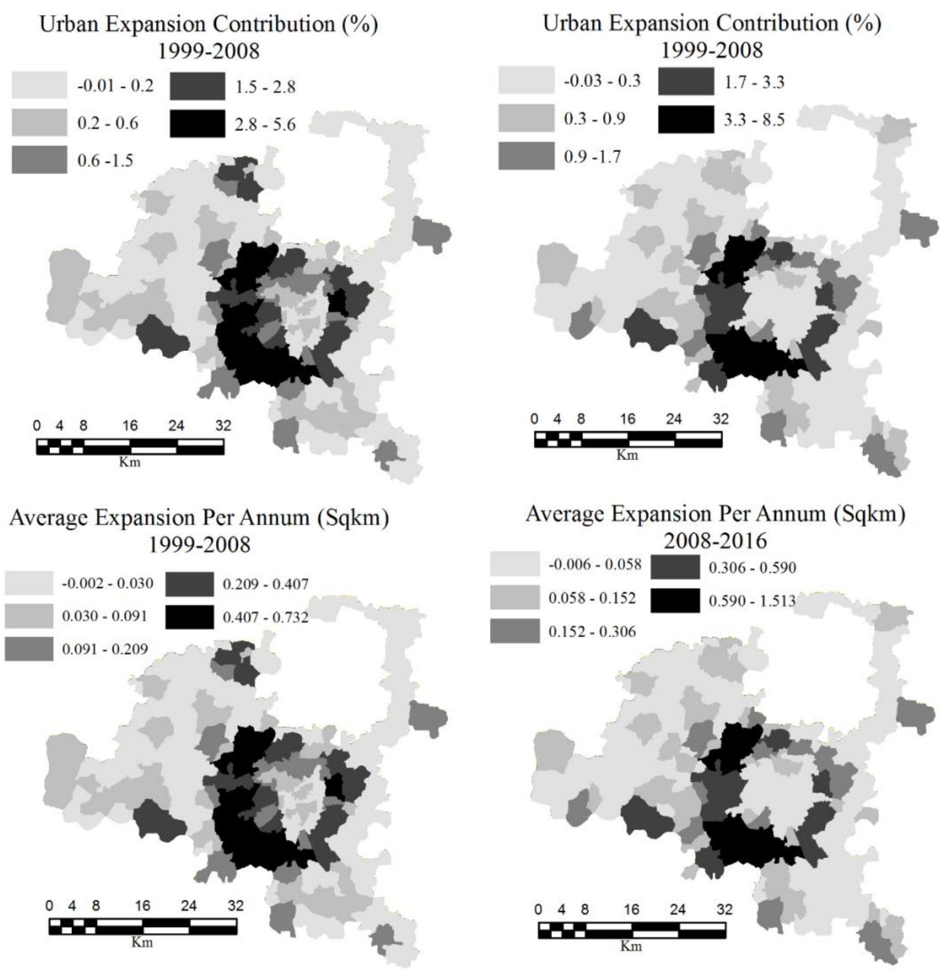

Figure 2.4: Urban growth metrics urban expansion contribution and average expansion per annum for the periods 1999-2008 and 2008-2016

Table 2.7: Descriptive statistics of land consumption indicators

	Minimum	Maximum	Mean	Std. Deviation
*NBA (Km^2)**	-0.05	12.11	0.60	1.27
Hden	9.94	21332.76	2088.22	4237.65
LAC	-23100.00	243000.00	1559.77	16284.02
PLAND	0.00	1.00	0.21	0.33
Pden	0.00	81022.54	8297.59	16022.16
PCO	0.00	16372.46	1341.71	1636.40
Plit	49.62	86.89	71.97	7.48
PMW	14.32	61.58	32.42	5.52
Rden	0.00	0.00	0.00	0.00
N= 238 observation, *= added built-up area during 2008-2016				

2.4.4 GeoSOM cluster

Using the land consumption parameters this study estimates spatially continuous clusters, Figure 2.5-2.6 depicts GeoSOM based land consumption (LC) clusters. Five major spatial clusters were extracted: LC Cluster 1 is highly dense and urbanised, LC Cluster 2 includes the areas that are within the AMC but not similar to the dense central city and peripheral expanding area. These clusters are highly accessible to less dense areas. LC Cluster 3 accounted the built-up emergence, open space availability with increasing density. This exemplified the potentiality of high land consumption shortly. A few administrative units that experienced high land conversion and socio-economic conditions do not appear in Cluster 3. Also, Cluster 3 includes one GC (Sanand), which is a potential site for future urbanisation. LC Cluster 4 covers the maximum remote village areas around the AMC, where Pden, Hden, and Rden are low; this cluster is opposite to the Cluster 3. This region includes a large tract of agricultural land and is not included in the current residential zonation process. Finally, LC Cluster 5, which considered the extreme western remote area, is one where per capita open space consumption is high. These clusters are far away from the present urbanisation pressure. This region will face a different development process (industrial zones) than the other parts of AUDA.

2.5 Discussion

2.5.1 Land consumption process

Compact high Pden and Hden in the central city indicate a high level of land consumption in the past. The intensity of land consumption rate is increasing in the peripheries, which is noticeable if we consider the pattern of per capita open space availability. High population growth was accounted in the eastern peripheries close to

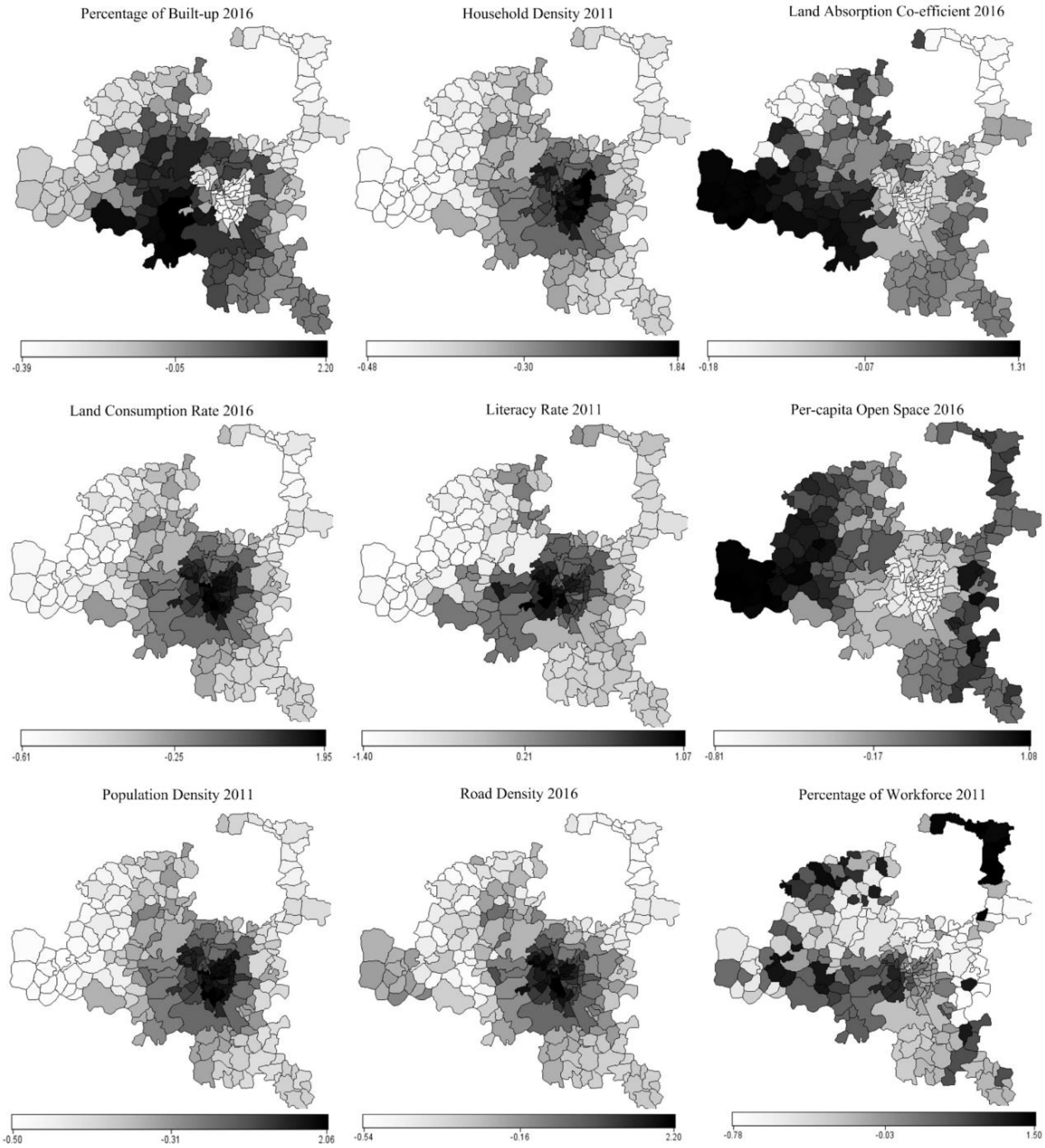

Figure 2.5: Factors of land consumption in AUDA region

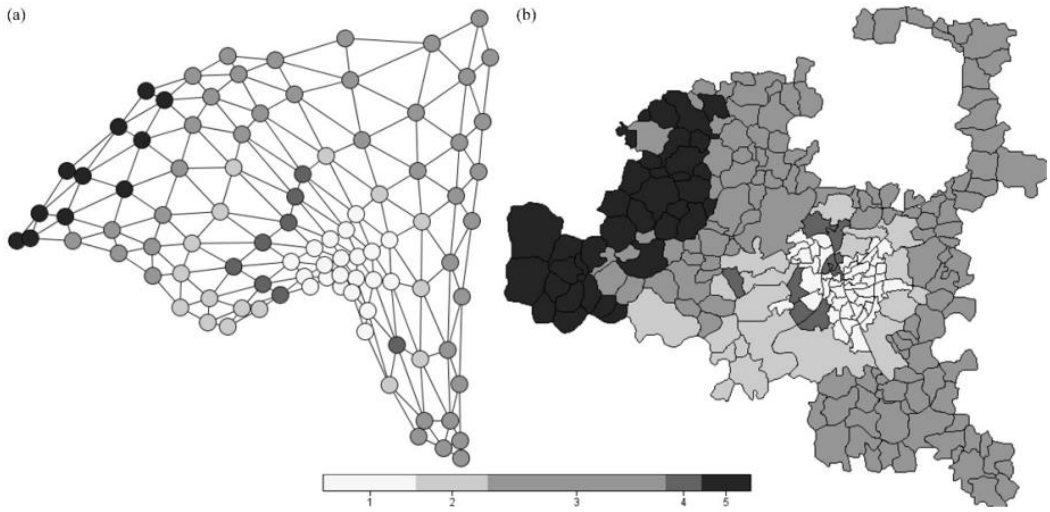

Figure 2.6: Five land consumption clusters of AUDA

the new industrial area (due to job accessibility), and high growth in the western bank occur due to educational facilities, service base blue collar jobs and good environmental availability (Adhvaryu, 2010). Also, large-scale land transformation occurs in the GCs of AUDA due to extensive industrial activity. Economic activity is one of the most important participant in the current land consumption process. On the other hand, household size shows declining trends in the western peripheries along with increasing built-up area, which indicates more nuclear family structure consumed a large number of lands. Urban expansion matrices show a significant decrease of built-up emergence in the core city at the same time, high LCR and LAC indicate residential sprawling in the western peripheries. The large-scale domestic housing market also actively influence the land consumption pattern in the suburban areas (Mehta et al., 1987).

Existing studies emphasised socio-economic attributes to investigate the pattern of land consumption (Gerundo and Grimaldi, 2011; Kumar et al., 2011; Roy, 2016). This research, on the other hand, has included a few land use parameters to understand the change process. It has also, emphasised the age-old debate on urban development discrepancies between the western river bank and eastern river bank. Based on the old data set and planning document, we have identified that land consumption rate was high in the eastern bank till 1999. After 1999 market-oriented planning and land use control measures in the western river bank have created a drastic change in land consumption rate (LCR). Average LCR is 48.16 m^2 in the central area, whereas LCR increases to 195.26 m^2 in the western bank (196.74 m^2), and 143.82 m^2 in the eastern bank (based on LULC 2016 and Census of India 2011). However, LULC 2008 and Census of India 2001 show opposite scenario. Eastern bank (512.73 m^2) consumes more land than the western bank (171.18 m^2). LCR significantly shifted to western peripheries after 2008. Perhaps due to the inclusion of 69 villages in the western peripheries by the AUDA Plan 2021, there exists a large availability for potential land which may account for consumption trends shifting towards western areas. At this point, land consumption cluster is used to identify the future potential consumption zone. To accommodate the large increase in suburban land consumption, simple zonation system is inadequate. Constant evaluation of sprawling scenario and housing market heterogeneity within the large clusters should be accounted aptly. This will help to maintain the urban land market imbalance, residential spillover, and optimum utilization of the land.

2.5.2 Planning and land consumption

All the previous Development Plans (DPs) of 1997, and 2011 (initiated in the year of 1987 and 2002 respectively) significantly influence the land consumption pattern. AUDA have started preparing their third consecutive development plan since 2007, which includes detailed land-use zonation and transportation plans. Former DP 2011 included only three residential zones (Figure A2.1 and A2.2), whereas most recent plans included pan-AMC affordable residential zones. Pan-AMC affordable zones are specified only for the economically weaker sections. Through a cross-comparison of residential zones of eastern river bank (DP 1997) and urban expansion, we observed that major growth occurred in the eastern river bank. Similarly, DP 2021 introduced high urban land consumption, but not consistent with natural preservation. However, LULC 2008 shows a significant increase of green space and water bodies which indicates uncontrolled land transformation to some extent restricted by the DP 2021. Significant improvement in LULC change has been observed after 2008. New DP 2021 makes a significant improvement, which is highly constructive and eco-sensitive. Despite that LULC 2008-2016 shows the significant transformation of cropland to open space. At the same time, AUDA boundary expansion affects the land markets. Planning scheme significantly reduces the uncontrolled land transformation, but unable to restrict the urban spillover and low density unidirectional urban expansion in the western peripheries. Land consumption cluster shows the outward spread of land consumption pattern (Cluster 2) which indicates a mismatch between high land consumption area and residential zones. A few researchers have highlighted the strong influence of large-scale local domestic markets on land consumption pattern (Ahmad et al., 2016; Hagenauer and Helbich, 2018).

2.5.3 Limitations of land consumption estimation

Although we explored the importance of land consumption clusters, this study is limited in three segments, i.e. data availability and quality, a limited number of explanatory variables, and the modelling techniques. The present study entirely depends on the Landsat images. LULC classification error can change the outcomes. Also, conversion of LULC pixel data into administrative units can invite large-scale aggregation error. Further, it is always better to present time series assessment to understand the land consumption clusters. However, widespread declassification of administrative units and the absence of proper information restrict the time series assessment. Based on planning literature, we have decided to ignore these small errors as long as we aim to account macro-scale land consumption behaviour. This study is also limited concerning available land consumption indicators. Only a few demographics and land use indicators can oversimplify the actual picture of land consumption behaviour. If we are unaware of such local robust indicators, then it is always difficult to replicate the reality. In the context of AUDA, income level is significantly associated with the land consumption pattern, according to the local expert. However, after detail examination, we prefer to drop our field survey based income data, which was not sufficient to infer any decision. Most importantly, we have selected a data mining model GeoSOM to extract the clusters. However, this model is better suited for large-scale datasets. The limitations of the study, notwithstanding, it provide good references to understand macro-level scenarios and can also be useful for macro-scale policymaking.

2.6 Conclusion

Most of the Indian cities show heterogeneous functions of land consumption factors. This study accounted for the land consumption situation in Ahmedabad based on LULC assessment between 1999-2016 using RS and GIS tools. It exhibits interesting insights into recent trends and patterns of land consumption. AUDA regions have experienced several planning phases and emphasised on the inclusive compact city plan. Our preliminary LULC assessment shows population decline in core city and increases in peripheries along with the massive increase of built-up area during 2008-2016. Built-up growth is shifted to the western area during 2008-2016. Population density increases in the peripheries in 2011, which indicates a decrease in land consumption in the central area. Estimated peripheral LCR shows a significant unidirectional increase of urban expansion (western area), which is represented in GeoSOM five unique clusters. Among the five clusters, Cluster 2 shows the high potentiality of future land consumption. This method efficiently established the linkage between data and train networks, which increase the level of understanding between data and their behaviour. The result shows land consumption heterogeneity exists in the AUDA region, i.e., core urban area, western suburban area, eastern suburban area, and the remote village area. In reality, despite some counter-intuitive outcomes, the study is useful to undertake regional policy. Also, this study can be replicated in other cities to evaluate the planning initiatives. It is recommended to the local authorities that rather than just new zonation system, broader land utilisation scheme greatly helps to regulate the planning failure. For instance, the unregulated urban expansion will occur in the potential land consumption clusters instead of residential zones. Further, to understand the details of policy failure, urban sprawling and housing market assessment will help to build an efficient LULC management system. Following chapters will explore these aspects to formulate a comprehensive policy framework.

Appendix

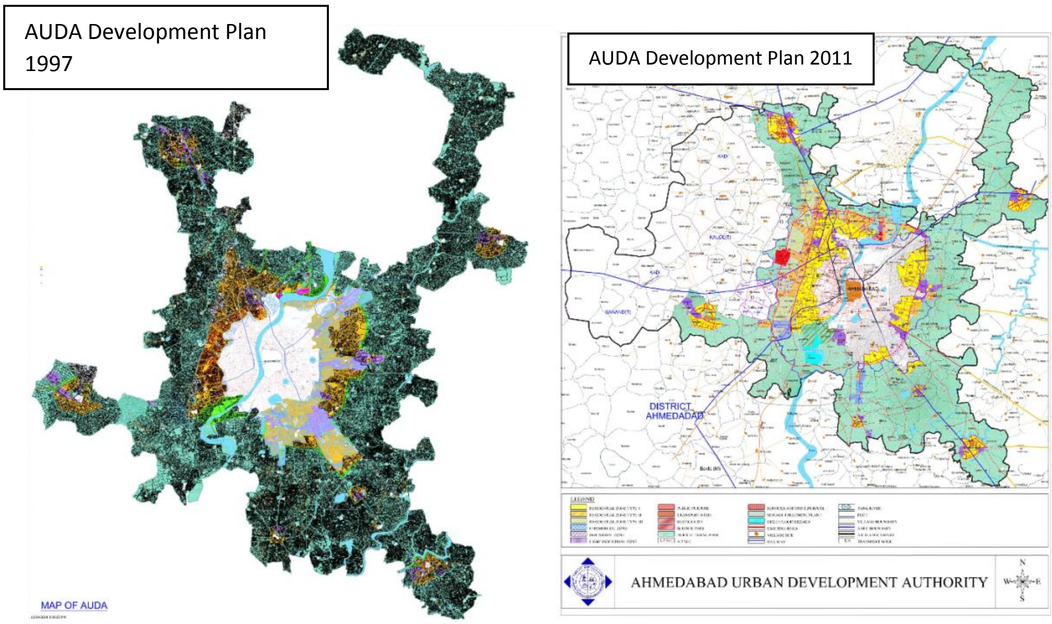

Figure A2.1: AUDA development plan 1997 and 2011

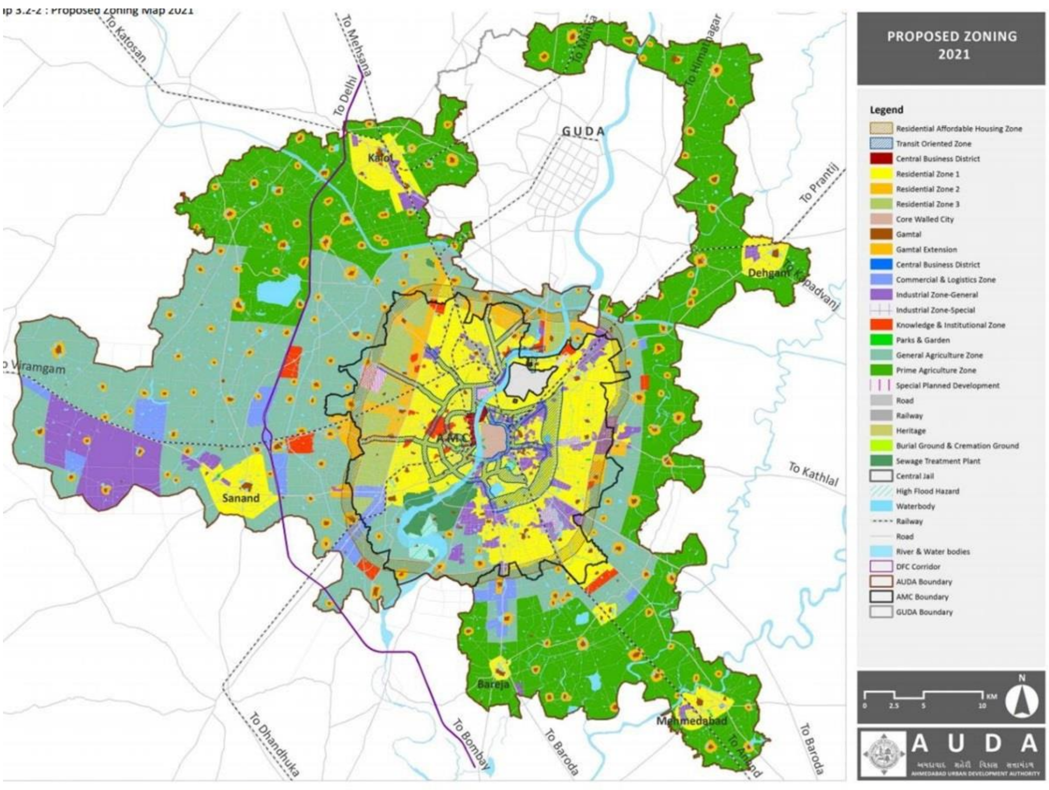

Figure A2.2: AUDA Development Plan 2021

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Chapter 3

Valuation of Environmental Amenities

3.0 Introduction

Across the world, urbanization scenarios trigger widespread ecological problems, both in urban areas as well as in their peripheries (Wu et al., 2013; Ardeshiri et al., 2016). One of the changes is an altered local environment- an issue of major concern (Brown et al., 2012). Specifically, in developing countries, the magnitude of the ongoing urbanization process has caused significant changes in urban form, pattern, rate, and functions (Seto et al., 2010). Chapter 2 already have illustrated the evidences of LULC change in the Ahmedabad. Factors including high pollution level and fragmentation of natural spaces like open space, green space and wetland (Sander and Polasky, 2009; Nilsson, 2014; Wen et al., 2014; Xu et al., 2016) have raised serious question against urban residential quality. Deterioration of natural amenities due to rapid industrial development and Urbanization make the task of achieving sustainable urban development goals even more difficult. Several studies show that the urban quality of life no longer depends on Urbanization and industrialisation, but is closely associated with the social and economic services of natural ecosystem (Goffette-Nagot et al., 2011). Trees cover, wetland, and open space reduce soil erosion, improve local air quality, reduce the effects of urban heat island, provide a natural condition for wildlife, provide shading to buildings, carbon sequestration, and reduce surface runoff erosion (Maller et al., 2006). According to Gidlöf-Gunnarsson and Öhrström (2007), garden and parks, green space, and trails are highly associated with wellbeing and satisfaction of urban resident. Waltert and Schlapfer (2010) observed that beneficial outcomes of natural amenities and differing qualities of land cover are reflected in housing price, open space and woodland regularly, and agrarian land once in a while. A recent study by Xu et al., (2016) on Beijing accounted that green spaces are 2.20% and 13.40% associated in the vicinity of housing development site inside a 100 to 550 m distance respectively. Apart from that, Belanche et al., (2016) demonstrated that environmental amenities are significantly associated with public health and livability in the urban area. Most of these studies show that residential demand is driven by local natural amenities besides house quality (Li et al., 2016). There is a justifiable reason to expect that the cost of housing will exhibit spatial heterogeneity inside vast housing markets due to the observed bundles of residential services (Li et al., 2016). Increasingly, these amenities are recognised as valuable attributes for sustainable urban planning.

Studies show that the environment in the sub-urban areas pulls the central city population (Neuman, 2005; Baker et al., 2016; Sinniah et al., 2016; Ströbele and Hunziker, 2017). We have identified two popular approaches to understand the environmental amenity induced residential pattern: (i) residential attractiveness, and (ii) residential spill-over. These two approaches are closely linked with each other, but their functions differ significantly. Residential attractiveness can be defined as a market, infrastructure, environment, and neighbourhood and their ability to influence the decision of the creative people (Romão et al., 2017). Increasingly neighbourhood design, recreational opportunities, and natural space preservation are the major planning goals to improve urban quality of life and satisfaction (Cao and Wang, 2016). A few studies have accounted high association between housing preference, environmental amenities, and residential attractiveness (Liu and Robinson, 2016; Maleki and Zain, 2011). In developed countries, residential attractiveness has been used as a popular agenda for shrinking city redevelopment (Miot, 2015; Sinniah et al., 2016). It is also observed that residential attractiveness and neighbourhood rurality construct an ‘Anti-Urban’ housing market (Ströbele and Hunziker, 2017). In contrast, across the developing countries, urban developmental agendas have greatly ignored the values of environmental amenities such as open space, green cover, urban lakes, and water bodies (Ibarra et al. 2013; Lee and Schuett 2014; Wen et al., 2015; Vollmer et al., 2016). Subsequently, residential attractiveness invites myriad problems of low-density residential development (Cao and Wang, 2016; Weber, et al., 2017), loss of agricultural land (Ströbele and Hunziker, 2017), and housing affordability (Baker et al., 2016).

On the other hand, residential spillover can be defined as housing demand and supply side scenario (Byun and Esparza 2014). A majority of the recent empirical assessments demonstrate that absence of open space, congestion and pollution, and the cost of public services are emphatically related to residential spill-over and sprawling (Ewing 1997). Sometimes, zonal policies increase the housing price, as a result of which housing demand shifts toward neighbouring areas. Similarly, less controlled peripheral areas are highly profitable to developers, hence housing stock increases (Paulsen, 2013; Rizzo, 2014; Vos et al., 2016). The benefits of having natural amenities in a locality will be given significant importance at the time of purchasing a house (Glaesener and Caruso 2015), only if the housing price is within an affordable range. Therefore, the willingness of people to pay for certain amenities sometimes drive against the zonal policy due to the price constraint, which can also affect the urban pattern.

Residential attractiveness and spillover both these approaches are worthwhile to understand the strength and weaknesses of compact city policy. In this respect, environmental valuation can be a suitable tool to quantify the amenities induced residential attractiveness. To the best of our knowledge, only a few studies have been conducted in India to examine the implicit price of non-marketable commodities at the time of house selling (Mehta et al., 1987; Tiwari and Parikh, 1998; Mahalik and Mallick, 2011; Edadan, 2015), but ignored the environment. Several studies are investigating the association between land use amenities and housing prices (Jim and Chen, 2009; Sander and Polasky, 2009; Brown et al., 2012; Li et al., 2016), but most of them ignore the spatial influence of people perception and environmental amenities on housing price. It won't be wrong to say that not a single study has tried to estimate the mismatch between residential zonation and environmental amenities through a valuation approach. Our strategy is not to deliver a reappraisal of the hedonic price model, but to improve the empirical understand of the residential attractiveness and spill-over in sustainable land use planning. This chapter comprises valuation approach to strengthen LESS framework, which is also worthwhile to quantify the mismatch between environmental amenities based housing region and master plan based residential zones. The objectives of this chapter are: (1) to quantify the services of local urban amenities with a special emphasis on environmental parameters, (2) to examine the association between residential zonation and environmental amenities and (3) to depict the spatial dependence of environmental amenities and spacing criteria on housing price.

Among the numerous housing market investigations, this study is unique in terms of (i) its comprehensive spatial assessment of potential residential zones through structural, local market situation, people perception, and environmental (including land use) amenities to disseminate the urban public policy, and (ii) it attempts to fill the gap in the assessment of residential attractiveness in the Indian context. Specifically, this empirical assessment is unique, when we consider monitory based trade-off between amenities and future threats. This contributes to the literature of the following grounds: it hopes to provide evidence on how the valuation approach and spatial association estimation process can be used to judge the residential spillover. Moreover, to the best of our knowledge, this spatial residential attractiveness assessment is the first attempt on the city of Ahmedabad which may be helpful to the local government. This study can also be used to formulate urban land use policies for other cities, and to regulate urban housing markets.

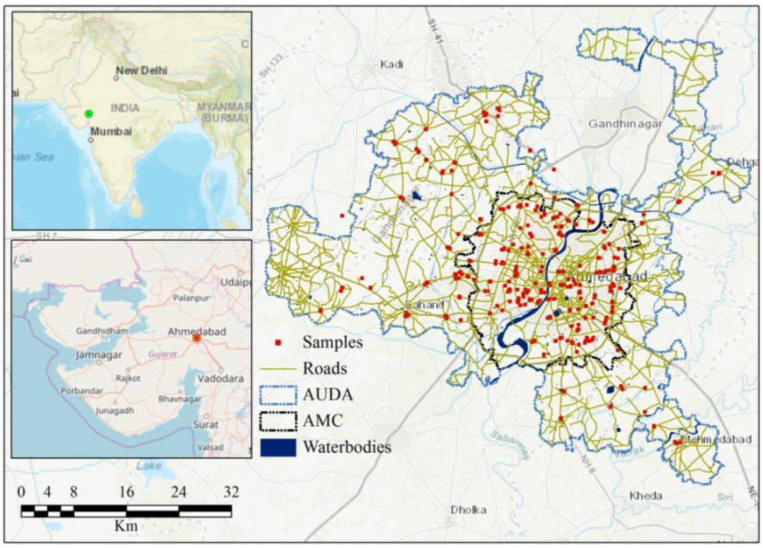

Figure 3.1: Samples of housing information of AUDA region

3.1 Materials and methods

3.1.1 Survey and data

The AUDA administrative boundary is quite large; it required extensive time and resources to collect optimum samples Figure 3.1. The present study used the map grid (500m x 500m) method for sample collection (Shabana et al., 2015), which divided the entire AUDA into several rectangular grids. Preferences were given to those map grids, which contains at least one settlement form among urban, semi-urban, growth centres, and peripheral townships (remote villages were excluded). The samples were collected from the preferred grids (the survey was conducted in September 2016) following the purposive random sampling scheme. Depending on settlement heterogeneity maximum of five samples were collected from preferred grids. In order to record the samples, a prerequisite questionnaire was designed. To explore the pattern of associations between housing prices and amenities, the location (latitude and longitude) of each sample were recorded, and we considered each respondent as a decision-maker. Finally, we have collected 465 paper-based samples, out of which only 397 were useful.

3.1.2 Housing price of AUDA

To estimate the value of urban amenities, housing price was used as a dependent parameter. The unit of the recorded house prices (10 lakh = 1million) is given in Indian Rupees (INR; Mean=46.41 lakh, SD=60.03 lakh, 1USD= [approximately] INR 66.69 according to 2016 exchange rate). Spatial distributions of the sampling units are shown in Figure 3.1. The AUDA showed spatial variability in housing price due to accessibility and availability of local amenities (Mehta et al., 1987). A preliminary assessment explained the type of houses (i.e., single stories, duplex, and apartment) that are actively participating in the dynamics of the housing market. Through the assessment, we observed specific admin units guiding the choice of houses. For instance, the demand for a duplex house within AMC is far high than the villages and suburbs (Figure 3.2).

3.1.3 Explanatory variables

The present study examined the driving parameters into five broad aspects, viz., structural, accessibility, environmental and land use, people perceptions, and market-based amenities. A few parameters of these components were directly collected from the field survey, and the others were processed (i.e., land use attributes). All the selected parameters have been found to be highly associated with housing price in the existing studies (Sander et al., 2010; Nilsson, 2014). A brief description of the selected attributes was presented in Table 3.1. Mainly, three different levels of information were used in this study viz., household, proximity, and neighbourhood. Household and proximity data

Table 3.1: Descriptive summary of the collected data

Variables	Units	Raw data source	Data collection	Mean	Standard deviation	Expected Sign
Housing Price	INR (Rs.)	Survey	Household	46.41	60.27	
Structural Characteristics						
Lot size (sqft)	Sqft	Survey	Household	901.79	678.66	+
House age	Year	Survey	Household	20.41	17.21	-
No of bedrooms		Survey	Household	2.63	1.25	+
Distance between dwelling units (m)	Meter	Survey	Household	7.06	38.22	+
Accessibility						
No of hospitals (r=5000m)		Google Earth	Neighbourhood	24.47	30.14	+
No of schools (r=3000m)		Google Earth	Neighbourhood	15.68	21.66	+
Nearest bus stop (m)	Meter	Google Earth	Distance	891.08	1174.83	-
Nearest rail station (m)	Meter	Google Earth	Distance	3665.44	3046.45	-
Nearest major road (m)	Meter	Google Earth	Distance	181.60	208.35	-
Environmental and Landscape[1]						
Nearest water bodies (m)	Meter	AUDA Plan 2021	Distance	820.49	687.95	-
Nearest parks (m)	Meter	AUDA Plan 2021	Distance	3815.15	4693.29	-
Thermal Index 2016 (r=250m)	Percentage	USGS	Neighbourhood	31.14	4.03	-
Vegetation Index 2016 (r=250m)	Percentage	USGS	Neighbourhood	41.07	5.81	+
Openness index 2008 (r=250m)	Percentage	USGS	Neighbourhood	0.35	0.30	+
Openness Index 2016 (r=250m)	Percentage	USGS	Neighbourhood	0.29	0.27	+
Tree cover 2008 (r=250m)	Percentage	USGS	Neighbourhood	4.08	7.32	+
Tree cover 2016 (r=250m)	Percentage	USGS	Neighbourhood	2.10	4.48	+
Perception						
Air quality	Score	Survey	Neighbourhood	5.63	1.85	-
Water quality	Score	Survey	Neighbourhood	6.55	1.89	-
Noise quality	Score	Survey	Neighbourhood	4.93	2.28	-
Transportation quality	Score	Survey	Neighbourhood	7.43	2.73	+

No of observation = 397, '+' indicates a positive association with house price, '-' indicate a negative association with house price, [1] indicate variables are processed, raw images are collected from USGS, INR=Indian Rupees

were collected during field survey and GIS tools respectively. Neighbourhood information was collected for environment, perception, and market class. Neighbourhood information was computed using the mean value of the pixels within a specified buffer, which is useful to estimate local spatial effect (Sander and Polasky 2009; Sander et al., 2010; Schläpfer et al., 2015). Different buffers (r=250m, r=500, and r=750m) were applied to draw the best fit neighbourhood limit. But, the majority of the neighbourhood variables were found to be multicollinear, as per the VIF value (Schläpfer et al., 2015). Therefore, those variables which had a high VIF value (VIF >10) were dropped.

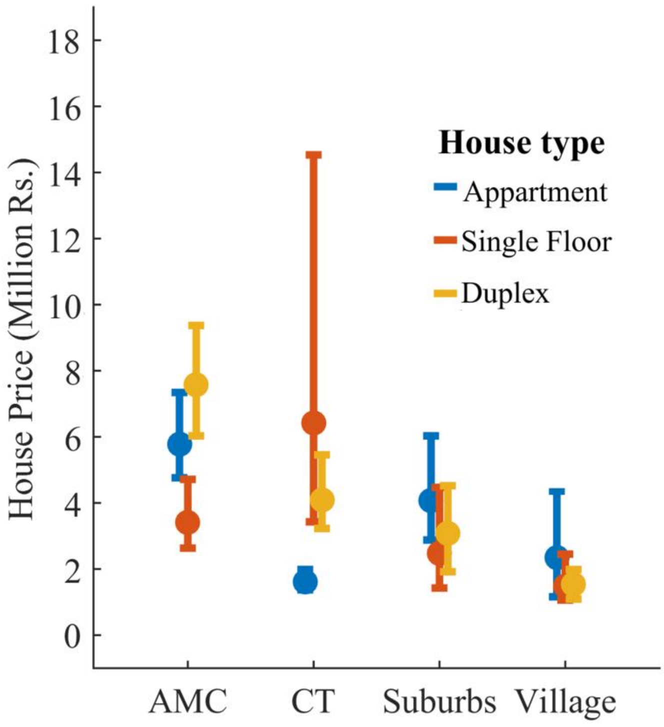

Figure 3.2: Observed housing price variation across the different administrative units

Structural variables

To establish housing price variability, we compiled the structural characteristics (i.e., lot size, house age, no. of bedrooms, and space between dwelling units) of 397 households across the AUDA administrative area. It was seen that the structural characteristics are still key factors determining the house prices (Shabana et al., 2015) and cannot be excluded from valuation research (Jiao et al., 2017). The preliminary descriptive analysis showed that housing price is closely associated with the number of bedrooms and age of the housing units. To put it clearly, house prices increase with the increase in a number of bedrooms (Mean=2.63, SD=1.25). Similarly, lot size (Mean=901.79, SD=678.66) and space between dwelling units are also associated with housing price variation.

Accessibility variables

Apart from structural parameters, accessibility parameters are also used to explore the housing price heterogeneity (Powe et al., 1995). On the basis of accessibility, rural housing demand and urban housing demand can be distinguished. Urban house prices are highly associated with accessibility to road, hospital, schools, and bus stop compared to rural housing. Minimum road distance measures are found to be useful to understand the value of the local amenities (Nilsson, 2014). GIS-based road distance between housing unit and amenities were recorded. The proximity to the road (Mean=181.60m, SD=208.35m), railway station (Mean=3665.44m, SD=3046.45m), and bus station (Mean=891.08m, SD=1174.83m) were generated with the help of Google Earth and AUDA Development Plan 2021. Apart from the proximity, neighbourhood information is also beneficial to estimate the value of speciality based amenities such as schools and health centres. For example, categories of schools (i.e., nursery, secondary, and high secondary etc.) and hospital clusters can exert a strong influence on home sales price (Shabana et al., 2015). Simple proximity based assessment is not enough to capture the values of schools and hospitals availability. Therefore, this study preferred GIS-based multi-buffer approach (3000m and 5000m) to include amenity clusters. No of hospital (r=3000, r= 5000) and no of schools (r=3000, r= 5000) around the housing units were captured. Initially, it was found that access to highway, bus service, hospitals, and schools are greatly associated with house price (Table 3.1). However, due to the high variance inflation factor (VIF) value, no of the hospital within 3 Km and no of school within 5 Km were dropped out of the final estimation.

Environmental and land use variables

Environmental and land use variables were categorised into two segments: accessibility and neighbourhood information. Accessibility measures only capture proximity to environmental amenities whereas, neighbourhood information considered intensity. Landsat data for November 2008 and 2016 were used to prepare the neighbourhood attributes, viz., land surface temperature (LST), normalised vegetation index (NDVI), and the land use land cover (LULC) based amenities. High temperature, as is known to all, affects a community's living environment and increases energy consumption, air pollution and stress on the aquatic ecosystem (Laurila-Pant et al., 2015). In contrast, NDVI minimises these harmful urban heat island effects. LST and NDVI were computed using B4, B5, and B10 band for the year 2016 and B3, B4, and B6 for 2008 to test the temporal effect (Eq 3.1 and 3.9 explain the LST and NDVI estimation process). Thermal and vegetation indices were computed as follows,

$$L_{\omega} = gain.DN + bias \qquad (3.1)$$

To convert the pixel digital number (DN) to spectral radiance (L_ω), the gain and bias conversion coefficient (Eq 3.1) was used (Walawender, Hajto, and Iwaniuk, 2012). Further, brightness temperature (T_b) was computed using L_ω, and Plank's constant for Landsat 8 B10 band is $K_1(774.8853\, W/m^2.sr.\mu m)$ *and* $K_2(1321.0789\ W/m^2.sr.\mu m)$ (Eq 3.2) (USGS, 2005; Rosas et al., 2017).

$$T_b = \frac{K_2}{ln\left(\frac{K_1}{L_\omega}+1\right)} \tag{3.2}$$

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{3.3}$$

$$\mathrm{V}_p = \left(\frac{NDVI - NDVI_{soil}}{NDVI_{veg} + NDVI_{soil}}\right)^2 \tag{3.4}$$

NDVI is computed for Landsat TM 2008 and Landsat OLI 2016. Sobrino et al., (2008) threshold modified NDVI method was used to estimate land surface emissivity (LSE). Standard emissivity (ε) value for soil (ε_{soil}) and vegetation (ε_{veg}) were used (Carlson and Ripley, 1997). The mixed pixels ε were computed using Eq 5, where V_p is the vegetation proportion (Eq 3.4), F is the geometrical factor, and C_ω stands for cavity effects (Eq 3.6).

$$\varepsilon = \varepsilon_{veg}.\mathrm{V}_p + \varepsilon_{soil}.\left(1-\mathrm{V}_p\right) + \mathrm{C}_\omega \tag{3.5}$$

$$\mathrm{C}_\omega = \left(1-\varepsilon_{veg}\right).\varepsilon_{soil}.F.\left(1-\mathrm{V}_p\right) \tag{3.6}$$

The single channel algorithm was applied to compute the land surface temperature (LST) (Jiménez-Muñoz et al., 2014). LST required atmospheric correction parameters to compute atmospheric function ψ_f, ψ_s, and ψ_t.

$$LST = \vartheta\left[\frac{1}{\varepsilon}\left(\psi_f L_\omega + \psi_s\right) + \psi_t\right] + \gamma \tag{3.7}$$

$$\vartheta = \left\{\frac{C_2 L_\omega}{T_\omega^2}\left[\frac{\lambda^4 L_\omega}{C_1} + \frac{1}{\lambda}\right]\right\}^{-1} \tag{3.8}$$

$$\gamma = -\vartheta.L_\omega + T_b \tag{3.9}$$

Atmospheric parameters were derived from MODTRAN web-platform (Barsi et al., 2003; Barsi et al., 2005). Plank's radiation constant C_1 and C_2, effective wavelength (λ) and two other parameters are ϑ and, γ were estimated given by Eq 3.8 and 3.9 (Jiménez-Muñoz et al., 2014). To avoid the extreme value biased this study further normalized LST and NDVI (Jiao et al., 2017). LST was converted to thermal ina dex $T_{index} = \frac{LST_i - LST_{min}}{LST_{max} - LST_{min}}$ where, LST_i is actual temperature, $LST_{max}, and\ LST_{min}$ is maximum and minimum temperature. Similarly, vegetation index was computed based on NDVI value. But, thermal and vegetation index for the year 2016 and only r=250m was considered for final estimation (VIF<10). The descriptive summary shows that the thermal index 2016 (Mean=31.14%, SD=4.03%) and vegetation index 2016 (Mean=41.07%, SD=5.81%) are highly variable across the AUDA.

The LULC maps were processed using maximum likelihood algorithms (using 250 training samples), and the accuracy was estimated using the Kappa index. The overall accuracy and Kappa index for LULC 2008 were found to be 87% and 84%, whereas LULC 2016 showed a value of 91% and 88% respectively, which can be used for further estimation (Congalton, 1991). LULC map contains five classes: built-up area, cropland, green space, open land, and water bodies (Figure 3.3). Numerous studies show LULC component significantly associated with quality of living, at the same time influence price of the property (Kim, 2018). Based on LULC classes this study prepared a few landscape based amenities, percentage of tree cover and openness index using GIS tools (VIF < 10 for r=250m). Openness Index was computed using the ratio of open land and the built-up area within a specified buffer, which indicate the amount of open land for each urban land unit. Open space includes ground, public space, plazas and current fallow agricultural land. Similarly, the proportion of tree cover was computed using the following formula: tree cover area within a specified buffer divided by the total area within the buffer.

Accessibility-based amenities (i.e., park and water bodies) were processed according to the AUDA draft plan 2021. Three types of parks were taken into consideration - neighbourhood parks that are small in size but distributed well across the residential areas, community parks that include recreational activities and city parks that are regularly maintained, and have an attractive recreational environment and access to public transportation. The aesthetic value of these areas is greatly beneficial in daily walking, spending safe time, and intensifying the scope of social relations (Nelson, 2014). Specifically, park accessibility is highly relevant in the congested central city. Similarly, different water bodies like canals, rivers, and ponds were included in this study. However, not all of these water bodies are maintained; some of them were used for waste disposal. Road distance between household and the park (Mean=3815.15m, SD=4693.29m), and water bodies (Mean=820.49m, SD=687.95m) were computed using the GIS tool. Preliminary assessment shows current residential expansion in AUDA is closely coupled with environmental amenities.

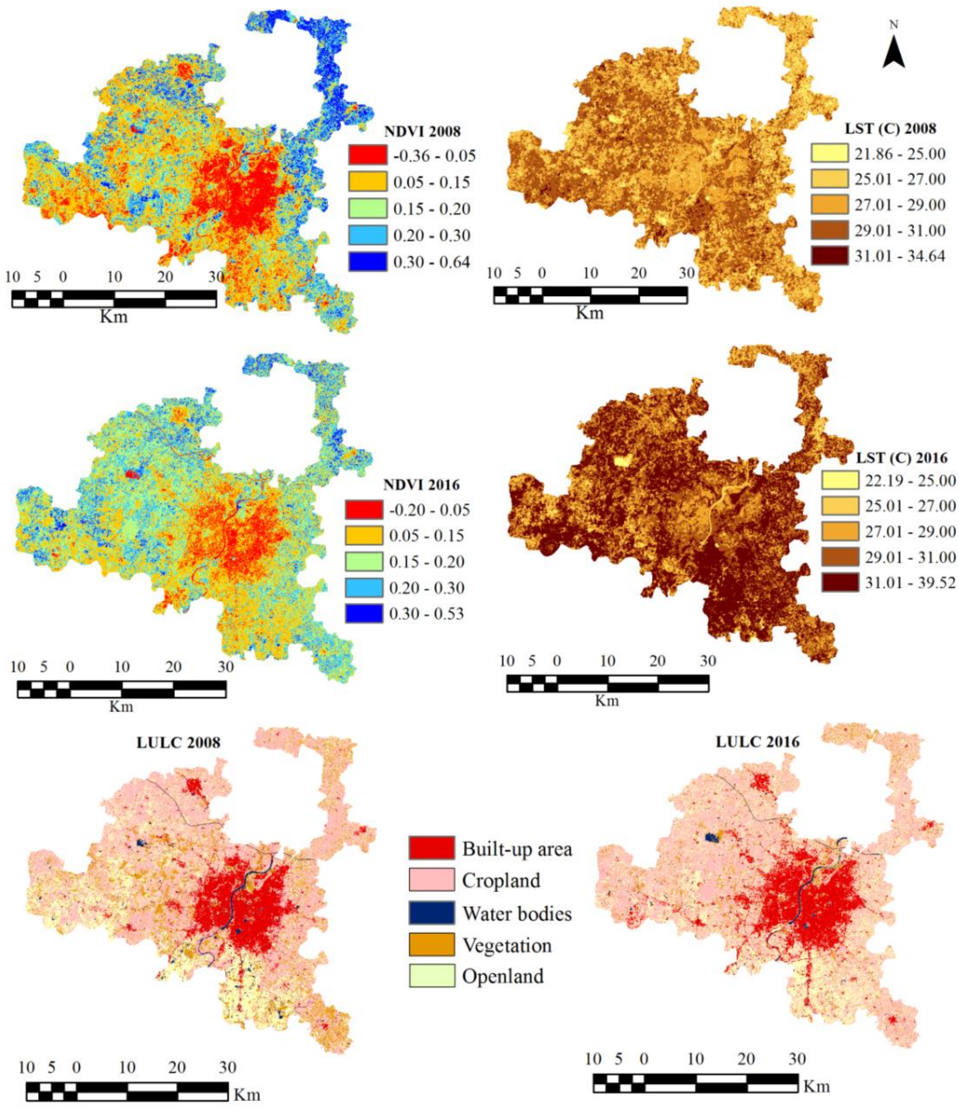

Figure 3.3: LULC, NDVI and LST for November 2008 and November 2016

People perception

According to Rey-Valette et al., (2017), the perception-based measure is a powerful and flexible non-monetary tool. At the household level, people perception was obtained based on interviews conducted during the field survey. Score based perception is used to capture the preference-driven urban residential attractiveness (Ardeshiri et al., 2016). All the perception-based variables are ranged between 0 and 10, where 0 indicated a poor condition and 10 indicated good conditions. To reduce the subjectivity, we created a five-point scale (Score=0, 2, 5, 7, 9) with the help of local experts. For example, the standard decibels (dB) threshold and characteristics of the local area were used to demarcate the noise quality score i.e., residential zone (55dB) ≥ 9, Market area (60dB) = 7, construction (65dB) = 5, traffic (70dB) = 5, heavy industrial activity (> 75dB) = 0. Similarly, usability was considered the criterion for evaluating water quality, i.e., directly drinkable ≥ 9, drinkable after filtering = 7, other than drink =5, bad smell = 3, not usable = 0. Residential and neighbourhood criterion was considered for air quality score i.e., quasi-residential (with > 30% natural space) ≥ 9, dense residential (with >10% natural space) = 7, traffic node and market area = 5, industrial activity = 3, and birthing problem = 0. The transport quality considered quality of the road and maintenance system, road width, issues of waterlogging, and garbage dumping as the scoring criteria. To minimise the extreme response, we have converted this household response to a neighbourhood response. However, only four major perception-based variables- air quality (Mean=5.63), water quality (Mean=6.55), noise quality (Mean=4.93), and transportation quality (Mean=7.43) were processed, only r=250m was found suitable for further assessments (VIF<10).

Market-based dummies

Finally, we included a few market-based dummy (binary) attributes which are assumed to be responsible for the sub-urban house price variation (Schläpfer et al., 2015). Market dummies are used to capture the sub-urban economic attractiveness. Binary (0,1) parameters such as public transport availability (Yes=1, and No=0), and plot planning (available=1, not available=0) were added to capture the land zoning intensity. Similarly, the nearest development project (Present=1, Absent=0) was included to consider large-scale public or private investment and townships around 1000m (present=1, no =0) were collected to demarcate domestic housing market. Likewise, the price change caused by speculation (available=1, not available=0) was used to generalize the market behaviour. All these market-based dummies were collected during the field survey at the neighbourhood level.

3.2 Spatial variability estimation

Apart from other valuation approaches, this study chose the hedonic approach to test the extent to which natural amenities influence residential attractiveness in Ahmedabad (Mondal and Das, 2018). Hedonic pricing method measured the implicit price that the consumers are willing to pay (Laurial-Pant et al., 2015). The quantification of amenities in monetary terms allowed us to make a trade-off between the benefits of amenities (Lavrilaand Pant, 2015). Although the hedonic theory ignored external influence for a while, it did emphasise the benefits of natural ecosystems on the living standard of humans. Initially, a hedonic approach considered housing as a homogenous service and the price of a housing unit depended on its structure and market behaviour. Later, with the advancement of modelling tools and methods, large numbers of applications were used to ascertain heterogeneity in the local housing market (Adair at al., 1996). As a result, non-marketable goods and services were broken down into several segments. Further, to improve interpretability and spatial variability, different spatial GIS-based hedonic forms along with landscape component were increasingly adopted (Bitter et al., 2007) and investigated. Often, the traditional Ordinary Least Square (OLS) hedonic form got challenged by the heterogeneity constraints (Fotheringham et al., 1998) and spatial residual dependence (Huang et al., 2017). Such limitations and shortcomings could not be afforded by the global estimation (Fotheringham et al., 1998). Thus to meet the challenge, the Geographically Weighted Regression (GWR) was considered as an alternative to OLS. Although, the GWR has a few limitations in terms of multicollinearity (Wheeler and Tiefelsdorf, 2005) and error dependency (Tiefelsdorf and Griffith, 2007), yet it is still used to explore local variations and decision-making (Helbich et al., 2014). In real estate research, the hedonic OLS model is a commonly used regression that evaluates the effects of explanatory variables on housing prices (Huang et al., 2017) and it can be examined as,

$$\ln(\text{house price}_i) = \beta_0 + \beta_1 structural_i + \beta_2 environmental_i + \beta_3 accessibility_i + \beta_3 perception_i + \beta_3 market_i + \varepsilon_i \quad (3.10)$$

Where, $\ln(\text{house price}_i)$ represents the natural log of house price at location i, $structural_i$ represents housing structural parameters, $environmental_i$ indicates environmental parameters, $accessibility_i$ includes accessibility parameters, $perception_i$ including score based people perception, $market_i$ is a market based dummy, and ε_i is an error term. However, to observe heterogeneity, the present study adopted a local spatial hedonic form which can be expressed as

$$ln\Upsilon_i = \sum\nolimits_{\mathrm{q}} \beta_q\,(m_i, n_i)\vartheta_{q,i} + \varepsilon_i \quad (3.11)$$

Where, Υ_i is a dependent variable; $\vartheta_{q,i}$ is an independent variable and ε_i is a Gaussian error. Here, $\beta_q(m_i, n_i)$ are varying conditional, and locational (m_i, n_i) is a coordinate of the location i;

The adaptive bi-square Kernel was used to calculate the weight matrix. Subsequently, the bandwidth size was determined using minimum Akieki Information Criteria (AICc) value (Fotheringham et al., 1998). The kernel type can be expressed as (e.g., Nakaya, 2009);

$$\mathcal{W}_{xy} = \begin{cases} \left(1 - \mathcal{D}_{xy}^2/\delta_{x(k)}\right)^2 & \mathcal{D}_{xy} < \delta_{x(k)} \\ 0 & \mathcal{D}_{xy} > \delta_{x(k)} \end{cases} \quad (3.12)$$

Where, x is the regression point index; y is the location index; $\mathcal{W}_{xy}$ is the observation weight for the location y to estimate the x coefficient at location. The Euclidean distance between x and y is denoted as $\mathcal{D}_{xy}$. The fixed bandwidth size δ_x is defined by a distance metric measure and adaptive bandwidth size $\delta_{x(k)}$is defined using k the nearest neighbour distance.

To assess the spatial heterogeneity between house prices and amenities, this study carried out a variability test for each parameter by comparing the Interquartile Range (IQR) of the parameter with the 2*Standard Error (SE) of that parameter. If IQR was higher than 2*SE, it indicated a non-stationary process (Helbich et al., 2014). Finally, to find out the goodness of fit, GWR estimated residual spatial autocorrelation was measured using a weighted distance matrix. This autocorrelation measure showed spatial error structure based on Moran's I (lower Moran's I represent a week spatial error structure).

3.3 Assessment of amenity-induced urban expansion

In addition to the local association estimation, demographic variables such as population density, population growth, newly added urban areas and the GWR estimated non-stationary environmental variables were extracted using different grids (250m, 500m, 750m, and 1000m). The bivariate local Moran's I was computed to examine the spatial association between the environmental amenity-induced housing market and the urban spacing condition. This study stressed the residential zonation policy primarily. We assumed that, if the demographic parameters and environmental amenities induced built-up area spatially coexisted in the residential zones, the policy was successfully implemented; else, the local authority needed to rethink about their zonation policy. Thus, we estimated the variation of environmental amenities across the residential zones. Further, to identify the environment-driven urban growth pattern we used non-stationary coefficients of environmental amenities (GWR estimated) along with population growth, population density, and new urban plot (2008-2016) to draw ten major housing clusters based on Pearson distance based KMeans++ model. Finally, we are intending to extract one cluster, which included newly built-up plots with environmental benefits, and indicated the most potent and rich housing regions.

3.4 Results

3.4.1 Estimation of global coefficient

The global estimation underlined a few insights of the spatial association between environmental amenities and housing price. The summary output of global OLS estimation is shown in Table 3.2. Before estimating the association, all the multicollinear variables (VIF> 10) were dropped. The adjusted R^2 of global OLS estimation is 0.73, which indicated that almost 73% variation in house price is significantly accounted for explanatory variables (OLS AIC= 1095.96). Lot size ($\beta = 0.0006, p < 0.01$), house age ($\beta = 0.0174, p < 0.01$), no of bed room ($\beta = 0.1942, p < 0.01$), proximity to the rail station ($\beta = 0.0001, p < 0.01$),

Table 3.2: OLS estimated coefficients

Variables	Estimate	Standard Error	t(Est/SE)	VIF
Intercept	0.6378	0.5516	1.1564	
Structural Characteristics				
Lot size (sqft)	0.0006	0.0001	7.7057***	1.4933
House age	0.0174	0.0017	10.1916***	1.5707
No of bed rooms	0.1942	0.0415	4.6748***	1.5006
Distance between dwelling units (m)	-0.0001	0.0013	-0.0870	1.1809
Accessibility				
No of hospitals (r=5000m)	-0.0080	0.0041	-1.9309*	8.6984
No of schools (r=3000m)	0.0157	0.0048	3.2378***	6.2574
Nearest bus stop (m)	0.0000	0.0000	-0.4445	1.6655
Nearest rail station (m)	-0.0001	0.0000	-4.2217***	2.3015
Nearest major road (m)	-0.0002	0.0002	-0.9467	1.1943
Environmental and Landscape				
Nearest water bodies (m)	0.0001	0.0001	1.8357*	1.6424
Nearest parks (m)	0.0001	0.0000	-1.7414*	2.7345
Thermal Index 2016 (r=250m)	-0.0097	0.0119	-0.8165	1.1799
Vegetation Index 2016 (r=250m)	0.0219	0.0121	1.8099*	2.5147
Openness index 2008 (r=250m)	-0.0171	0.0321	-0.5322	5.1511
Openness Index 2016 (r=250m)	0.0279	0.0277	1.0055	6.3640
Tree cover 2008 (r=250m)	0.0060	0.0076	0.7895	1.9840
Tree cover 2016 (r=250m)	-0.0269	0.0099	-2.7112***	1.4267
Perception				
Air quality	0.0229	0.0277	0.8282	1.9735
Water quality	0.0150	0.0324	0.4617	1.9606
Noise quality	-0.0183	0.0261	-0.7015	1.9356
Transportation quality	0.0984	0.0210	4.6819***	1.8647
Market-Based Dummy				
Public transport availability	0.1101	0.0736	1.4968	1.4971
Plot plan availability	0.0864	0.2112	0.4088	1.6179
Nearest development project	-0.0147	0.0980	-0.1497	1.4012
Township (r=500m)	-0.2634	0.1898	-1.3877	1.4976
Nearest township (m)	-0.0594	0.0374	-1.5884	1.8855
Price change due to any speculation	0.1281	0.0830	1.5429	1.5835

AIC: 1095.96, Adjusted R square: 0.73, *=Significant at 90% level, **= Significant at 95% level, ***= Significant at 99% level, and VIF <10 (for all variables)

Table 3. 3: GWR estimated local coefficients

Variables	Mean	STD	Lower Quartile	Median	Upper Quartile	Non-stationarity
Structural Characteristics						
House age	0.0129	0.0043	0.0115	0.0133	0.0159	*
No of bed rooms	0.2280	0.0794	0.1819	0.2429	0.2973	*
Lot size (sqft)	0.0006	0.0001	0.0006	0.0006	0.0007	
Distance between dwelling units (m)	0.0008	0.0027	0.0001	0.0016	0.0025	
Accessibility						
No of hospitals (r=5000m)	-0.0052	0.0065	-0.0092	-0.0079	-0.0007	*
Nearest bus stop (m)	0.0000	0.0001	-0.0001	0.0000	0.0001	*
Nearest rail station (m)	0.0000	0.0001	-0.0001	0.0000	0.0000	*
Nearest major road (m)	-0.0002	0.0004	-0.0006	-0.0002	0.0003	*
No of schools (r=3000m)	0.0091	0.0059	0.0059	0.0101	0.0137	
Environmental and Landscape						
Nearest water bodies (m)	0.0002	0.0001	0.0002	0.0002	0.0003	*
LST 2016 (r=250m)	-0.0209	0.0179	-0.0331	-0.0179	-0.0076	*
NDVI 2016 (r=250m)	0.0511	0.0235	0.0306	0.0528	0.0670	*
Openness index 2008 (r=250m)	0.0344	0.0770	-0.0319	0.0400	0.0871	*
Tree cover 2016 (r=250m)	-0.0195	0.0143	-0.0222	-0.0185	-0.0121	*
Tree cover 2008 (r=250m)	0.0030	0.0081	-0.0036	0.0032	0.0090	
Openness Index 2016 (r=250m)	-0.0295	0.1046	-0.0144	0.0154	0.0290	
Nearest parks (m)	-0.0002	0.0001	-0.0002	-0.0001	-0.0001	
Perception						
Air quality	-0.0632	0.0471	-0.1002	-0.0711	-0.0313	*
Transportation quality	0.1020	0.0360	0.0710	0.1001	0.1329	*
Water quality	0.0216	0.0351	-0.0013	0.0209	0.0407	
Noise quality	-0.0212	0.0290	-0.0431	-0.0136	0.0007	
Market-Based Dummy						
Public transport availability	0.0225	0.1303	-0.0864	0.0059	0.1428	*
Plot plan availability	2.1426	2.4342	-0.1996	1.8363	4.1223	*
Township (r=500m)	-0.3523	0.6059	-0.8353	-0.5482	0.3127	*
Nearest township (m)	0.0685	0.1578	-0.0459	0.0265	0.2345	*
Price change due to any speculation	0.0472	0.0996	-0.0374	0.0157	0.1379	*
Nearest development project	-0.0371	0.1196	-0.1150	-0.0417	0.0363	

*Bandwidth size: 292.14, AIC: 1031.21, Adjusted R square: 0.78, *=Non-stationarity, and VIF <10 (for all variables). Note= To estimate the Gaussian kernel bandwidth, this study used the manual golden search rule. Optimal bandwidth size was determined by comparing AIC of different bandwidth.*

water bodies ($\beta = 0.0001, p < 0.10$), parks ($\beta = 0.0001, p < 0.01$), tree cover ($\beta = -0.0269, p < 0.01$), and transportation quality ($\beta = 0.0984, p < 0.01$) are found to be closely associated with housing price. Moran's I test showed a significant residual dependence ($Moran's\ I = -0.12, p < 0.05$) which indicated that the estimation is not efficient to draw the association. Therefore, to minimise the error dependence, the local model is attempted.

3.4.2 Estimation of local coefficient

The summary of the GWR estimation is presented in Table 3.3. The result confirmed that the spatial model had a substantial impact on housing price estimation. The GWR estimation efficiently captured the local variation (R^2 = 0.78, p < 0.00, AIC = 1031.4) and shows insignificant error dependence (Moran's I=-0.041, p=0.11) (Figure 3.4), while the spatial estimation captured the housing market heterogeneity (Figure 3.5). It is also found that the local adjusted R^2 ranged between 0.68-0.91. Overall, the GWR estimation under-predicted the extreme cases of housing price, while housing price variation in the northern AMC and southern AMC areas were explained efficiently.

3.4.2.1 Structural attributes

Among the four major structural attributes viz, lot size, house age, number of bedrooms and the distance between dwelling units, only two attributes varied across space– house age ($\beta = 0.0129, p < 0.01$) and number of bedrooms ($\beta = 0.2280, p < 0.01$), both of which are positively associated with housing price (Figure 3.5). The south and the western

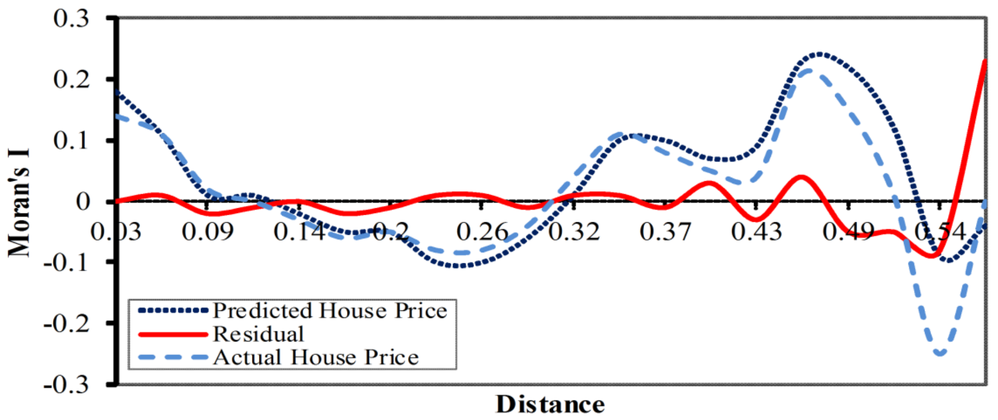

Figure 3.4: GWR estimated spatial error dependence

portions of AMC displayed the strongest positive effect of house age on housing price, with 1% increase in house age increasing the housing price to Rs. 97461. Real estate business and redevelopment initiative in the AMC have influenced the housing prices of old properties. Such local association reversal also is also reported by Helbich et al., (2013) and Wheeler and Tiefelsdorf (2005). In the eastern section of the river Sabarmati, a rise of almost Rs. 1.5 million in house prices is accounted for due to the increase in the number of bedrooms.

3.4.2.2 Accessibility

Overall, the accessibility parameters confirmed the spatial heterogeneity of the housing market across the AUDA. Proximity to hospitals ($\beta = -0.0052, p < 0.01$), roads ($\beta = -0.0002, p < 0.01$), and railway ($\beta = 0.0001,\ p < 0.05$) are found to be location-specific influence. The mean local coefficient showed that bus stops and railways are positively associated with housing price. Local coefficient suggested that with a single unit decrease in the distance from the housing area to a bus stop, road and railway station, the house prices reduced by Rs. 9282, Rs. 9200 and Rs. 51051 respectively. Likewise, with the increase in the number of hospitals, housing price tended to go up to Rs.74256. Clearly, accessibility is proved to be one of the dominant decision-making factors for purchasers.

3.4.2.3 Environment and land use

Apart from structural and accessibility parameters, environmental and land use-based parameters too, are highly associated with the purchaser's demands. Our estimation showed that the availability and accessibility of a natural landscape act as stimuli to housing price. Overall, water bodies ($\beta = -0.0002, p < 0.05$), NDVI ($\beta = 0.0511, p < 0.01$), and openness index 2008 ($\beta = 0.0344, p < 0.01$) are positively associated with housing price, whereas tree cover 2016 ($\beta = -0.0195, p < 0.05$) and LST 2016 ($\beta = -0.0209, p < 0.01$) are found to be negatively associated with the same. However, they did not guarantee temporal consistency (Table 3.3).

The local estimation (Figure 3.5) showed that a single unit increase in the presence of water bodies caused housing price to rise by Rs. 1392 in the AMC, whereas an increase of temperature could reduce housing price by Rs. 1856-Rs 0.3 million. On the contrary, healthy vegetation in the core areas and the western periphery of AMC caused the housing price to increase by Rs. 0.5 million. In the case of the northern peripheries of AMC, the proportion of tree cover 2016 raised housing price by Rs. 88129. Although tree cover 2008 is insignificant, is shows contrasting results compared to tree cover 2016. Successful implementation of the city beautification and green city plan after 2011 increased the value of tree cover in recent years, whereas, open land availability are found significant in the past (Rs. 0.5 million).

In reality, the urban heat island (UHI) effect goes against buyer willingness. Interestingly, it is observed that healthy vegetation compensates for high temperature roofed locations. For instance, homebuyers are often willing to pay for a small proportion tree cover in the core city against high temperature. Though healthy vegetation is not a decisive factor determining house prices at the peripheries of AMC, the proportion of tree cover is indeed one. Another finding was that riverfronts and well-maintained lakes do not lose their importance with the increase in distance from the dwelling units. Overall, environmental variables make sense on the western bank, not in the industry dominated the eastern riverbank.

3.4.2.4 Perception

In addition to amenities or their lack, locational perceptions too, play a key role in home selection. Our estimation showed that the air quality ($\beta = -0.0632$, $p < 0.01$) and transport quality ($\beta = -0.1020, p < 0.01$) in the AMC influence housing price. It was also found that the absence of air pollution will raise housing price by Rs. 0.4 million in the northern peripheries. Similarly, transportation quality, rather than transport accessibility is highly associated with the housing price (Rs. 0.8 million) in the southern peripheries. In most of the cases, the quality of transportation system enhanced locational attraction, while in some others, transport accessibility continued to matter.

3.4.2.5 Market-based dummy

Sharp difference is observed in the local housing markets of the eastern and western banks of the river. The availability of public transport increased the housing price by Rs. 0.47 million on the eastern bank, while it failed to make any difference on the

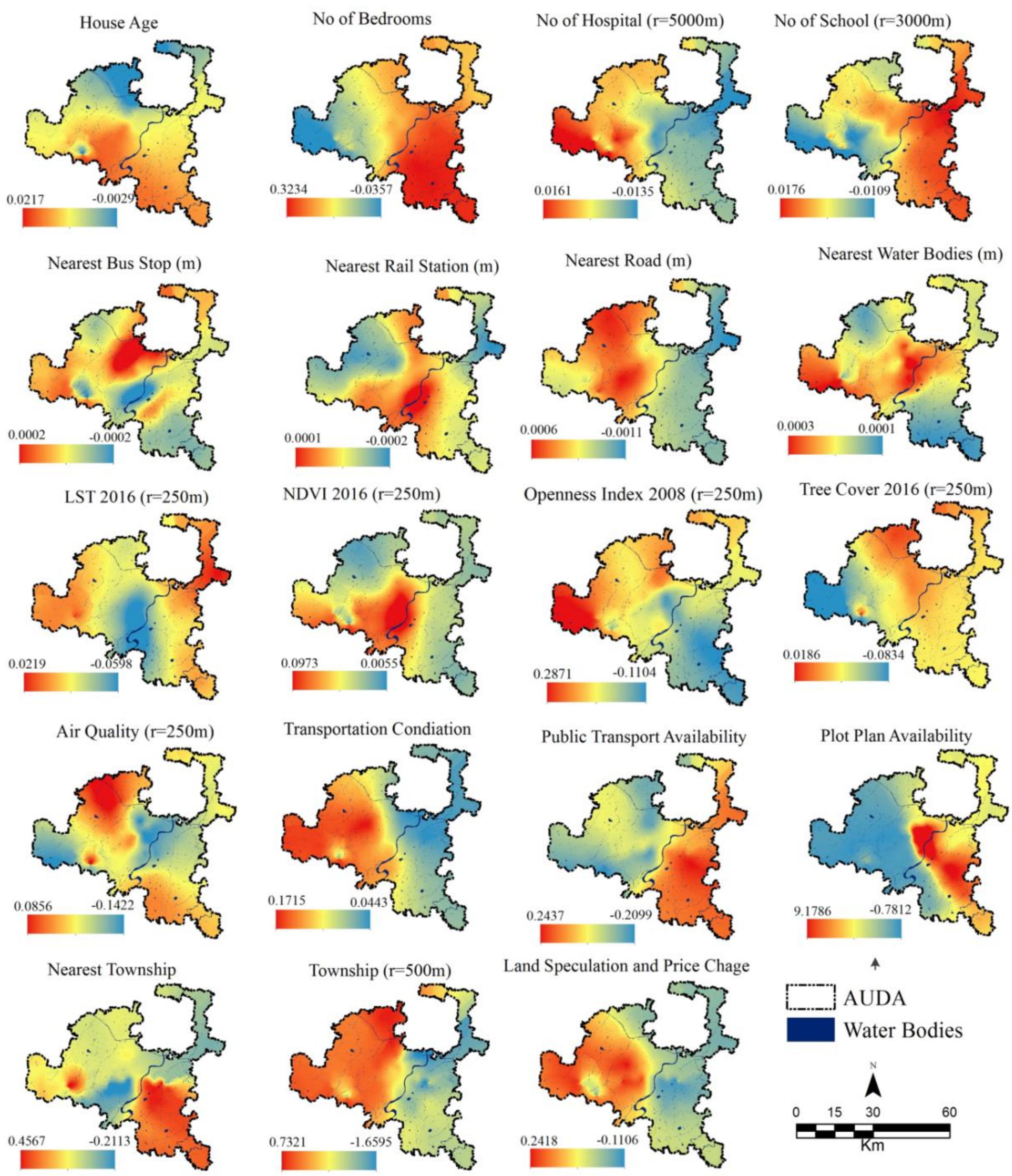

Figure 3.5: Local association between covariates and housing price

western bank. Since the eastern bank is quite congested and unplanned, a properly-planned plot could make a huge impact on housing price there. On the other hand, factors that are positively associated with house price on the western bank are township ($\beta = 0 - 0.7321$, $p < 0.01$) and land speculation ($\beta = 0 - 0.2418$, $p < 0.01$). Besides, environmental amenities and planned development are actively associated with housing price in the western river bank.

3.4.3 Residential zonation and amenity valuation

The strong influence of environmental and land use amenities on house price were served across the AUDA region. AUDA region showed a significant variation of housing price (Figure 3.6). The AUDA demarcated four major residential zones, viz. R1, R2, R3 and R4 with a coverage area of 222.38 Km^2, 41.12 Km^2, 44.90 Km^2 and 68.65 Km^2 respectively. The R1 is the oldest and has limited vacant space available for development. Figure 3.6 shows the most expensive amenities and their corresponding residential zones. Almost 13 Km^2 areas in R4 saw an increase of Rs. 0.17-0.22 million in house prices due to favourable temperature. Similarly, R1, R2, and R3 faced house price drop whenever their thermal environment was considered an inconvenience by house purchasers. The quality of vegetation increased the house price from around Rs. 0.39 to 0.45 million in the western R1 (27 Km^2). The house price in the R2 (3.8 Km^2) and R4 (13.9 Km^2) mostly varied due to tree cover (Rs.0.12-0.14 million). Shrinking of open space in the R3 increased the house price by Rs.0.14-0.22 million. Likewise, water bodies in the R1 zones exerted a strong influence on the housing price.

3.4.4 Influence of environmental amenities on urban pattern

Further, we examined how the environmental amenities co-existed with urban spacing. Bivariate Moran's I estimation shows that population density 2011 significantly associated with coefficients of NDVI 2016 ($Moran's\,I = 0.46, p < 0.01$), water bodies ($Moran's\,I = 0.35, p < 0.01$), LST 2016 ($Moran's\,I = -0.49, p < 0.01$), tree cover 2016 ($Moran's\,I = 0.46, p < 0.01$), and air quality ($Moran's\,I = 0.36, p < 0.01$) (Figure 7). Similarly, built-up area 2008-2016 significantly associated with NDVI 2016 ($Moran's\,I = 0.28, p < 0.01$), LST 2016 ($Moran's\,I = -0.28, p < 0.01$), water bodies ($Moran's\,I = 0.16, p < 0.01$), and air quality ($Moran's\,I = -0.15, p < 0.01$). BLISA estimation indicated that the association between housing price and environmental amenities was intensified from 2008 to 2016 on the western river bank. Air pollution level is significantly associated with population growth in the north-eastern area. Conversely, built-up growth is strongly associated with environmental amenities in the south-western region.

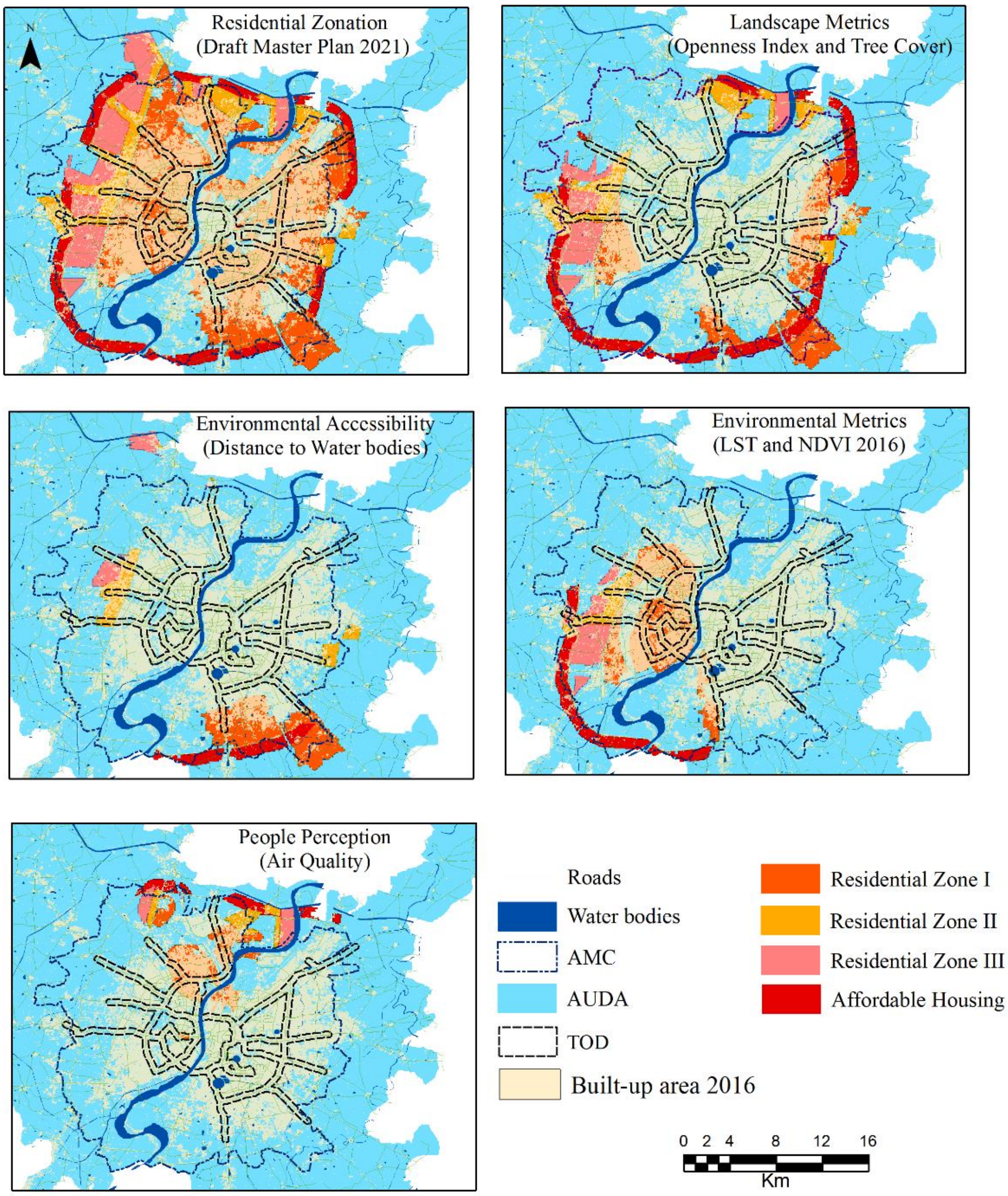

Figure 3.6: Estimation of local association across the planned residential zones (Residential zones are prepared using Draft Development Plan 2021 [Second Revised], dated 20/12/2014, Source: Ahmedabad Urban Development Authority)

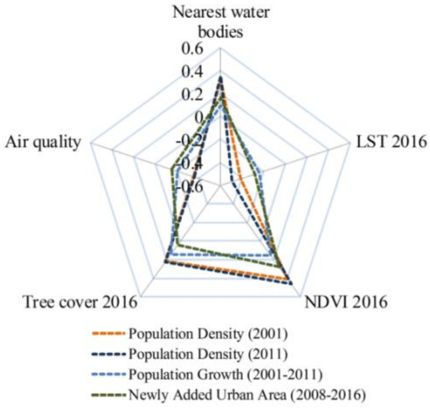

Figure 3.7: Local association between demographic parameter (population density, population and built-up growth) and coefficient of environmental amenities

The KMeans++ clustering distinguished the urban pattern based on environment, which showed that almost 108 Km² newly emerged area is strongly associated with amenity-rich housing region in the western bank, while a negligible proportion emerged on the eastern riverbank (Figure 3.8). Besides structural and accessibility parameters, almost, 22 Km² residential areas in R2, 12 Km² in R3, and 15 Km² in R4 are seen to be developed due to the influence of environmental amenities.

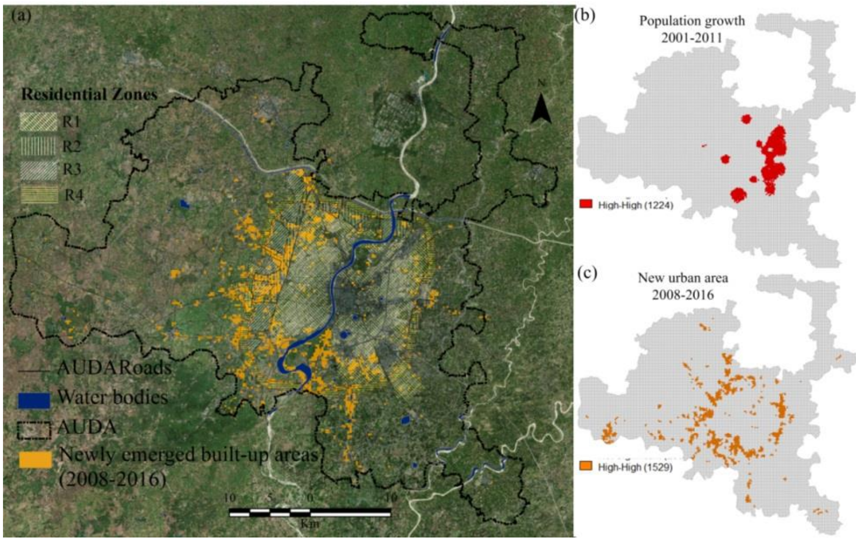

Figure 3.8: Mismatch between residential zones and environmental amenities induce high built-up and population growth areas. (a) Environmental amenities based built-up cluster areas. (b) Significant high population growth areas (999 Monte-Carlo permutation, p< 0.01) and (c) Significant new urban areas (999 Monte-Carlo permutations, p< 0.01)

3.5 Discussion

3.5.1 Spatial valuation approach

It was found in our study that the traditional OLS estimation is inadequate to unveil the heterogeneity of housing price. However, the GWR adhered to capture the spatial heterogeneity of housing price in Ahmedabad. The benefits of the road, hospitals, open space, tree cover, water bodies have been accounted for by several studies, but the evidence of environmental amenity dependent residential development through valuation approach is not accounted effectively. The present study highlighted new evidence of environmental amenity-based residential attractiveness in the Indian context, which shapes the current urban pattern. This novel approach shows that residential attractiveness fuels residential spillover. However, this study has a few limitations; (i) data were collected from different dates, (ii) proxy variables for neighbourhood assessment and (iii) buffer selection for neighbourhood estimation. Firstly, there is a mismatch between good quality satellite image and Census of India. Also, our survey was conducted in 2016, five years after the last Census (Census of India 2011). Therefore, in accordance with the survey and satellite data, we prefer 2016 as a base year. Secondly, neighbourhood estimation is itself a disputed process if local dynamics is activated for long. Further, people perception based investigations are enveloped with subjective judgement, but highly useful to account the ground reality (Rey-Valette et al., 2017). Finally, buffer-based estimation sometimes elevates over-aggregation problem. To some extent, over-aggregation can be minimized through AIC and VIF test for optimum buffer size selection.

This local estimation found a few counter-intuitive coefficients, viz. hospitals. These variables confirmed a negative association with housing price in multiple locations. Likewise, a few intuitive, positive coefficients too are found, which is house age. These counterintuitive and intuitive coefficients, however, need to be revisited. Despite that, estimation of local amenities can be used to find a valuable policy question on how financial assistance should be distributed locally to improve the residential quality.

3.5.2 Pattern of residential spillover

Local estimation approach efficiently explains the spatial heterogeneity. However, the root of this spatial heterogeneity is arisen due to the three planning phases (Adhvaryu, 2010), the domestic housing market (Mehta, 2016; Munshi et al., 2014), and social segregation (Chatterjee, 2009; Dutta, 2000). Three planning phases (1987, 2002, and 2011) formulate different residential zonal policies. Former plans mostly emphasis on the eastern river bank, whereas recent AUDA plan emphasized on the western river bank. Past AUDA plans have initiated infrastructural development and industrial activity (eastern river bank) and urban green space development. Recently, AUDA has concentrated on executing their compact and green city plan properly. Residential attractiveness has been significantly affected by this planning shift (Adhvaryu, 2010). Developers and local business house are well-adjusted with the domestic demand and planning shifts. But no one can deny the effect of social tension on residential development (Chatterjee, 2009).

Recent AUDA plan undertakes a zoning mechanism to regulate landscape fragmentation and promote sustainable development. Generally, we assume that the four zones (R1, R2, R3, R4) are amenity-rich with great growth potential zones. Since the majority of the space in R1 has been utilized, recent urban expansion was observed in the R2 and R3 zones mainly due to the availability of tree cover, water bodies, good water quality, and transportation. On the other hand, zone R4 is highly attractive to home buyers but specified only for the economically weaker sections. A large section of land within R4 is underutilized. During 2008-2016 only 7.9 Km^2 new built-up areas emerged under R4 out-off 68.65 Km^2 area.

Further, this study observed that the housing price in suburban areas (3 Km buffer around AMC) is closely associated with water bodies, vegetation quality, tree cover, air quality, accessibility, structural parameters (almost 107 Km^2 area emerges during 2008-2016), while the housing age largely controls that of the nearby growth centers of AMC, i.e., Sanand and Kalol. With one unit decrease of house age, housing price is increased by Rs. 13473. Similarly, no of bedrooms significantly associated with housing price in Sanand (Rs. 0.02 million/ unit bedrooms) and Kalol (Rs. 0.12 million/ unit bedrooms). Overall, the structural attributes are highly associated with housing price in the emerging small towns whereas environmental benefits seem more valuable in the core and suburban areas of the large city.

Depending on the demand of amenities, this study found two clear housing regions along with different stages of urban development- an amenity-rich western bank and an industry based eastern bank. These two housing regions have distinct characteristics such as (a) rich environmental and accessibility based residential spillover with huge housing stock and (b) affordable housing with high accessibility and population growth. Finally, the study ascertains that the pattern of urban development not only depends on the complex multi-dimensional willingness of homebuyers but also depends on the market reorientation by local government in the form of zonal policy. Indeed, the mismatch between housing stock and population expansion was a common phenomenon of AUDA.

3.5.3 Urban policy-making through valuation approach

A dynamic housing region is closely intertwined with structural, environmental, accessibility, and perception parameters. This study accounted for large-scale unregulated housing stock in western Sabarmati bank that creates substantial fragmentation of existing land-use pattern. In reality, no new zonation policies can improve the scarcity of environmental amenity as long as polycentric industrial development is active in the eastern bank. However, by the time the zonal attractiveness is enhanced, local authorities will levy a hefty tax and real estate companies will start controlling the zones (Mahadevia, 2011). Insofar as, younger residential zones (R2 and R3) can serve only an opulent living environment, which is far away from the affordability of the majority (Munshi et al., 2014). New zones will fail to serve the economically weaker sections (Adhvaryu, 2011) as long as developers and speculators tend to control the housing market to maximize their profit (Mahadevia, 2011). Consequently, the economically weaker sections will deviate from a decent living environment. It is evident that high housing prices force people to compromise the influence of environmental benefits (Mell, 2017). This leaves the question on the affordability of the present zones. If the local authorities are unable to control the price imbalance, the majority of homebuyers will refrain from house purchase. Ideally, the trade-off between environmental amenities and affordability must be prioritized, and the zonation process must be enriched with well-adjusted amenity services so that more inhabitants get to enjoy the benefits of a good neighbourhood.

Meanwhile, the promise of sustainable urban development as proposed in the AUDA draft master plan 2021 is not only deceitful, but also indicative of unidirectional residential prosperity (southwestern area). We identified a few criteria that distinguish the urban growth pattern between eastern and western river bank, viz. a polycentric industrial development, population growth, absence of clean environment, and the locational history (Dutta, 2000). To improve the living environment, besides ensuring accessibility, the local authority should give a boost to the living environment by preserving small lakes and green spaces along with restricting uncontrolled investment in housing sector by developers or local people in the business. Also, local government should provide financial assistance for environmental amenities in the eastern river bank to facilitate healthy residential area.

3.6 Conclusion

Spatial variability of residential attractiveness in the form of environmental amenities is the critical factor that can shape the suburbs of large cities. Mostly, the amenity-rich residential environment is more affordable in the outer suburbs than planned residential zones. This will increase the housing stock in residential zones but fails to generate housing demand. Widespread incompatibility between housing stock and affordability boost large-scale urban sprawling. Although, local amenities is a useful aspect to understand the urban residential attractiveness, substantial evidence of environment-induced urban expansion is absent in the literature. The present study can provide a scientific approach for the enquiry of the influence of residential attractiveness on urban expansion pattern in Ahmedabad. As an alternative to OLS approach, GWR is proved to be useful to understand the buyers' willingness to pay for certain environmental amenities in and outside of the residential zones. Noteworthy, spatial variability of local amenities is accounted on the eastern and western banks of Sabarmati. Compared to the eastern side, significant residential spillover is evident in the western suburbs. Urban residential zones in western suburbs are facilitated with infrastructure, urban services, environmental amenities, and an absence of polluting industries. It is evident that high temperature can reduce house prices in core municipal areas, whereas healthy vegetation raises the same. Similarly, proximity to water bodies in the AMC can also increase the housing price. More interestingly, spatial cluster estimation shows a substantial mismatch of population growth and housing supply, which indicate an increase in housing stock, cannot solve the issues of housing affordability. The environmental amenity-driven urban expansion is predominant in the western suburbs. This assessment demonstrates that amenity accessibility and affordability do not coexist. It is anticipated that inclusive and sustainable zonation plan should provide the accessibility of environmental amenities and no one is excluded from the benefit.

The present outcomes are beneficial to understand and address the alternative to the locational scarcity of amenities in Ahmedabad. This nature-based solution can be useful to understand the effectiveness of residential zones and alternative to infrastructure and technology for sustainable living. The outcome of the study can serve as a reference for other Indian cities too. To restrict the residential spillover and sprawl, further we have supplied the outcomes to the simulation environment. Next chapter will examine cost of sprawl in the Indian context, which is help to understand directly and indirect relationship between environmental amenities and sprawl.

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Chapter 4

Urban Sprawling

4.0 Introduction

Land consumption pattern in suburban areas is beyond its planned utilisation, which stimulates large-scale residential sprawling (Hamin, 2003), and becomes a cause of concern across cities worldwide (Jaeger, et al., 2010). Present urban sprawling pattern invites myriad essential service issues such as housing, land utilisation, public health, energy, social welfare, transportation and finance (Bell and Kim, 2014). Tsai (2015) rightly mentioned that sprawl primarily occurs due to unmet housing demand in the high-density central city, when the surrounding areas are well equipped with excellent livability. It is now well accepted that the intensity of sprawl depends on inadequate policy synchronisation (Byun and Esparza (2005); Cobbinah and Aboagye, 2017; Tian et al., 2017), which aggravates market distortion and residential spill-over in the suburban area (Knaap, 1990; McLoughlin, 1991). These concerns notwithstanding, a few studies have highlighted the advantages such as affordable housing, optimum open spaces, green spaces, better quality of life that a sprawling city offers over a compact one (Gordon, et al., 2007; Bagheri and Tousi 2017). Several others, however, have claimed that the benefits of sprawl are undermined by the problems that it engenders, i.e., congestion, social cost and segregation (Hortas-Rico and Solé-Ollé, 2010). Such controversial responses regarding the benefits and shortcomings of urban sprawl are unending. Debates on 'sprawl v.s compact city' policy create confusion in decision making and highlight the inadequacy of containment policy to effectively confine urban sprawl. Even today, we are unable to adjudicate these debates due to the complexity and multidimensional characteristics of urban sprawl. The primary concern is, should we disregard the compact city plan or endorse urban sprawl?

Most of the existing empirical assessments on the global cities convey the relative strengths and weaknesses of compact city plan but unable to converge into a single policy solution to urban sprawling. It has been suggested that the contribution of individual driving factors not be appropriately quantified in most of these studies. Ongoing research does not sufficiently examine causes and consequences of urban sprawl in developing countries (Tian et al., 2017), not a single study has been attempted to examine individual factor contributing to urban sprawl. Rather repeating the previous studies, present study adopts a non-linear modelling approach to measure factor contribution to urban sprawl. The Generalized Additive Model (GAM) is highly suitable to examine the factor contribution. GAM competently adjusts with non-linear association where polynomial functions end up with large residual (Wood, 2006). Chapter 2 and 3 presented enough evidences of LULC change and amenity dependent growth in Ahmedabad. This chapter introduce an empirical assessment, which emphasizes containment policy and intensity of sprawling. The objectives of this chapter are to assess the individual factor contribution to urban sprawl considering the compact policy element and its consequences in the context of developing countries.

Rest of the article is structured into six sections. Section 4.1 represents literature reviews on theoretical background, methodological development, and existing sprawling literature on Indian context. Section 4.2 introduces the study area and brief description of data and methodology. Modelling results are presented in Section 4.3. Section 4.4 presents details discussion of the cause and consequences of sprawl. Finally, Section 4.5 brings the conclusion.

4.1 Literature review

4.1.1 Theoretical background

Compact city policies in the form of zonation system, floor space restriction, and ring road development are common actions to curb the cost of urban sprawl (Gordon and Wong, 1985; Kim, 2013; McWilliam, et al., 2015). It is a popular belief among planners that to restrict fuel consumption and drive less; compact development is the most suitable policy recommendation (Stevens, 2017). A few studies accounted that compact development is useful for social equity (Ewing, 2007), and also demonstrated a strong association with neighbourhood satisfaction (Mouratidis, 2017). Ewing (2007) shows compact policies are required to reduce the vehicle travel mile (VTM), energy consumption, pollution, public service cost, loss of natural resources, and social cost. While, the effect of compact and high-density development through better design, infrastructural investment, and regulations is well established, it is not immediately transparent to all how can it reduces sprawl (McLoughlin, 1991). It is not clear how accurately the zoning regulation reflects consumer preferences (Windsor, 1979). Stevens (2017) and Moos et al., (2018) shows that a compact plan is not the most cost-effective method to reduce driving and is also unable to reduce congestion. Gordon and Richardson (2001) criticise the compact policy and its associated sprawling cost. They strongly argue that compact policy is always in favour of the market-driven planning system, and raise a serious question on housing affordability. Affordability is severely affected in the residential zones due to economic and aesthetic value (Moos et al., 2018). Nelson (2017) rightly argued that a compact policy is only successful when the market condition is favourable. Therefore, the containment policy should be well equipped with the principle of containment concurrency, ecological conservation, and provide an incentive to avoid urban sprawl (Janssen-Jansen, 2005). Like urban sprawling, compact city policies also elicited varied responses vis-a-vis cost and benefits. However, evidence of the effects of compact policy on urban sprawling in the cities of developing countries is lacking (Heres and Niemeier, 2017). Strong evidence of causes and consequences of urban sprawling in cities of developing countries is required, which can be helpful to understand the effectiveness of containment policies (Cho and Roberts, 2007; Canedoli, et al., 2017), before constructing any universal policy solution. To improve the understanding of the effectiveness of the containment policy, the present study is attempted in the Indian context.

4.1.2 Approaches to urban sprawl measurement

With the advancement of RS and GIS technology, urban sprawl quantification has become more efficient in terms of cost, time and scale (Laidley, 2016). Most studies lay emphasis on widespread assessment on landscape configuration, estimation of driving factors and temporal dynamics. Usually, landscape metrics, geospatial metrics and spatial statistics are used to quantify landscape configuration and composition (Taubenböck et al., 2009; Sarzynski et al., 2014; Reis et al., 2016; Salvati and Carlucci, 2016). All these matrices have demonstrated their merit in exploring ecological complexity (Yue et al., 2016). On the other hand, instead of landscape composition metrics, global regression models are used widely to explore the driving factors. Global regression models unreasonably assume a single coefficient to represent complex phenomena (Finley et al., 2011). Consequently, various spatial models such as Geographical Weighted Regression (GWR), and Spatial Autoregressive (SAR) models etc. are often used to investigate causal relation (Frenkel and Ashkenazi 2008; Weilenmann et al., 2017; Feng et al., 2018). All these spatial models are too highly exposed to multicollinearity constraints and spatial dependency (Tiefelsdorf and Griffith, 2007; Jaeger et al., 2010; Feng et al., 2018). Apart from these common parametric models, several robust non-parametric models (i.e., Decision Tree, Artificial Neural Network, and Generalized Linear Model) are worthwhile for prediction (Song et al., 2016). Due to the weak interpretation capability (Chen et al., 2012) non-parametric models are not applied frequently. Besides this causal estimation, simulation-based models like Cellular Automata-Markov, SLEUTH, Artificial Neural Network, and Logistic regression are attempted extensively to assess the driving factors. All these different groups of models are inadequate when we aim to quest individual factor contribution (Helbich, 2015). Therefore, this chapter deals with urban sprawl assessment, which is a crucial aspect of LESS framework. In addition to simple sprawl quantification the present study contemplates the individual factor response to urban sprawl using GAM.

4.1.3 Urban sprawling in India

The sprawling rate is burgeoning over the years (Taubenböck et al., 2014; Abhishek et al., 2017), and is particularly noted in the immediate neighbourhood of the municipality. There are a few conventional studies which show that densification is not enough to restrict residential spill-over in the outskirts (Tv et al., 2012; Sridhar and Narayanan, 2016). The resultant sprawl which is a by-product of the process intensifies the risk of urban sustainability of Indian cities (Sridhar, 2010; Swerts et al., 2014; Mondal et al., 2017). Besides, service deficit and institutional malfunctioning are the most visible issues of the major cities (Nandi and Gamkhar, 2013). It will not be wrong to say that 'collaborative market-driven policy' in India has shaped 'sprawl as an expression of the demand for home purchaser and pattern of housing supply by the developers'. Overall, in the Indian context market imperfections, transportation, fragmented land use control system, and poor local governance structure indulge residential spillover.

A recent empirical investigation has demonstrated that extensive urban expansion can catalyse the risk of food security in India (Gibson et al., 2015) and degradation of natural ecosystems (Mondal et al., 2017). This study firmly believes that without an understanding of the complicated association between urban sprawling and compact city plan it is impossible to pursue sustainable urban management. Therefore, considering the debate 'compact city and urban sprawling' the present study contributes to the literature by attempting to assess the extent to which compact city plan (i.e., residential zonation, floor-scape ratio, and ring road development) can act as an effective approach to manage sprawling in the Indian context (Figure 4.1).

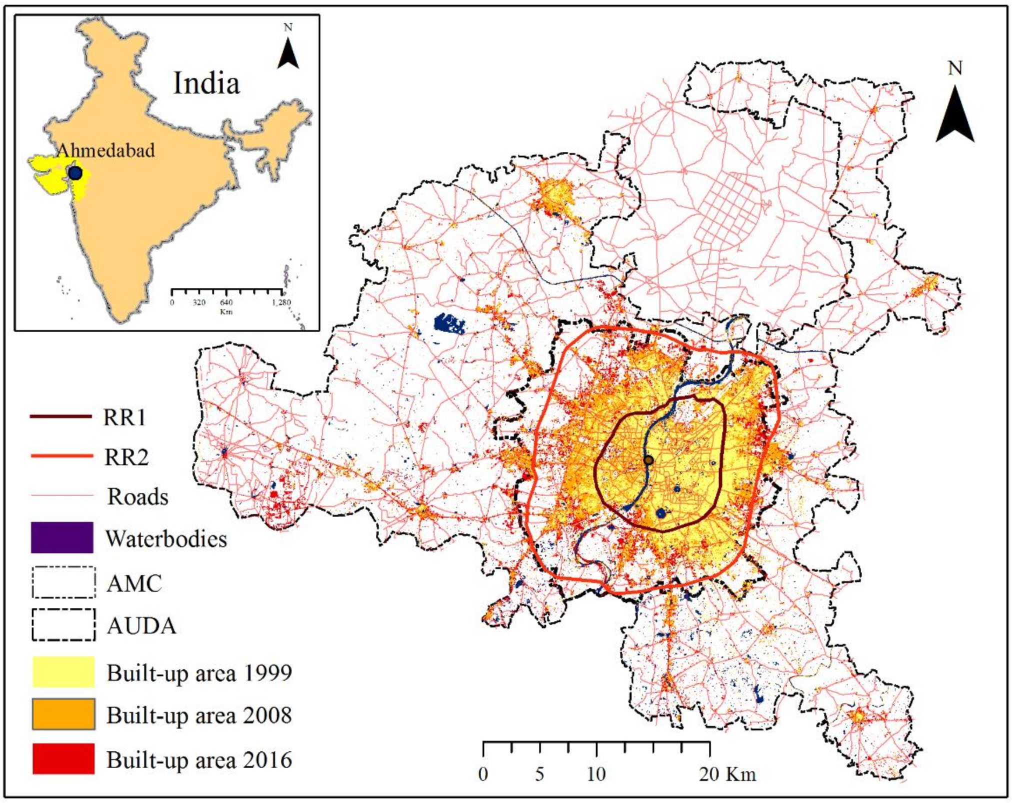

Figure 4.1: Urban expansion pattern along the major transportation corridor

4.2 Materials and method

Data application of RS & GIS to assess urban sprawl is a novel approach as it provides cost-effective, time-saving policy solutions (Bhatta, 2009). Three different datasets are created based on field survey, LULC maps, and the Census of India, 2011. To prepare the land use land cover (LULC) map Landsat data for the years 2008 and 2016 were collected from Gloves (0% cloud, November). The LULC data were further submitted to process landscape metrics and land use parameters such as openness. We have collected 397 samples based on pre-designed questionnaires, which cover socio-economic parameters and local perception. Considering the absence of suitable data, the present study integrates the field survey and the Census of India to understand the causal relationship between urban sprawl and its covariates.

4.2.1 Landscape metrics and urban sprawl

LULC map of 2008 and 2016 were prepared using supervised classification techniques (see Chapter 2). Five spectral classes were identified: Built-up, cropland, open land, water bodies and green spaces. Two LULC maps 2008 and 2016 show an overall accuracy of 87% and 91% and Kappa value is 84% and 88% respectively. LULC maps were submitted to quantify estimate urban sprawl pattern.

Urban sprawl characterization is a complicated and multi-dimensional task. Different researchers have adopted different metrics to quantify the urban sprawling, and these do not present any unidirectional outcomes (Brueckner, 2000; Wolman et al., 2005). For the sake of better understanding, Reis et al., (2016) subdivided the landscape metrics into shape, aggregation, diversity, accessibility and density categories. Majority of these metrics are highly multicollinear (Riitters et al., 1995), which can mislead the inferences of any statistical estimation (Taubenböck et al., 2009). Despite the multicollinearity issue, these metrics are rigorously applied to understand the eco-social transformation of urban sprawl (Clifton et al., 2008) because landscape based assessment can be a useful analogy to demonstrate the ecological complexity. Considering all its strength and weakness, the present study used eight landscape surface matrices (following Taubenböck et al., 2009 framework) to quantify urban sprawl. Commonly used Largest Patch Index (LPI), Landscape Shape Index (LSI), Fractal Dimension (FRAG), Patch density (PD), Interspersion-Juxtaposition Index (IJI), Edge density (ED), Total Edge (TE) and Shannon Diversity Index (SHDI) are computed using 100x100m moving window to minimise the problem of over-aggregation (Table A4.1). To avoid multicollinearity, we have used a threshold correlation coefficient value ($R^2 \leq 0.8$). Finally, the Principal Component Analysis (PCA) was employed to manage the eight matrices into a single composite index. PCA based urban sprawl pattern Index (USPI) can be useful to quantify location-specific urban sprawling. USPI is used to estimate cause and consequences of urban sprawl.

4.2.2 Estimation of Bivariate Local Indicator of Spatial Association (BLISA)

The theoretical discourse of urban sprawl embedded in policy synthesis, infrastructure, urban neighbourhood, natural geographic condition, and the urban economies of scale (Bagheri and Tousi, 2017). The local association were measured between landscape composition and covariates using BLISA. BLISA is useful to examine the urban and semi-urban landscape pattern. After carefully reviewing the existing literature we have selected twelve explanatory variables (Byun and Esparza, 2005; Baics and Meisterlin, 2016; Canedoli et al., 2017). Based on a threshold Variance Inflation Factor (VIF<5) only twelve parameters from four major dimensions were selected for further assessment- Density, Accessibility, People perception, and Housing market. Density dimension considered Population density (*Pden*) as an only predictor, accessibility contains travel time (*Ttime*), No of Institutions (*NInst*), No of health centre (*NHealth*), perception includes transportation quality (*Tq*), Neighbourhood quality (*Nq*), and air quality (*Aq*), and profitability (*Proft*), plot plan (*PLp*) (Table A4-2), and market dimensions includes housing price (*Hp*), fuel consumption (*Fc*), and lot size (*Ls*) (Figure A4.1).

4.2.3 Application of GAM

To develop the urban sprawl model landscape matrices based USPI is taken as a response parameter. Two different scales of measurement (administrative units, grid-based) were considered (Figure A4.2). VIF score were estimated to finalize the grid size (among 250 x 250m, 500 x 500m, and 1000 x 1000m). Instead of dropping the variables, measurement grid selection was found to be more convenient. Based on the two different scales present study has framed three regional GAM, i.e., administrative (Admin), inner ring road, and outer ring road. Admin model considered village, municipal ward, and town boundary as a measurement unit. Instead of the administrative boundary, outer ring road model considered 3 km buffer area with the 1km x 1km grid as a unit of analysis, whereas inner ring road model considered 2km buffer area around the inner old ring road. The outer ring road includes new planned residential zones, whereas inner ring road emphasised on city core area. Maximum influence area of the ring road is demarcated based on DP 2021 and the assessment of local experts. The response and predictor variables were prepared in accordance with the three models. Finally, with the help of R-Package 'mgvc' (Wood, 2006) we have estimated the urban sprawl. Each model contains fourteen GAM forms to address the factor contribution, where GAM forms subsequently progress in a descending order towards final GAM. To establish the factor contribution final admin model and outer ring road model included the three dimensional (3-D) spatial interaction (Longitude, Latitude, and House Price) using tensor product splines along with thin plate splines. Final inner ring road model used two-dimensional (2-D) spatial effects, i.e., spatial coordinate (Longitude and Latitude) along with thin plate regression splines. To increase model reliability and to minimise the overfitting, deviance explains criteria (DEC) and generalised cross-validation (GCV) scores were included (Chen et al., 2012). DEC value shows the individual factor contribution to urban sprawl. DEC is an R^2 version of non-linear models to estimate the discrepancy between fitted and actual value. Further, to test the error structure of three models, semi-variogram was estimated which is useful to understand the unexplained variance according to distance functions.

4.3 Result

4.3.1 Spatial patterns of covariates

The pattern of covariates is not consistent across the three-different models (from grid unit to admin unit). The result shows *Pden* follows the similar pattern, i.e., dense core area (25463 person/Km^2) and fragmented outer ring road areas. The overall assessment shows health accessibility is high in north-western areas, whereas the western riverbank area is rich in institutional accessibility and facilitated with good transportation as well as the commercial activities. According to local experts, recreation environment is spread well across western peripheries, whereas *Nq* is accounted in eastern peripheries. Most importantly, we observed a monotonic trend of *Fc*, and high median *Hp* (Rs.2.93 million) coexists with high fuel used. After removing the extreme cases, AUDA accounted for a range of median *Hp* (Rs. 0.6-20 million) is each admin unit. Interestingly, we observed that like *Hp* and *Fc*, *Ls* also increases in peripheries, but *Tq* is far better in the central city area.

4.3.2 Estimated BLISA and USPI

The result of landscape metrics shows a significant amount of urban sprawl in AUDA (Figure 4.2). Grid-based and administrative unit based estimation show almost similar pattern, however, change in scale leads to the negligible difference. Almost all the matrices show a high level of fragmentation in the suburban areas. The average ED score is 140.276, which indicates urbanisation occurs on the edges of the urban-rural interface, but not in a single patch. Similarly, LPI score indicates the entire urban area, is not appear in a single patch. Large LSI score also confirmed high urban fragmentation in the suburban areas.

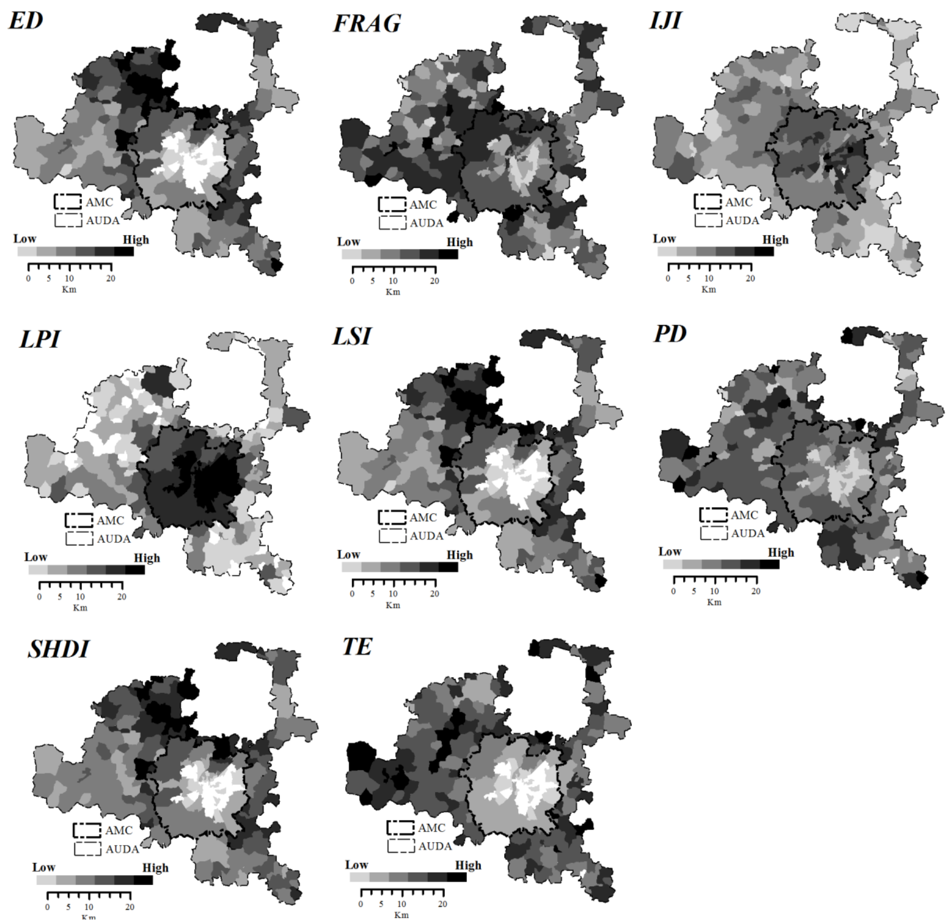

Figure 4.2: Selected landscape metrics at administrative level; Largest Patch Index (LPI), Landscape Shape Index (LSI), Fractal Dimension (FRAG), Patch density (PD), Interspersion-Juxtaposition Index (IJI), Edge density (ED), Total Edge (TE) and Shannon Diversity Index (SHDI).

TE (Mean =82.76) and PD (Mean = 129.9) indicate urban expansion occurs not in a single fabric. Landscape metrics show a similar outcome as previously estimated by Taubenböck et al., (2009) with a minor increase in intensity. The three landscape metrics, IJI (mean=78.18), FRAG (mean=1.012), and SHDI (mean= 0.56) are efficient in shows fragmentation and landscape diversity in the suburban areas. As we intend to develop a landscape pattern based composite score. It is assumed that the significant relationship between sprawling parameters and covariates (Figure A4.3, A4.4) are visible over the space. As expected, in western bank ED positively associated with *Fc, NHealth, NInst, Proft, Pp,* and *Hp,* whereas in the eastern suburb ED positively associated with *Pden, Ls,* and *Tq*. FRAG highly associated with *Hp, Ls, Tq, Fc, Proft,* and *Pden*. In contrast, IJI and LSI, TE, PD, SHDI coexisted with all the covariates in the western peripheries. In contrast, LPI is highly associated with the covariates in the eastern river bank. However, LPI is negatively associated with USPI. Therefore we have converted it into a positive indicator (nLPI=1-LPI). All these landscape matrices explain 81% variance of the overall USPI. High USPI score accounted for the significant amount of urban sprawling in the peripheries of AMC (0.75-0.94) (Figure 4.3). Average USPI score in AUDA is 0.75, whereas outer ring road and inner ring road accounted only 0.68 and 0.54, indicating the degree of urban sprawl is higher in the outer area compared to the inner city.

4.3.3 Model selection

GAM application significantly improves the capability to estimate the non-linear relationship between urban sprawl and its covariate as compare to simple OLS estimation (OLS AIC =1095.68 and GAM Admin model AIC= 1031.25). This study evolves with three models and fourteen different GAM forms. It is observed that 3D spatial interaction (*Longitude, Latitude, and Hp*) is better performing than 2D spatial interaction (Longitude, Latitude). Detail explanation capabilities of each form are presented in Table 4.1. Table 4.1 shows GAM Admin model explained 91.8% variance and accounted lowest GCV value (0.0055) as compared to other models. Despite the minor increase of GCV, these two models are also capable of explaining a significant amount of variance (final inner ring road model R^2= 0.75, outer ring road R^2= 0.69). In the Admin model, most essential covariates are *Ls* and *Hp,* followed by *Nq* and *Tq,* whereas inner ring road model shows *Hp* is the most important determinant followed by *Ls, Ttime*, and *NHealth*. In the case of the final outer ring road model, *NHealth* is most useful covariates, followed by *NInst, Tq, Ttime*, and *Fc*. GAM forms with single covariate can only explain 82.6%, 47.6% and 46.3% variance by initial Admin, inner ring road, and outer ring road models.

4.3.4 Modelling urban sprawl

Multicollinearity test shows all the covariates are well below the threshold VIF value (VIF<5). Urban sprawl in the peripheries is strongly associated with *Hp, Pden*. Functional nature of this relationship to urban sprawl is still not well established. OLS estimation shows *Pden, Ttime, Tq, and NInst* negatively associated with urban sprawl. It is evident that *Hp* can increase the urban sprawl (β=0.002, p< 0.001) in the AUDA region. A minor change is observed with the change in scale of the study. In the outer ring road region, *Hp* is found not significant, but low-density development is active in this region (β=0.08, p < 0.001). Amount of *Fc* is significantly high in this region, which implies auto-dependent urban sprawling. High *Hp* and less accessibility coexisted in inner ring road where population density is low. Overall OLS estimation underlines less dense areas with the absence of adequate infrastructure summons high level of urban fragmentation.

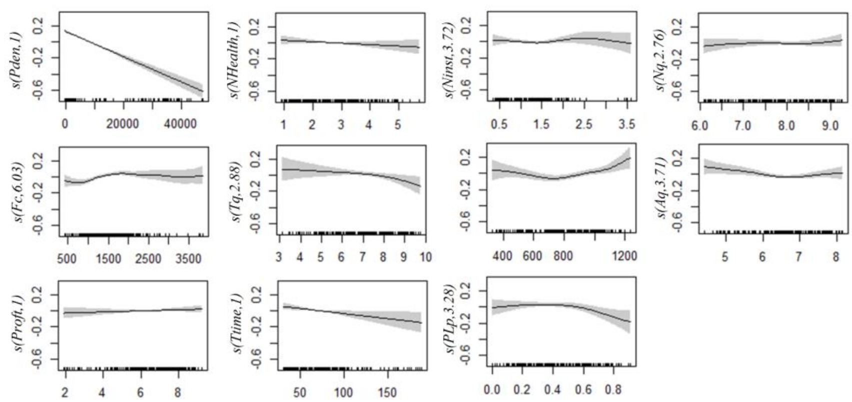

Figure 4.3: GAM estimation for Admin model; Population density (Pden), No of Institutions (NInst), No of health centre (NHealth), transportation quality (Tq), Neighbourhood quality (Nq), air quality (Aq), and profitability (Proft), plot plan (PLp), fuel consumption (Fc), travel time (Ttime), and lot size (Ls).

Table 4.1: Performance of the three GAM forms

Sl. No.	GAM Forms	GCV(R^2)		
		Inner Ring Road	Outer Ring Road	Admin
FI	***USPI ~ s(PDen) + s(NHealth) + s(Nq) + s(NInst) + s(Fc) + s(Hp) + s(Tq) + s(Ls) +s(Aq) + s(Proft) + s(Ttime) + s(PLp) + te(Lon, Lat)***	**0.0138(0.75)**	NA	NA
F2	***USPI ~ s(PDen) + s(NHealth) + s(Nq) + s(NInst) + s(Fc) + s(Tq) + s(Ls) +s(Aq) + s(Proft) + s(Ttime) + s(PLp) + te(Lon, Lat, Hp)***	NA	**0.0088(0.69)**	**0.0055(0.92)**
F3	*USPI ~ s(PDen) + s(NHealth) + s(Nq) + s(NInst) + s(Fc) + s(Hp) + s(Tq) + s(Ls) +s(Aq) + s(Proft) + s(Ttime) + s(PLp)*	0.0138(0.74)	0.0092(0.63)	0.0057(0.90)
F4	*USPI ~ s(PDen) + s(NHealth) + s(Nq) + s(NInst) + s(Fc) + s(Hp) + s(Tq) + s(Ls) +s(Aq) + s(Proft) + s(Ttime)*	0.0159(0.67)	0.0096(0.58)	0.0060(0.89)
F5	*USPI ~ s(PDen) + s(NHealth) + s(Nq) + s(NInst) + s(Fc) + s(Hp) + s(Tq) + s(Ls) +s(Aq) + s(Proft)*	0.0172(0.65)	0.0098(0.57)	0.0062(0.89)
F6	*USPI ~ s(PDen) + s(NHealth) + s(Nq) + s(NInst) + s(Fc) + s(Hp) + s(Tq) + s(Ls) +s(Aq)*	0.0185(0.62)	0.01(0.56)	0.0069(0.88)
F7	*USPI ~ s(PDen) + s(NHealth) + s(Nq) + s(NInst) + s(Fc) + s(Hp) + s(Tq) + s(Ls)*	0.0184(0.62)	0.01(0.55)	0.0070(0.88)
F8	*USPI ~ s(PDen) + s(NHealth) + s(Nq) + s(NInst) + s(Fc) + s(Hp) + s(Tq)*	0.0185(0.61)	0.0101(0.54)	0.0071(0.87)
F9	*USPI ~ s(PDen) + s(NHealth) + s(Nq + s(NInst) + s(Fc) + s(Hp)*	0.0206(0.56)	0.0101(0.54)	0.0075(0.86)
F10	*USPI ~ s(PDen) + s(NHealth) + s(Nq) + s(NInst) + s(Fc)*	0.0208(0.54)	0.0102(0.53)	0.0081(0.85)
F11	*USPI ~ s(PDen) + s(NHealth) + s(Nq) + s(NInst)*	0.0215(0.52)	0.0103(0.52)	0.0080(0.85)
F12	*USPI ~ s(PDen) + s(NHealth) + s(Nq)*	0.0217(0.51)	0.0105(0.50)	0.0080(0.85)
F13	*USPI ~ s(PDen) + s(NHealth)*	0.0218(0.50)	0.0106(0.49)	0.0081(0.84)
F14	*USPI ~ s(PDen)*	0.0223(0.47)	0.0112(0.45)	0.0081(0.84)

GCV: Generalized gross-validation score, R^2: adjusted varience explained by the model, s: regression splines, te: tensor product splines, Inner ring road model containes 196 observation, Outer ring road model containes 525, and Asmin model containes 238 observation, F1 and F2 are the final GAM forms. Population density (Pden), travel time (Ttime), No of Institutions (NInst), No of health centre (NHealth), transportation quality (Tq), Neighbourhood quality (Nq), air quality (Aq), profitability (Proft), plot plan (PLp), housing price (Hp), fuel consumption (Fc), and lot size (Ls).

GAM estimation shows a few interesting insights of unrecognised association between urban sprawl and social, demographic, economic covariates. In the AUDA area, final Admin model shows low *Pden* significantly associated with urban sprawl. The low-density urban expansion is the predominant pattern of suburban expansion.

It is observed that an increase in the density urban sprawl reduced dramatically (Figure 4.3). Similarly, *Tq, Fc, Pp, Ttime, Ls, Aq*, and spatial price effect shows a strong non-linear association with urban sprawl. Among these Ttime and Tq negatively associated with urban sprawl, indicate high congestion, but well-connected transportation in central area indirectly discern sprawl in outskirts. Consumption of fuel positively associated with sprawl, indicate to some extent auto-dependent urban sprawling. Initially, *Aq* and *Ls* show negative coefficient but later shows a strong positive association with urban sprawl (Figure 4.3 shows the 'U' pattern). In contrast, *Ls* shows a unimodal association with urban sprawl. Spatial interaction of *Hp* shows non-linear positive association with urban sprawl, indicate sprawling can increase the cost of housing across the AUDA. The spatial shift of this non-linear relationship can be assessed by the inner ring road model (Figure 4.4). Outer ring road model shows a strong negative non-linear association between USPI and *Pden, Ls, Ttime, Tq*. In the outer ring road area, home purchasers prefer less congestion and large personal housing space. However, *Hp* strongly associated with USPI, around the inner ring road due to the expensive duplex housing. Most importantly, unlike the situation in AUDA, *PLp* in the central city have a strong influence on the urban fragmentation. Unlike final Admin model, inner ring road model and outer ring road accounted *Fc* and *Tq* in the suburban area produce a more significant association with urban sprawl. Besides, substantial spatial price effect observed in the suburban areas (Figure 4.5).

In summary, GAM estimation accounted *Pden, Ls* and *Tq* have a substantial influence on peri-urban sprawling. This GAM estimation captures large vacant tract in the outer ring road areas are enclosed with fragmented development along with the increase in *Fc* and extensive housing stock. Seemingly, one can realise that the increase of *Fc* and *Hp* inflation is a cost of sprawling in AUDA region.

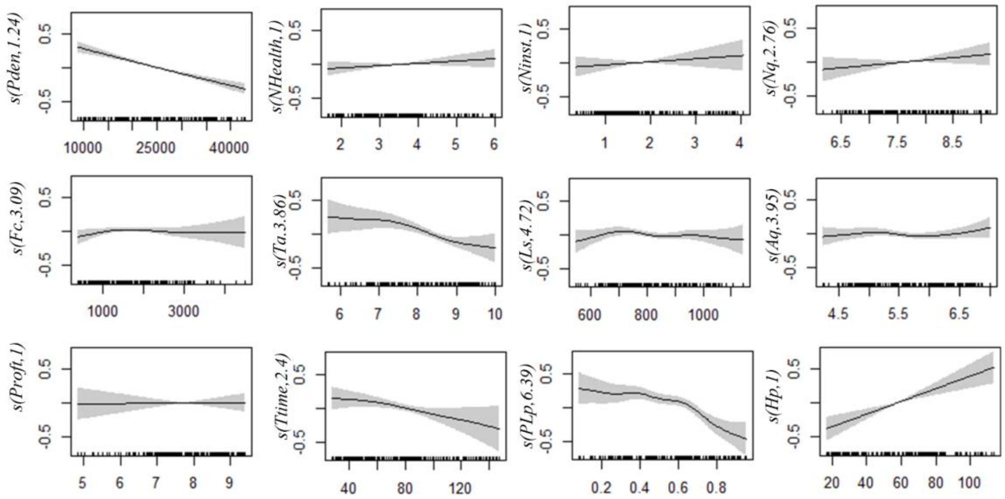

Figure 4.4: GAM estimation for inner ring road model; Population density (Pden), No of Institutions (NInst), No of health centre (NHealth), transportation quality (Tq), Neighbourhood quality (Nq), air quality (Aq), and profitability (Proft), plot plan (PLp), fuel consumption (Fc), travel time (Ttime), lot size (Ls), and house price (Hp).

In summary, GAM estimation accounted *Pden*, *Ls* and *Tq* influence peri-urban sprawling. Also, GAM estimation suggests a large vacant tract in the outer ring road area enclosed with fragmented development along with the increase of *Fc* and extensive housing stock. In general, from another viewpoint, we realise that the increase of *Fc* and *Hp* inflation is a significant cost of sprawling in AUDA region.

4.3.5 Prediction and validation

Among these models, the admin model improves prediction accuracy (R^2= 0.94, $p < 0.001$), whereas prediction capability reduces successively in the other two models (Figure A4.5). Inner ring road and outer ring road model explain 80% and 76% variance. Besides, sensitivity test shows GAM accuracy significantly decreases almost 4%-8%, if we randomly select the 50% of samples from the datasets. Indeed, GAM is well performed as compared to simple OLS estimation. Further spatial residual dependence for three GAM models indicates short distance error structure. Finally, Moran's I indicate error structure in Admin model and outer ring road model is not significantly autocorrelated but in the case of inner ring road negligible error autocorrelation is encountered due to the geographic scale of measurement. Semivariance structure indicates error variance significantly decreases with the increase of distance. The variance of error structure indicates short distance heterogeneity and large distance homogeneity (Figure 4.6). It is observed that short distance error structure is largely controlled by *Pden*, *Hp*, transportation and *Ls*.

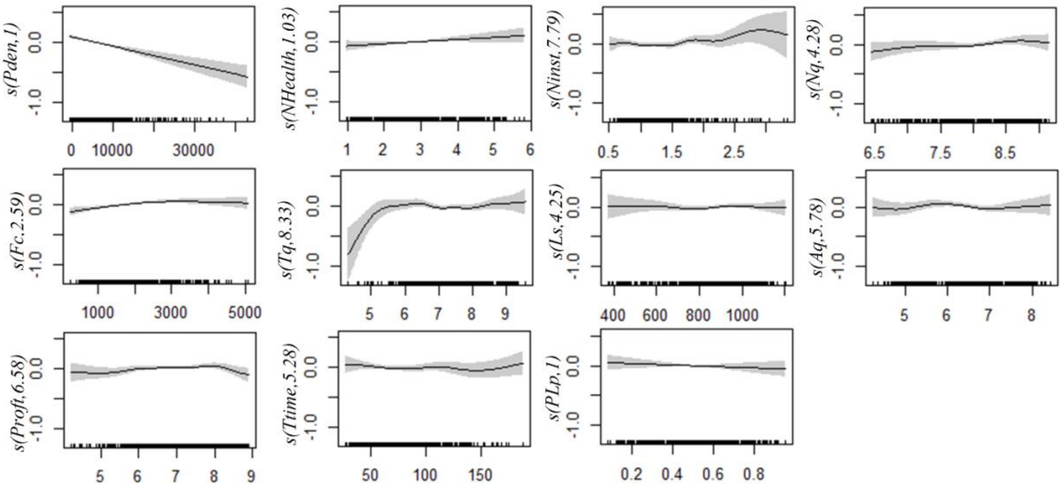

Figure 4.5: GAM estimation for outer ring road model; Population density (Pden), No of Institutions (NInst), No of health centre (NHealth), transportation quality (Tq), Neighbourhood quality (Nq), air quality (Aq), and profitability (Proft), plot plan (PLp), fuel consumption (Fc), travel time (Ttime), and lot size (Ls).

4.4 Discussion

4.4.1 Performance of GAM estimation

The aim of this study is not only to examine the different GAM forms but also to explore location-specific factor contribution to urban sprawl. The present study is unique in terms of the systematic introduction of people perception, different scales of measurement, and the use of spatial effects to improve the urban sprawl estimation. Existing literature has provided evidence that urban fragmentation is an outcome of housing, infrastructural, and policy settings (Downs, 1999; Brueckner, 2000; Burchfield, et al., 2006; Ewing and Hamidi, 2015; Ewing et al., 2018). This chapter shows a causal relationship and consequences of urban sprawl using three models and fourteen different forms for each model. Most comprehensive and complete Admin model explains 91.7% variance followed by inner ring road model and outer ring road model. Inner ring road model and administrative model are used to capture the influence of compact growth policies, whereas the outer ring road model can better represent urban land use fragmentation. After 2008, urban expansion has occurred within 3 Km around the outer ring road. After generalising the GAM estimation, we found *Pden, Hp*, and *Tq* are shaping the urban growth pattern.

GAM shows strong ability to replicate the factor space than any other linear estimation (Feng et al., 2018). A large body of literature shows that GAM is much superior to any commonly used aspatial and spatial models (Chen et al., 2017; Corona-Núñez et al., 2017). However, it suffers from some limitations such as (a) GAM non-linear effects sometimes leads to large residual deviance and parsimony (Bio et al., 1998), (b) Sometimes GAM estimation across space can create difficulties in decision making. However, in this application, GAM presents some interesting outcomes but we should be familiar with some issues that closely associated with this study, (a) spatial resolution and data collection time, (b) moving window selection, and (c) zonal estimation of landscape metrics and measurement scale. Firstly, this study is bound to use 30m x 30m Landsat images due to the unavailability of the finer resolution data. Coarse resolution data generalized the actual landscape pattern. Despite this shortcomings, most of the landscape based studies relied on Landsat 30m x 30m resolution data and ignored the negligible resolution biased (Li et al., 2017; Feng et al., 2018). Secondly, deviance in time between field data collection and the freely available satellite data is present in this study. Sometimes, this minor deviance in urban land use structure and the attribute data might elevate bias inferences (Song et al., 2016). Finally, moving windows selection can create large difference (100m x 100m, 250m x 250m, and 500m x 500m). Based on GCV and degree of freedom (df) this study prefers the 100m x 100m window to avoid the over-aggregation bias. Also, we should be aware of the zonal assessment scales. This study used two different scales of measurements such as administrative level and grid level (1Km x 1Km). Due to the high multicollinearity and small sample problems, we are unable to use a single measurement scale for three locational models. Use of administrative units at ring road level can create small observation error, whereas, grid-based assessment at an administrative level causes high multicollinearity issue. Therefore, to maintain the data redundancy and avoid large aggregation this study prefers 1Km x 1Km grid level assessment at ring road model and administrative units for admin model. Along with these three issues, GAM has a potential problem of over fitting (Li et al., 2017). However, spatial autocorrelation estimation nullifies the zonal over fitting of admin model, but negligible spatial dependencies exist in grid-based ring road models. It is well accepted that rigorous sensitivity test in each step can minimise estimation bias.

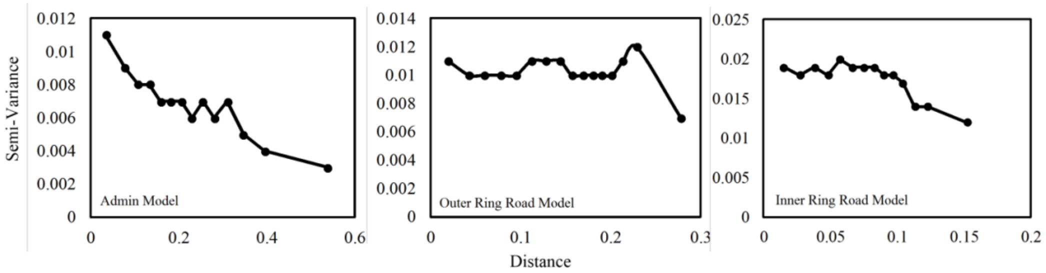

Figure 4.6: Semi-variance test for three models

Table 4.2: GAM estimated contribution of the covariates to the urban sprawl

Covariates	Drop in deviance explained (%)		
	Inner Ring Road Model	Outer Ring Road Model	Admin Model
PDen	47.6***	46.3***	82.6***
NHealth	3.7*	3.9***	0.1
NInst	1.0*	1.5**	0.3
PLp	5.2***	6.6*	1.1***
Ttime	2.9***	0.3***	2.9***
Proft	0	2	0.1
Hp	1.8***	1.4*	0.1***
Fc	3.3*	0.9***	0.3
Ls	5.1***	0.6	1.9***
Aq	1.7	0.2**	0.1
Nq	1.6	1.2*	0.5**
Tq	1.9*	1.6**	1.0***
ADE	75.80%	66.60%	90.80%

*Inner Ring Road Model: GAM form F1 for inner ring road area, Outer Ring Road Model: GAM form F2 for outer ring road area, Admin model: GAM form F2 for AUDA administrative area, ADE: Accumulated deviance explained, *** indicate significance level <0.001, ** indicate significance at < 0.05, * indicates significant at < 0.1; Population density (Pden), travel time (Ttime), No of Institutions (NInst), No of health centre (NHealth), transportation quality (Tq), Neighbourhood quality (Nq), air quality (Aq), profitability (Proft), plot plan (PLp), housing price (Hp), fuel consumption (Fc), and lot size (Ls).*

4.4.2 Contribution of covariates on urban sprawl

Existing studies largely focus on driving factors assessment using spatial models and landscape matrices. However, the intensity of individual factor contributing to the urban sprawl has largely remained unanswered. Market failure, regulations, and infrastructure have been identified as the most significant factors for urban sprawling. Apart from these well-established sprawl controlling factors present study estimates the extent to which individual factor contribute to urban sprawl. In summary, the contributions of *Pden* and *Hp* to urban sprawl are consistent in the three models (see Table 4.1). Admin model shows first factor *Pden* explained 82.6% variance, whereas *Ttime* explained 1.3 %, *Pp* explained 1.4%, *Hp* explained 0.4%, *Ls* explained 0.9%, and *Tq* explained 1% variation. Accumulated Deviance Explanation (ADE) power of these factors is 89%. Similarly, outer ring road model shows *NHealth* (2.9%), *Ttime* (1.8%), *Tq* (1.4%) and *Fc* (1%) are the most influential factors. Inner ring road model also shows *NHealth* (2.6%), *Ls* (4.3%), *Tq* (2.4%), *Hp* (8.2%), *Ttime* (3.1%) and *PLp* (1.6%) significantly affects urban sprawling. As we expected, people perception is found useful to understand urban sprawl. Arguing contrary to most existing research, which emphasizes proximity, factors to account for urban growth; this study has confirmed the substantial effect of people perception across the AUDA region. Moreover, this study highlights the benefits of incorporating people perception in formulating any public policy initiative aimed at combating urban sprawling.

4.4.3 Compact growth policy to curb urban sprawl

AUDA has build two ring roads and four residential zones as a major tool to restrict urban sprawl. Inner ring road model covered residential zones I, whereas the outer ring road model considered all four residential zones (Zone I, II, III, affordable zone). According to the Census of India, 2011, the area surrounding inner ring road is highly dense compared to outer ring road area. Therefore different locational models, as well as the scale of the assessment, show their own merits to explore the urban sprawl. The high land conversion rate is accounted for in the outer ring road area. Almost 119 km^2 of open lands have been converted to built-up, and 2.44 km^2 cropland has been converted to built-up during 2008-2016. Despite a comprehensive residential zonation system, utilisation of land is not adequate in the outer ring road area to restrict urban sprawl. Highest USPI score is accounted in outer ring road area due to the sharp *Hp* variation. A major cause of urban sprawl is *Hp*, proximity to an educational institute, health centre, large *Ps*, and proper planning for the plot. Areas that are highly accessible and amenity-rich are only accessible to high-class residents. This study identifies *Hp* inflation in planned area, unwanted housing stock and land conversion, an increase of *Ttime*, and *Tq* in the outer ring road area, with an increase of *Fc* and absence of road and health service are significantly associated with urban sprawling. However, in the AUDA region and inner ring road area, only *Hp* inflation dominates, whereas in the outer ring road region *Fc* is increased with suburban sprawling. Moreover, GAM accounted that urban sprawl is uniformly associated with low-density residential development.

This study summarises the influence of compact city policy on urban sprawling into two facets; firstly, affordability is affected due to the oversupply of land by the local government (Mahadevia, 2011). Developers established their hold on large tracts of land and increase the housing stock beyond the planned area. During 2008-2016 AUDA pre-defined affordable zones were least developed, whereas housing stock increased in the western residential zones (Mondal and Das 2018). Secondly, high *Hp* in residential zones pushes home purchasers to rural areas immediate to the municipal area, which will increase auto-dependent urban sprawling. It is clear that physical plans can only create a specific restriction, which can frequently be devalued by developers and local people. Therefore, land use control mechanism should retract informal transaction of rural lands. Similarly, instead of promoting any arbitrary physical element, i.e. ring road or municipal boundary, local authorities should underline inclusionary, mix-use residential zones. Above all affordability of different income groups along with intensified land use, transit use, and local social diversity should be considered to restrict residential spillover and urban sprawling.

4.5 Conclusion

This study has accounted containment policy and urban sprawling using landscape metrics and GAM exercise. This eco-social assessment shows suburban built-up fragmentation and its controlling factors. GAM is capable of explaining the deviance. Partial effect of individual factors is directly measured in this study. Unexpectedly, due to multicollinearity, several essential factors were excluded from the study (i.e., land surface temperature, distance to green space and proximity to the road). We preferred only those variables, which are consistently not correlated throughout the different measurement scale. For the same reason, despite including all the available landscape matrices, a few surface landscape metrics were considered to prepare the sprawl index. In urban sprawl modelling major emphasis is placed on perception-based parameters. Selected parameters can be used for two-way interpretation (i.e. cause and consequences), and which is used to address issues of compact policy. GAM show a few interesting facts of urban sprawling in the context of developing countries. Using a wide range of data, this study shows *Hp, Tq, Nq*, and *Ls* are the major controller of urban sprawling. It is also evident in all the models that sprawling reflected in the AUDA in the form of low-density settlement with increased *Fc* and *Ttime*.

The present study is useful to understand the cause and cost of sprawl in the presence of containment policy in the context of developing countries, which is still under-researched. This assessment is unique in respect of statistical relationship in association with compact city planning. This study can be a valuable reference to other cities to understand public policy response against urban sprawl. We firmly believe that LESS approach is incomplete if we ignored the sprawl assessment in the LESS framework. To make this approach more effective one should must include local political judgement. It is evident that future scenario based on sprawl can be a useful guideline for land use policy formulation.

Appendix

Table A4.1: Description of the landscape metrics to represent the urban sprawl pattern

Surface	Metrics	Description	Value	Expected Sign
Class	*LPI*	Largest patch based total landscape area estimation.	0 ≤ LPI ≤ 100	Negative*
Class	*TE*	TE metrics is used to understand the total patch edges at LULC class level.	TE ≥ 0	Positive
Class	*FRAC*	FRAC estimate the LULC class level shape complexity, it adjusts the perimeter-area ratio.	1 ≤ FRAC ≤ 2	Positive
Landscape	*ED*	ED metrics is useful to understand the patch edges at the landscape level	ED ≥ 0, 0 = No Edge	Positive
Landscape	*IJI*	IJI is useful to understand the patch adjacencies in the form of patch types intermixing.	1 ≤ IJI ≤ 100	Positive
Landscape	*PD*	PD is useful to compare the landscape of varying size.	PD > 0	Positive
Landscape	*LSI*	LSI is a valuable component to estimate the landscape shape complexity	LSI ≥ 1	Positive
Landscape	*SHDI*	SHDI is generally used to estimate the landscape structure.	SHDI ≥ 0, 0 = single patch	Positive
Landscape	*USPI*	PCA based composite score to show the urban landscape fragmentation or better to say urban sprawl pattern.	0 ≤ USPI ≤ 1, 1=maximum fragmentation (sprawl)	Positive

*Note: All these metrics are computed in FRAGSTAT 4.2 (McGarigal, 2014), * =indicate positive conversion (nLPI=1-LPI)*

Table A4.2: Brief description of the covariates used in this study

Covariates	Description	Source	Year
PDen	*PDen* is calculated by dividing the total population of the admin unit by its area. Grid-based density extracted from the administrative data.	Census of India, 2011	2011
*Nhealth***	All identified health centres per administrative unit and 1km x 1km grid.	Google Earth, 2016	2016
*Ninst***	No of schools, college and university per administrative unit and 1km x 1km grid.	Google Earth, 2016	2016
PLp	Binary variables, if *PLp* present than 1, otherwise 0.	Survey	2016
Ttime	Travel hour/day is collected for 397 locations and interpolated to extract the zonal mean *Ttime*.	Survey	2016
Proft	Cumulative score based assessment, 0=no commercial activity, 3=sub-urban interior, 5= distant from commercial strip, 7= Sub-centre markets, 9= CBD and near road.	Survey	2016
Hp	397 house price observations are used to extract the zonal median *Hp* for admin unit and 1km x 1km grids.	Survey	2016-2017
Fc	Fc/day in monetary value are collected for 397 locations and interpolated to extract the zonal mean *Fc*	Survey	2016
Ls	*Ls* is collected for 397 locations and interpolated to extract the zonal mean *Ls.*	Survey	2016
Aq	Cumulative score based assessment, 0=heavy industrial waste, 3=heavy construction area, 5= Heavy traffic, 7= residential congestion, 9= Green environment.	Survey	2016
Nq	Neighbourhood composite score of availability of open space, park and garden, and green space. Extracted for admin units and 1km x 1km grids.	LULC*	2008 and 2016
Tq	Cumulative score based assessment, 0=no maintenance poor condition, 3=Highway accessibility, 5= Proper gridded route, 7= space for cycling, 9= Highly accessible and well maintained.	Survey	2016

Note: '' = Landsat images collected from USGS and processed LULC data, '**'=with the help of AUDA Draft Plan 2021*

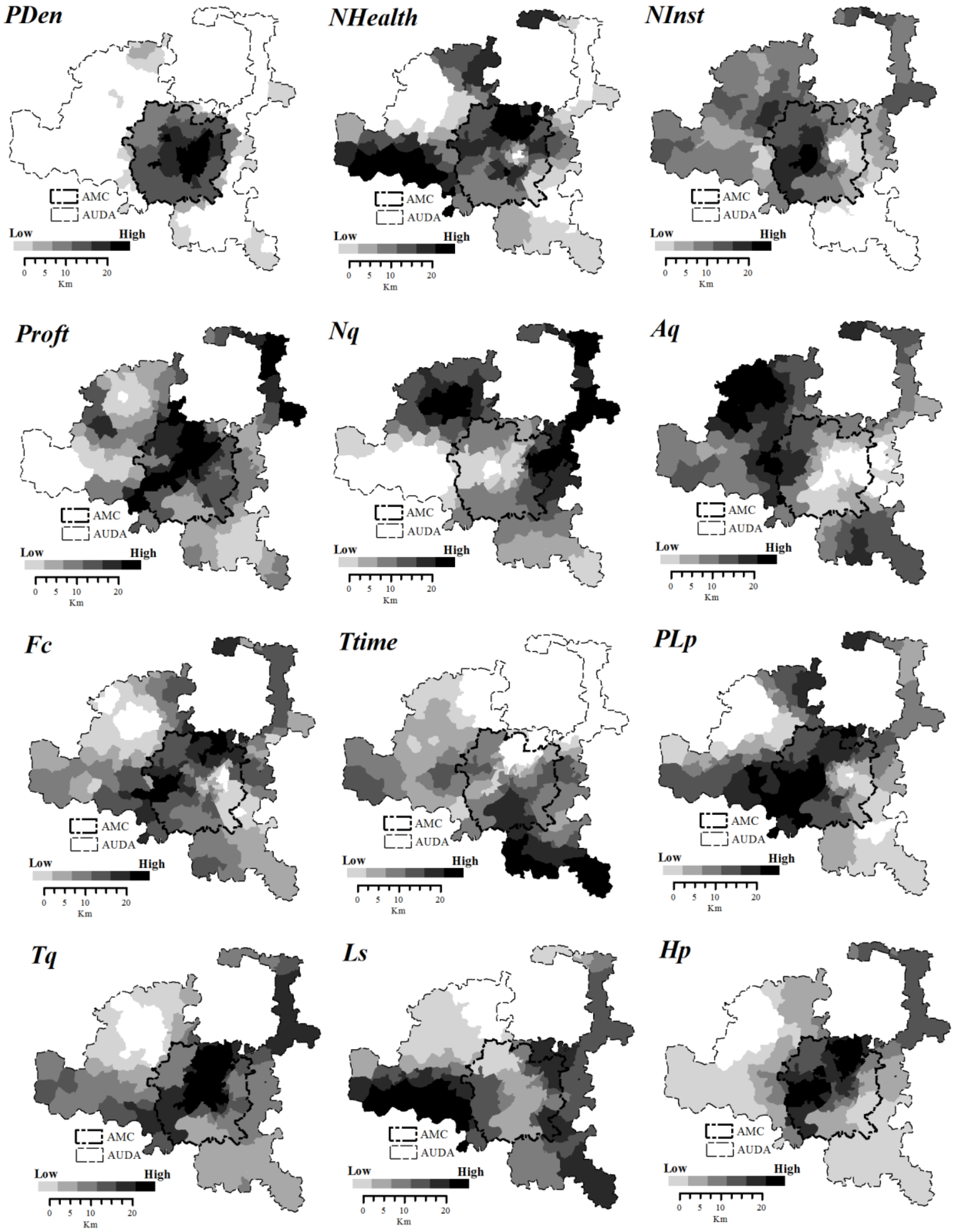

Figure A4.1: Covariates of urban sprawling

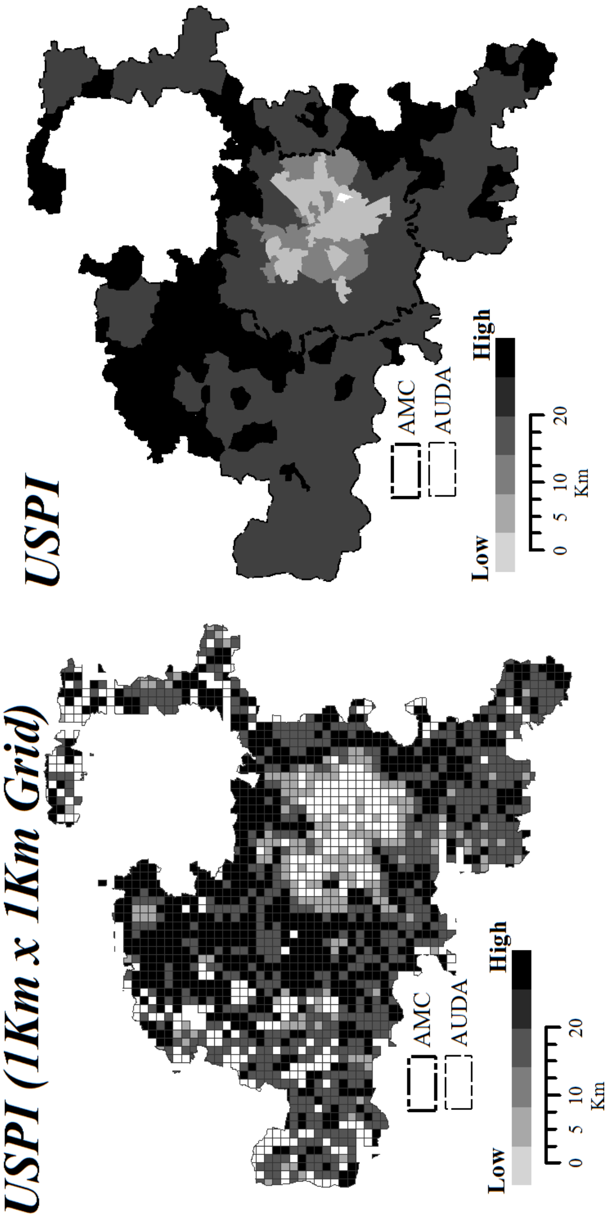

Figure A4.2: Comparison of Administrative USPI and Gridded USPI

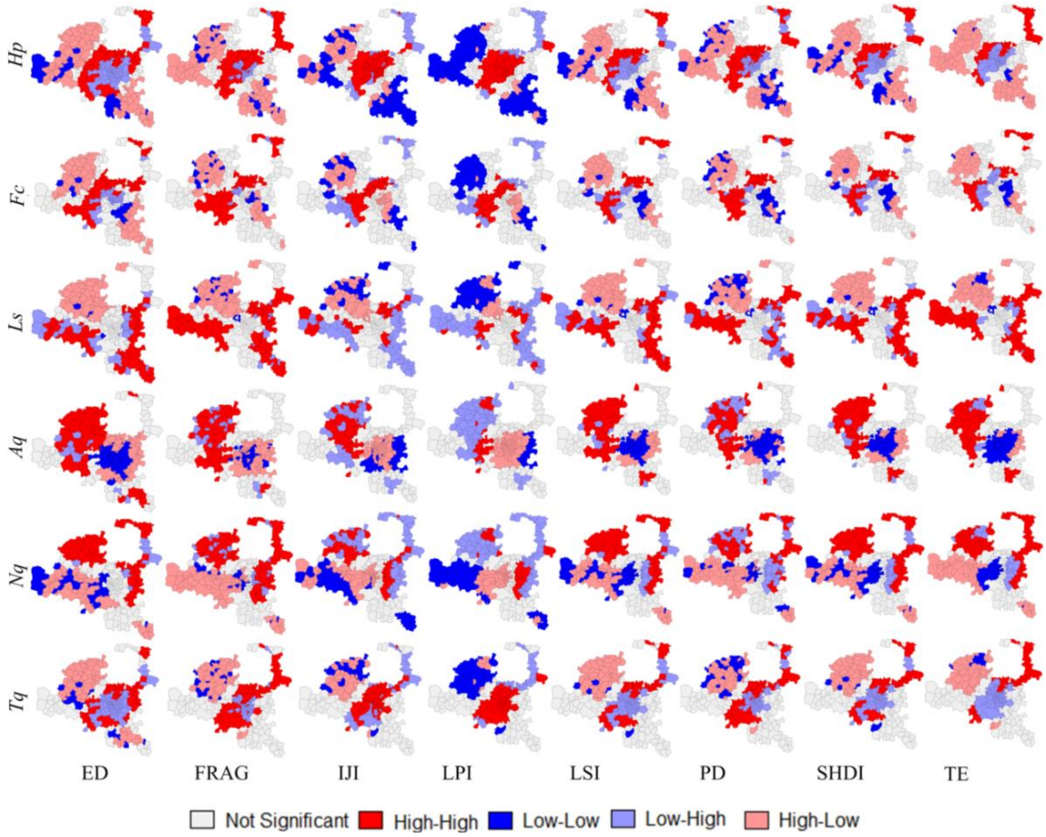

Figure A4.3: BLISA for landscape metrics and covariates of USPI.

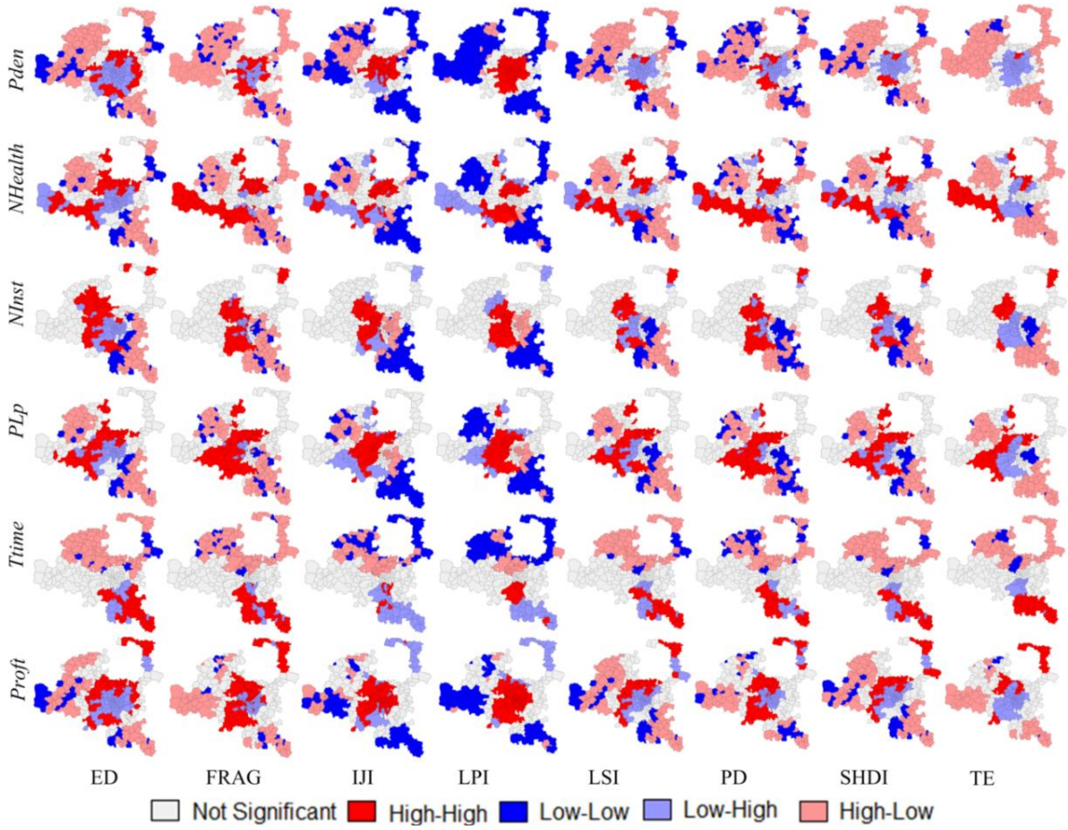

Figure A4.4: BLISA for landscape metrics and covariates of USPI.

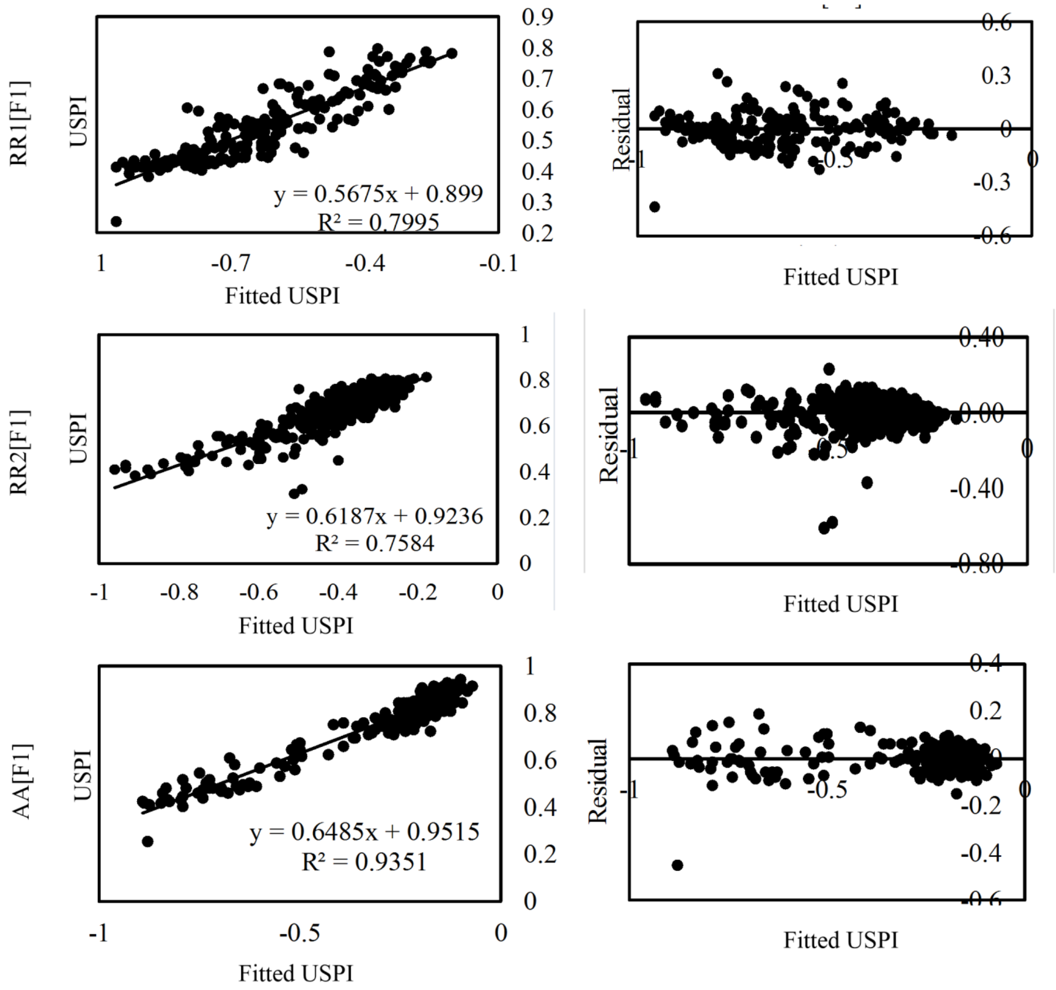

Figure A4.5: Performance of the three models. Fitted USPI is plotted against actual USPI

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Chapter 5

Scenario Development

5.0 Introduction

Since the introduction of the new economic policy in 1991, the face of urban India has transformed immensely. The Economic reforms of 1991 ushered a bunch of attractive market initiatives, which helped to create urban agglomeration of economics (Nandi and Gamkhar, 2013). Liberalisation, privatization and globalization (LPG) have rejuvenated the scope of Indian urban growth (Chadchan and Shankar, 2012). Unlike China's hyper-urbanisation (started back 1980's), India unleashed unplanned polarised urbanisation (Gibson et al., 2015). Unplanned urban growths are now concentrated in the 53 million-plus cities. Most cities are experiencing large-scale land use land cover (LULC) change and urban sprawling (Kantakumar et al., 2016). It is evident that major million plus cities like Delhi, Kolkata, Mumbai, Bangalore, Chennai, Hyderabad and Ahmedabad experienced extensive growth in the peripheries. In the previous chapters this study presented intensity of urban sprawling in suburban Ahmedabad. Also, these cities have gone through several phases of urban planning initiatives (Nandi and Gamkhar, 2013; Jain and Pallagst, 2015; Grant, 2015). However, poor articulation and management of urban land policies further increase the issues of land use conflict, property rights, regulation violation, and experimentation of resources (Raparthi, 2015). One of the major reasons for these issues is an absence of a holistic land use policy. The urban land policy first enacted in India dates back to the nineteenth century (Sridhar, 2010; Biswas et al., 2017). While there have been subsequent emendations in the policy, it still ignores the user aspect and focuses primarily on acquisition and rehabilitation (Spodek, 1980; Swerts et al., 2014; Sridhar and Narayanan, 2016). A second major emphasis is laid one land pooling and readjustment system (Chakravorty, 2016; Acharya et al., 2017). However, the application of land regulating mechanisms varies significantly across the states (Sridhar, 2010). Consequently, the intensity of use triggers different levels of counter urbanisation and suburbanisation. Issues associated with the different level of urbanisation are environmental degradation, congestion, lack of infrastructure, unemployment, and urban sprawling (Atkinson and Oleson, 1996; Brueckner, 2000; Byun and Esparza, 2005; Altieri et al., 2014; Bagheri and Tousi, 2017).

It is evident that the urban landscape in India has undergone unprecedented transformations, since 1991 (Jain, 2018). In earlier chapters, we have discussed the urban sprawling situation in Ahmedabad and also furnished ample evidence of environmental amenities based on residential development. Now we turn our focus to the urban growth scenario. Due to residential, commercial, and infrastructural accessibility, peri-urban vacant land rapidly transforms into the built-up area (Narain, 2017; Nijman, 2013). Residential developments in the peri-urban areas have intensified land policy violations (Narain, 2009). Market-oriented planning has created the scope for intensive real estate development in the major million plus cities (Datta, 2013; Shaw, 2013; Pethe et al., 2014). Second home selection, auto-oriented residential development, township enclave, and corporate urbanisation is going to shape the future of Indian cities (Narain, 2009; Roy, 2009; Chadchan and Shankar, 2012; Jain, 2017). Residential attractiveness and urban spill-over, on the other hand, delivered satisfaction as well as the encouraged crisis of pan-India housing affordability. Informal land utilization, loss of natural space and issues of housing affordability is persistent, not due to weak 'future –proof' but also influenced by infrastructure and service dispersal of the planning mechanism (Roy, 2009). Roy (2009) also argued that major planning failure in India proceeds through the process of informality, i.e. 'a system of deregulation, not unregulation'. Even modest master planning is not enough, large cities need a holistic approach to restrict the urban land issue, and land policy should be acquainted with the local informality.

Large cities of India have prepared their visionary plans, which acts as the single source of guideline for land use management. Orientation of the national urban land policy is inclined towards land acquisition, land pooling, and readjustment mechanisms (Acharya, 1988; Sridhar, 2010; Biswas et al., 2017). Such policy orientation approach alone cannot solve the issues of 'participative land utilization' where rural and urban residents both are involved (Narain, 2009). Complex urban land speculation, population growth, 'informality' created an amorphous built-up form (Jain, 2017). According to Vidyarthi et al., (2014) elitedriven centralized top-down planning system along with local factors, dysfunction the land use management system. Munshi et al., (2018) argued that spatial reconfiguration in the form of sprawl-type development, the emergence of sub-centres away from the central business districts (CBD) are dominant in Indian cities, which are most important criteria behind land use regulation violation. It is quite evident that the master plan and actual space utilisation are significantly mismatched, indicating urban planning in India is extremely difficult (Pethe et al., 2014). In this conscience, several studies show 'peripheralization' and spatial reconfiguration can create a large-scale loss of centrality. At this moment, what Indian cities need is deterministic planning (Banerjee, 1996) rather than zonation based master planning. However, urban density and environmental and land use scenarios can be a more effective alternative to determine 'futuristic patterns instead of strategy making'.

The futuristic problem-solving approach is useful for eco-social investigation, as well as to undertake land use policy. With the advancement of remote sensing and geographic information systems (RS and GIS), computational investigation of land use scenarios are highly popularised (Chakraborty and Mcmillan, 2015). We have discussed how simulation and spatial models are extensively used across the World in the Chapter 1. Simulation-based models are highly relevant in the fields of LULC change, ecological complexity, urban growth monitoring and scenario building (Shearer, 2005; Sang et al., 2011; Rosenberg et al., 2014; Ramirez et al., 2015; Li and Gong, 2016). Commonly applied simulation models are MCCA-Markov, MLP, SLEUTH, CLUE, DINAMICA, LCM, PSO-CA, and CA-genetic algorithms (Li and Gong, 2016). All these models belong to three different categories viz., rule-based, artificial intelligence, and optimization. The major advantages of these models are flexibility, simplicity, intuitiveness, and ability to integrate spatial and temporal dynamics (Abo-El-Wafa et al., 2017). Among the three categories of simulation, modelling CA-based models are one of the most successful and widely applied tools (Sang et al., 2011). However, all these three types of models can capture changes in economics, geography, and social complexity over the space (Li and Gong, 2016). In the LULC change estimation CA-based data-driven models can easily capture the statistical relationship and address the dynamics, are applicable for small areas to the macro-regional investigation. The transition, neighbourhood, and stochasticity in the CA models pull large audiences (Vaz et al., 2012). Increasing popularity of CA-based models is further strengthened due to a few graphical user interfaces (GUI), i.e. Idrisi, GeoSOS, LanduseSIM, DINAMICA EGO, LUCCME etc. In addition, a few non-GUI like UrbanSIM, SELUTH, and CLUE (Silva et al., 2012) are popular in urban land use simulation. Although there are several forms of CA-based application, yet their frameworks are almost similar, in terms of land demand, land allocation, and validation. Predominantly, CA Markov is quite efficient to work on multiple land use types, and its simplicity efficiently shows the complexity of the highly dynamic landscape (Vaz et al., 2012). On the other hand, non-simulated spatial models are used to access the factor association but are unable to visualize the multiple land use dynamics (Webster, 2016; Zhou et al., 2017). However, several studies have applied the regression-based spatial model to address location-specific policy issues. In urban planning and policy assessment, urban scenario-based models are more useful than simple simulation or regression approach. Meanwhile, it is evident that CA-based urban scenario models are highly successful in setting alternative planning goals.

Increasingly the static modelling approach without alternatives fail to address the dynamic effect of land use regulation (Kryvobokov et al., 2015). Urban scenario planning provides relevant information regarding the effects of different sets of actions on the urban region (Amer et al., 2001; Chermack, 2004, 2005). The scenario-based assessment shows potential opportunities and constraints of sustainable urban development (Coates, 2000; Kindu et al., 2018; Xiangô and Clarke, 2003; Varum and Melo, 2010). Scenario-based approaches are widely used in different aspects using simulation-based models. Ecosystem assessment (Rosenberg et al., 2014; Liu et al., 2017; Martinez-Harms et al., 2017; Mukul et al., 2017; Sherrouse et al., 2017; Zhang et al., 2018), land use assessment (Sohl et al., 2012; Sun et al., 2012; Troupin and Carmel, 2016; Najmuddin et al., 2017; Sherrouse et al., 2017; Kindu et al., 2018;), urban growth (Thapa and Murayama, 2012; Vaz et al., 2012; Gounaridis et al., 2018), transportation and accessibility (Zegras et al., 2004; Sahu, 2018), climate modelling (Varum and Melo, 2010; Deilami and Kamruzzaman, 2017; Trihamdani et al., 2017; Zhao et al., 2017), environmental risk and management (Yin et al., 2016; Zhao et al., 2017) are popular areas of scenario-based investigation. Scenario-based assessment of the LULC change and urban expansion shows the location-specific potentiality to minimise the loss of natural amenities. Goudie (2006) shows scenario modelling is highly efficient to balance the development and environmental services using CA-based model. Vaz et al., (2012) show CA-based scenario modelling is highly beneficial for a wise distribution of infrastructure and maintaining the carrying capacity of the environment. In fact, scenario-based models carry two major advantages, (i) easily accommodate several types of information and can also update new information, and (ii) uncertainty in the scenario modelling reduce significantly due to the flexibility of policy inclusion. Despite such advantages, the application of scenario-based simulation modelling has been completely ignored in decision making by Indian planners and policymakers.

Urban growth situation in Ahmedabad is considered to be a liveable and well planned. However, sprawl and low-density urban development are still active in the peri-urban area. It is evident that ring road development and residential zoning are the major drivers of the current urban development pattern. The planning authority has projected a population of 10.8 million by 2031. Major visions of the planning authority are to develop compact urban form, well-connected roads, land use, green network buildings, and affordable and equitable future development. We have seen, in earlier chapters, the long road that AUDA has to travel to be able to fulfil their agendas. Sprawl and illegal land conversion have emerged due to the densification and low rise urban structure. Till now 137 km^2 residential area still lies vacant in the AMC. In addition, 67.29 Km^2 is available in the outer ring road area. The affordable residential area is the least use, but affordable regions show potentiality of future demand. Along with the residential planning, special investment region (SER) and special economic zones (SEZ) are demarcated on the vast tract of land around the AMC. To protect the agricultural region, AUDA has introduced the prime agricultural zone (509 Km^2). Besides, in the future land use plan, AUDA mentioned the 0.42 million housing units are required to accommodate the future population. AUDA significantly improved the 'green street plan' and recreation environment, which has proved to be relevant for better urban living. This study finds that Ahmedabad needs a 'what if' scenario to understand the extensive threats and opportunities of different policies. AUDA does not have a 'what if' scenario which can advise authorities in preparing long-term LULC management strategies. A well accounted and coordinated visionary plan is required to minimize the mismatch between master planning and current land utilization system.

At the end of the LESS framework this study include a novel approach to understand the planning situation better and to undertake the best-suited land use policy. Instead of simple LULC simulation, this study considered relevant policy components. Considering the modelling literatures this study adopts the CA-based scenario modelling approach to estimate the strength and weaknesses of the current planning framework. Based on current policy components four scenarios were prepared. These scenarios consider all the available LULC types, driver variables, incentives and constraints. The objectives of this chapter are (a) to enhance the dimension of LULC simulating the environment in policy making, (b) to estimate the effects of sprawling, environmental amenities and land consumption on the city visionary plan, and (c) to evaluate the capability of LULC based simulation models. The present assessment is unique and significantly contributes to the literature in the ground of (i) how sprawling and environmental pattern change the LULC pattern, and (ii) is scenario planning is a useful tool for typical Indian cities? We believe that this study can be used as a reference for other cities in developing countries to evaluate the land use policy.

5.1 Comprehensive scenario framework

5.1.1 LULC scenarios

This research chapter to develop LULC based future scenarios to examine the potential effects of environmental amenities, high sprawling intensity, containment policies, and past LULC change. Historical LULC assessment shows that AUDA is intensely growing in the western suburban area. This study accounted for several environmental amenities, infrastructural incentives, and containment policies that have a remarkable effect on the present urban pattern. In this context, a scenario-based future assessment has been considered as a planner's toolkit (Thapa and Murayama, 2012). Scenario-based models served the purpose of future land consumption alternatives (Troupin and Carmel, 2016). This study develops a few alternatives to access the effects of current land use policy. Different pathways of urban management using different zonal policies in the Indian context are not accessible, which can be used as a reference to scenario making. In the case of the USA, Europe, and China, different approaches to land use scenario have been accessed. To explore urban expansion, a few studies designed spontaneous and environmental protection scenario (Thapa and Murayama, 2012). Abo-El-Wafa et al., (2017) designed business-as-usual (BAU) and densification scenario to understand the inter-relationship between settlement and green development. Similarly, Troupin and Carmel, (2016) prepared two scenarios viz., regulated and unregulated. A comprehensive scenario planning has been designed by Deilami and Kamruzzaman (2017), which considered five scenarios viz., (i) BAU, (ii) Compact, (iii) Environment, (iv) Motorway corridor, and (v) Sprawl. Based on this recent literature, the present study has designed four major scenarios, i.e., trends or BAU, sprawl, compact, and environment scenario.

Trend scenario

Trend scenario assumes current growth patterns remain consistent in the future. Generally, trend scenario considers historical process without any restriction and limitation (Thapa and Murayama, 2012). All the other alternatives can be compared with this trends scenario. Most of the studies used trend or BAU as an initial scenario. According to Chakraborty et al., (2015) BAU is usually used to express “when things are not changing”. Trend scenario is preferred in most of the predictive scenario assessment literature. In the assessment of ecosystem service, urban growth, transport development, and climate change, trend scenario has been adopted to trace the past processes. Initially, trend scenario can have several advantages as well as disadvantages: First, trend scenario is an absolute future representative of past process. In LULC assessment, past process is always considered as a reference criterion. Secondly, trend scenario is better suited to represent the uniformity. Factors responsible for change are considered to be a constant influence across space. In this scenario, local accessibility always carried a higher weight, for example, proximity to road, railway, existing built-up area significantly control the residential choice optimization (Coates, 2000; Amer et al., 2001; Chakraborty et al., 2015). Most importantly, trend scenario does not include any planning constants or incentives, which produced a simplistic view of the reality.

In this research, the initial trend scenario of AUDA is highly relevant in the context of urban expansion. AUDA has already implemented its planning constants and incentives, which are extremely location specific. At the same time, the current urban growth situation in AUDA can be characterised as central city densification with suburban sprawling. This existing open-ended situation cannot be replicated through any closed scenario such as sprawl and compact. Trend urban expansion model usually extrapolates the missed policy and regulated locational development efficiently. Several assumptions were undertaken to stimulate the AUDA trend scenario: (i) future growth may occur at any location except military cantonment, airport area and water bodies as such locations are reserved for future use, (ii) accessibility in the form of highways, rail stations, and transit networks remain consistent throughout the periods, also no new accessibility input can change the path of development, and (iii) urban expansion is even more intensive in the existing built-up area than in isolated settlements. Vacant surrounding potential sites will be first converted into urban land, indicating housing demand is decreasing with the increase in distance from a certain amenity. In reality, proximity to the road, rail station, central city, and local built-up are responsible for urban growth (Amini Parsa & Salehi, 2016; Banerjee, 1996; Chadchan & Shankar, 2012). These simple common factors were only used to develop the trend scenario. All these features show the distance decay effect, with the increase of distance, potentiality to change into built-up land decreases. To take advantage of past policy-oriented alternatives urban development trend is an initial figure. Based on this initial information we can estimate the multi-dimensional policy outcomes.

Sprawl scenario

Assessment of sprawling urban scenario should have to consider the incentives, constraints, and market dynamics (Chermack, 2005). Sprawl scenario significantly differs from trend; although trend may have accounted for sprawl, the intensity varies considerably in both the scenarios. In general, trend scenario is situated in the middle of a policy continuum, while sprawl and compact scenario are the two extremes of that continuum. Sprawl scenario underlines a situation which is completely uncontrolled and policy regulation is not competent to restrict (Godet & Roubelat, 1996; Ramirez et al., 2015). Existing researches on urban scenario development prioritised accessibility, housing market, job opportunities, and economic agglomeration criteria, which are closely associated with urban fragmentation (Troupin & Carmel, 2016). Urban expansion and natural resource depletion is a concurrent event which cannot be restricted through simple policies and plans (Vos, Acker, & Witlox, 2016; Wadduwage et al., 2017; Windsor, 1979). In the previous chapter, we have already presented how plans and regulations themselves often encourage urban sprawling. Sprawl scenario exaggerated housing and commercial development at the cost of natural space in the form of low-density development despite several control measures. In addition, this scenario is worthwhile to compare locational competitiveness and potential zones that support housing for the majority.

Our estimation suggests that during the last decade, sprawl is a dominant form of urban expansion in AUDA. If this situation persists for long then, large-scale harm will spread into the entire AUDA region and affect future sustainability. Sprawl provides benefits to a specific section of people, however high-intensity urban sprawl increase the ‘informal’ land transition system. It is relevant to examine how complete sprawl state prevails and its immediate effect on land use structure. Basic assumptions behind this scenario are as follows: (i) development of new corridor (AMC to Sanand) can induce large flux of economic gain that increase the living standard and accessibility further, (ii) suburban transportation and transit plans have summoned widespread sprawling in which housing price decay followed the distance decay effect of amenities and urban basic services, (iii) scope of infill development is minimal, whereas development of employment sub-centre at the margins encourage polycentric development, and (iv) housing market dynamics effortlessly disrupt land use regulations. A major issue which needs to be revisited is why housing demand has increased outside the residential zones? To address such planning disarrangement, the current study used proximity to the road, rail situation, central city, focal built up, and TOD as a common urban growth factor. Along with these growth factors, two urban sprawl incentives such as urban fragmentation (USPI) and high land consumption clusters were comprised. These two incentives have already been discussed in Chapter 4. Additionally, we have not used any major zonal constraint to restrict urban expansion except water bodies. Incentives can be considered as favourable sprawl factors, which will accommodate possible low-density urban expansion in the city outskirts. Most importantly, land consumption cluster and urban fragmentation areas can boost sprawl development in a dispersed manner and account for the rural spread.

Compact scenario

We have already elaborated the compact urban expansion in a previous chapter. It is also clearly noticeable that the vision of AUDA is to restrict the urban sprawl and to promote an efficient, sustainable use of land. The local authority promotes compact city policy in several ways, in the form of ring road, residential zonation, floor space, and natural space preservation. However, existing urban growth situation to some extent devoid of their proposed zonal plan. It is now valuable to recognise the potential outcomes of zonal policy, whether all the rules and regulation is well functioned or not. In this context, the present study simulates the compact scenario while considering all growth management incentives and restrictions. Existing literature argued that consideration of containment policy in the scenario planning is the alternative way to estimate the future compact development situation. Several researchers have used densification or building regulation to intensify the urban growth in the central city (Bardhan, Kurisu, & Hanaki, 2015; Couch & Karecha, 2006; Mouratidis, 2017). All the previous compact scenarios have included constraints and density criteria of core city (Troupin & Carmel, 2016). It is well established that the compact scenario is useful to understand the effect of constraints and incentives at the local level. Also, it is valuable to account long-term benefits of urban ecosystem services. Seemingly, the compact scenario can be a valuable tool to quantify the maximum possible preserved area which can be lost if sprawl scenario dominates.

Sprawl and compact development both are possible, but a compromise needs to be established between the advantages of both. In the case of AUDA, the compact scenario is useful, as they have implemented four different residential zones, as well as commercial zones and core cropland area. This scenario can evaluate the success of the current policy and its flaws. While there are several other problems associated with the compact policy, it is nonetheless, effective to curb the cropland conversion and green space development. To develop compact scenario, this study considered several assumptions such as (a) growth will occur around the existing developed area in central city, however, residential zones in the inner periphery of the AMC attract more buyers than old core city, (b) core cropland area should be preserved for ecological security but, growth around Gamtals (villages) and growth centres within core cropland area should continue within the specified development buffer, and (c) linear expansion should be completely restricted to the outside of proposed residential zones. Considering these assumptions, the present study lays emphasis on residential zones, ring road, and transit-oriented development (TOD) as important incentives of compact scenario, whereas common driving variables are proximity to the road, rail station, focal built-up, and central city. Most importantly, water bodies, green space in the central city, and core cropland were considered as constraints.

Environmental sensitive scenario

Unlike extreme cases, this growth scenario is constructed to understand the environment sensitive growth. Due to the planning regulation and housing price dynamics, AUDA shows the potentiality of rich environmental amenities directed development. This scenario efficiently shows the effect of green space, water bodies, and temperature on future urban growth along with cropland and water bodies as constraints. The basic assumption behind sensitive environmental scenario is that an amenities-rich area can attract a certain section of people, also facilitate urban sprawling. Considering such importance of environmental amenities this study includes green space, tree cover, temperature, and housing price to generate future environmental sensitive scenario. Moreover, this scenario can be used to show the potentiality of amenity-rich residential zones and possible future threats to these amenities.

5.1.2 Scenario dataset

Scenario models integrated different datasets to fulfil the assumptions. Four scenarios try to illustrate different possibilities of urban expansion. Trend and environment scenario are to some extent closely associated with trend scenario, but the only difference is neighbourhood environmental quality. Sprawl and compact scenarios are the two extremes of outcomes continuum, which are highly associated with planning incentives and constraints in the causality continuum. In general, scenario models used two groups of factors, i.e. common proximity based driving forces, which are consistent across the models and scenario specific local incentives and constraints. We have prepared five common driving factors viz. proximity to the road, rail, developed area, and CBD. All these factors are converted to Euclidian distance using GIS tools (Fu, Wang, & Yang, 2018; Han & Jia, 2017; Hassan, 2017; Hipp & Boessen, 2017; Knaap, Avin, & Fang, 2017). According to the Tobler's first law ('nearest service is more important than farthest one'), proximity-based factors are useful to understand accessibility dependent urban expansion (Keller & Vance, 2017; Munshi, Zuidgeest, Brussel, & van Maarseveen, 2014; Vaz et al., 2012). Proximity to certain services is the initial priority for new housing or commercial use which follows Tobler's law 'closer the infrastructure higher the potentiality of development'. However, a variable like focal built-up specify urban spread growth is more common than isolated rural breed in the large urban centres. Existing studies show all these common factors are worthwhile for all four scenarios (Chermack, 2004; Rosenberg et al., 2014). The intensity of common factors along with different combinations of local incentives and constraints can generate a different growth pattern. This study used common factors, and two development constraints viz. water bodies and reserved government area to simulate the trend scenario. Green network and core cropland constraints were not accounted for in the past planning phases; therefore, to replicate the past process we dropped these constraints from the trend scenario. Similarly, due to the inconsistency of incentives like riverfront, lake, and reservoir development project have been introduced in the AUDA region but were not supplied to build trends scenario. Sprawl scenario additionally incorporated high land consumption zone (see Chapter 4) which shows high employment rate, open space availability, low population density, and high built-up growth. This zone has the potential to attract more economic benefits and population influx as well as sprawl. Indeed, a major portion of this sprawl potential land consumption cluster is spread beyond the planned residential zones. TOD and intensity of urban fragmentation were considered to be the most important criterion to simulate urban sprawl scenario. These two factors can amend the urban expansion pattern if rules and regulations are not strictly followed. Therefore, these factors were best suited to capture urban sprawling in Ahmedabad. Compact scenario reflected all the common factors along with containment policy. We prefer areas of high accessibility and close to the central city, preferably within the residential zones that faced high built-up and population growth during the immediate past. A high weight is placed on residential zone II and surrounding areas of outer ring road followed by residential zones I and III and inner ring road. Also, proximity to green space, water bodies, core cropland and government reserved area all are considered to be a constraint. In contrast, environment scenario uses GWR estimated coefficient instead of planning policy. This environmental scenario reflected common growth factors, compact growth constraints along with environmental parameters. Coefficient of green space, openness, NDVI, LST and air quality shows significant association with housing price, which indicates the potential location of environmental amenities. In Chapter 3, we have discussed its effect on urban development. This section aims to understand a location with natural advantages, which does not, include any planning policy. Local authorities should include these components to gauge the sustainability of residential zones.

5.1.3 Suitability of different scenarios

Land supply mechanism is one of the key aspects to simulate the scenarios, which quantifies the most potential urban development land. An efficient land supply system ranked the land according to their potentiality. Among several available methods, most commonly used ones are multi-criteria evaluation (MCE). Three advantages of this method are as follows: (i) flexibility in terms of constraints and incentives selection, (ii) entropy based weighting scheme and (iii) process of trade-off. This study used Weighted Linear Combination process to trade off the factor space. Based on the four scenarios and its associated factors and constraints this study has generated four urban growth suitability surfaces. Before suitability estimation, all common factors are standardized by using the fuzzy membership function (Figure A5.1). We have used fuzzy J-shaped and linear monotonic decreasing functions to address the distance decay space (Table 5.1). Fuzz standardization is used to convert the value into 0-1 range. Additionally, the fuzzy function can be well-adjusted with the uncertainty. J-shaped and linear monotonic function can be expressed as (Eastman, 2012; Mondal, Das, & Bhatta, 2017),

$$\mu = \begin{cases} \frac{1}{\left(1 + \left(\frac{x - p_2}{p_2 - p_1}\right)^2\right)} \end{cases} \quad (5.1)$$

Where, p_1 = control point 1, , p_2 = control point 2; when $x > p_2$, then $\mu = 1$

$$X_i = \begin{cases} \left(\frac{r_i - r_{min}}{r_{max} - r_{\min}} . S_R\right) \end{cases} \quad (5.2)$$

Where, r_i = raw score of factor i, r_{min} = minimum score of factor i, r_{max} = maximum score of factor i, S_R = standardized range.

Table 5.1: Scheme of fuzzy standardization.

Factors	Membership function type	Membership function shape	Control points
Distance from Center	Linear	Monotonically decreasing	0-8000m
Distance from Built-up	Linear	Monotonically decreasing	0-2000m
Distance from Rail station	J-shaped	Monotonically decreasing	100-4000m
Distance from Road	J-shaped	Monotonically decreasing	10-500m
Focal Built-up	J-shaped	Monotonically decreasing	0-100m

To generate the weight, the degree of disorder and degree of valid information were estimated using entropy (Dong, Ai, Cao, Zhang, & Wang, 2010). Entropy measure assigned the weight to the factors in accordance to the degree of change made by the factor (Malczewski, 2004). In this system, smaller information entropy, arise due to significant factor variance. Large level of entropy indicates a lower level of capability to the land use change event, which can be expressed as (Fu et al., 2018),

$$E_j = -k \sum_{i=1}^{m} f_{ij}\, ln f_{ij}, \qquad f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}}, \qquad k = \frac{1}{ln.m} \quad (5.3)$$

Where, E_j = the entropy of the j factor, values ranges between 0-1, r_{ij} is the observation i of the selected j factor in $m\, x\, n$ standardization matrix, total observations is m and number of factors submitted is n . The weight of the j factor can be defined as (Dong et al., 2010),

$$w_j = \frac{1 - E_j}{\sum_{j=1}^{n}(1 - E_j)} \quad (5.4)$$

Where, w_j is the weight of j factor, $0 \leq w_j \leq 1$ and $\sum_{j=1}^{n} w_j = 1$. Finally, weights and fuzzy factors are used to prepare the scenario suitability surfaces. MCE weighted linear combination can be expressed as (Eastman, Jiang, & Toledano, 1998),

$$t_{suitability_{ij}} = \sum_{j=1}^{a} fs_{ij} \times w_j \qquad i = 1, 2, 3 \ldots n \qquad (5.5)$$

Where, W_j =Weightage for factor j, fS_{ij}=suitability factors for change at time t, standardize score based on number of (*x=1, 2, …,n*) factors, n is the number of suitability factor.

5.1.4 Land demand for urban scenarios

The land demand is depends on the stochastic transition process which is useful for land use prediction (Sang et al., 2011). Markov system efficiently shows the transition between two states. Transition prediction capability enhances the use of the Markov process to quantify future land use change. Based on land use change matrix and base year information Markov process predicts future change which can be expressed as $S^{(t+1)} = S_L \times P_{ij}$, where $S^{(t+1)}$ indicates future state of land use, S_L= current state of land use, and P_{ij} matrix shows the transition. P_{ij} can be expressed as,

$$P_{ij} = \begin{bmatrix} P_{00} & P_{01} & P_{02} & \cdots \\ P_{10} & P_{11} & P_{12} & \ldots \\ \vdots & \vdots & \vdots & \ldots \\ P_{i0} & P_{i1} & P_{i2} & \ldots \end{bmatrix} \qquad (5.6)$$

$$P_{ij} \geq 0, \qquad \sum_{j=0}^{\infty} P_{ij} = 1 \qquad (5.7)$$

$$i, j \geq 0; \quad i = 0,1, \ldots$$

Where, P_{ij} is a transition probability matrix from state *i to j*.

In this study, we have considered a transition matrix that indicates future land demand. For each scenario, two transition matrixes were computed (i.e. 1999-2008, 2008-2016).

5.1.5 Land allocation system for urban scenarios

Scenario models require suitability surface, transition matrix, initial LULC data, neighbourhood filter, and iteration time to stimulate future change (Fu et al., 2018; Sang et al., 2011), for example, to stimulate LULC 2016, we have to consider LULC 2008 as initial LULC, suitability surface, and transition matrix of 1999-2008. Along with eight years as iteration time, and 3x3 neighbourhood filter to rank suitability surface. Potentially suitable parcels were converted to claimant class (i.e., urban) and after each iteration model accessed whether land demand is met or not. The entire process was reiterated to simulate LULC 2031 using LULC 2016 as a base year, transition matrix 2008-2016, iteration time was set to be 16 years, and 3x3 filters.

5.1.6 Scenario validation

This study used actual LULC 2016 data to validate the simulated 2016 scenarios. Two levels of accuracy assessment were initiated viz., agreement and agreement/disagreement statistics and total operating characteristics (TOC). Agreement and disagreement statistic was used to estimate information quality and quality of simulation scenario (Pontius & Millones, 2011). TOC measure was used for each scenario which is more informative compared to the relative operating characteristic (ROC) (Pontius & Si, 2014). TOC and agreement/disagreement measure can be useful to compare the scenario models.

5.2 LULC transition

Although, Chapter 2 illustrated details of LULC transition process, yet to demarcate future land demand detail understanding of periodical LULC shift is necessary. Past LULC change assessment highlights unidirectional gain of built-up area. However, the contribution of different LULC class to built-up growth differs significantly during the two periods. During 1999-2008 open lands and croplands are the major contributors to built-up growth, whereas during 2008-2016 croplands to built-up area change has reduced dramatically, and open lands are the major contributor to built-up gain. It is observed that planning regulation and land use policy to some extent protect the redundant transformation of cropland to the built-up area (see Chapter 2). Similarly, water bodies significantly decreased during 1999-2008. Most importantly, the water level in the Sabarmati River declined to a critical level during 1999-2008. After 2010, new land utilization schemes, riverfront development and water bodies preservation initiatives helped to gain water bodies. At the same time, the green city initiative during the second plan (2002-2011), somehow increases the green space proportion (average 5.76 Km^2/year). However, the western area received more vegetation during 1999-2008. Nevertheless, large-scale transformation and development activity further increase loss of green spaces (14.35 Km^2). We have also found a significant level of transition between open lands, croplands, and green spaces. During 1999-2008, AUDA gained green spaces, but during the same period, built-up areas grew at the cost of croplands (cropland loss is 120.45 Km^2). Open spaces losses during 1999-2008 (45 Km^2) were low compared to croplands. Previous plan successfully restricts the loss of green spaces, but an oversimplification of croplands, regulation accounted large loss. After 2011 when AUDA made strict regulation of core cropland area, then automatically open space utilization increased dramatically. During 2008-2016 loss of open lands increased to 146.12 Km^2 areas, whereas green spaces and croplands loss is reduced. In fact, significant charges of croplands increase the availability of the open lands for development. For example, AUDA demarcates core cropland and secondary agricultural land. This secondary land can be used for development. Therefore, large-scale conversion of cropland categories has been recorded due to the local land market. This study accounted that high demand for housing units due to population growth along with economic development after 2011 (Adhvaryu & Echenique, 2012; Munshi et al., 2014) influenced the land use conversion. The built-up area gained almost 59% (143 Km^2) lands during 2008-2016. It is assumed that such level of growth can create widespread pressure on land resources if we ignore the land use policy.

5.2.1 Determinants of LULC changes

Urban expansion and sprawl cannot be explained through population growth, accessibility, and economic growth. Cities across the world have shown the complex combination of growth factors. This study uses different sets of factors to account for these different patterns of urban growth if factor space changes. Four scenarios considered different levels of importance of the driving factor (Table 5.2). The entropy-based assessment shows focal built-up share almost 32% urban growth, followed by land use likelihood (25%), proximity to road

Table 5.2: Entropy-based weights for each incentive in accordance with the four scenarios.

Incentives	Trends	Environment	Sprawl	Compact
Distance from Built-up	0.37	0.08	0.12	0.23
Distance from Center	0.02	0.02	0.03	0.05
Distance from Rail station	0.04	0.03	0.04	0.03
Distance from Road	0.11	0.05	0.06	0.07
Focal Built-up	0.30			0.14
LULC Likelihood	0.16			0.06
Distance from TOD		0.07	0.08	0.09
Land Consumption Zone			0.21	
USPI			0.32	
Gamtals				0.08
Residential Zones				0.26
Air Quality		0.12		
LST 2016		0.08		
NDVI 2016		0.21		
Open Space 2008		0.08		
Tree Cover 2016		0.16		
Distance from Water Bodies		0.10		
	CR=0.5	CR=0.02	CR=0.02	CR=0.3

CR=Consistency Ratio

(21%), proximity to rail (12%), and central city (10%). Sprawling is primarily driven by the degree of urban fragmentation (35%) followed by focal built-up (22%), and the high land consumption area (18%). Proximity forces are also significantly associated with urban sprawling viz., TOD (8%), road (6%), rail station (4%), land use likelihood (5%), central city accessibility (3%). Compact urban growth in AUDA can be arranged through containment policy viz. ring road development and residential zonation. Residential zonation system can influence urban growth pattern by up to 34%. Within the residential zone, focal built-up (27%) and TOD (10%) shaped the urban form into a compact pattern. Similarly, sensitive environmental growth will occur due to the accessibility and availability of environmental amenities. Availability of healthy vegetation (NDVI) strongly influences the urban growth pattern (21%). Besides, tree cover (16%), proximity to the water bodies (10%), air quality (12%), and open space (8%) increases the urban growth potentiality. Environmental sensitive growth along with accessibility factors, i.e. proximity to CBD, road, rail station, TOD significantly influences the urban growth in the Western Sabarmati river bank. Reliability of scenario and its associated factors are measured. Among the four scenarios, environment and sprawl models are the most consistent (Consistency Ratio=0.02) followed by compact (Consistency Ratio= 0.04) and trend (Consistency Ratio=0.05).

Suitability ranked surface of four scenarios shows the locational potentiality for future urban growth (Figure A5.2). Trend scenario relied extensively on the accessibility factor. Sprawl scenario considered urban fragmentation and potential land consumption clusters. The compact scenario used high weight on residential zones and ring roads and sensitive environmental scenario used core cropland constant along with environmental amenities (i.e. green space). Their relative influence adjustment shows the site-specific development process. To simulate the scenario this study prefers the same relative weight scheme for validation and future simulation. Factor dependent trend suitability surface shows surrounding areas of existing built-up is more potential for growth. Sprawl scenario shows the south-western direction of AUDA is the potential future economic zone, indicating urbanization induced sprawling direction. If policies and regulations are implemented appropriately, then land supply can effectively bring urban expansion to the outer AMC. However, the environment can also produce different growth pattern as well as sprawl in outer AMC areas.

5.2.2 Model performance

Scenarios for past change (1999-2008) show different outcomes specifically in term of urban growth pattern. All the past change scenarios performed well. AUC of the scenario models is ranged between 0.83-0.85 (Figure 5.1), indicating the appropriate use of urban growth factor. Trend model (AUC=0.83) performed well, efficiently captured the past suitable areas of urban development. At land use level agreement and disagreement, measures show a significant level of agreement between actual LULC and trend LULC scenario (Kstandard=0.77). Compared to trend, the sprawl model also efficiently captured the past LULC change. Sprawl scenario shows the high suitability of urban sprawl pattern (AUC=0.846). Sprawl model avoids 80% error at LULC level.

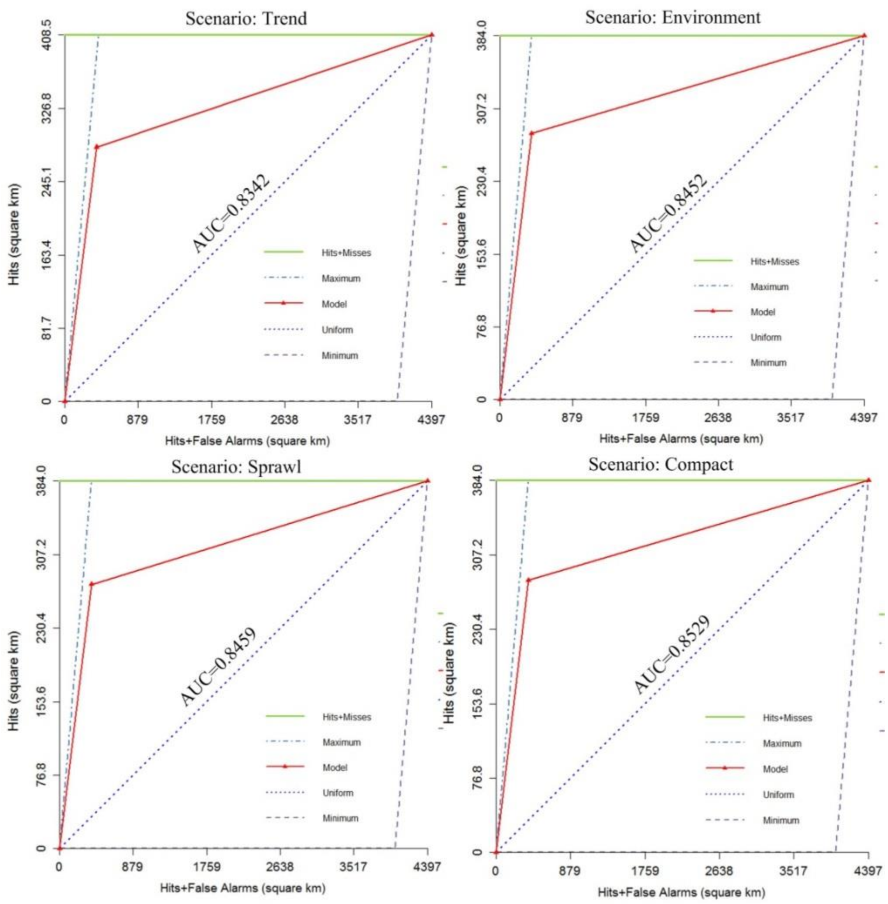

Figure 5.1: Comparison of four scenarios using AUC value

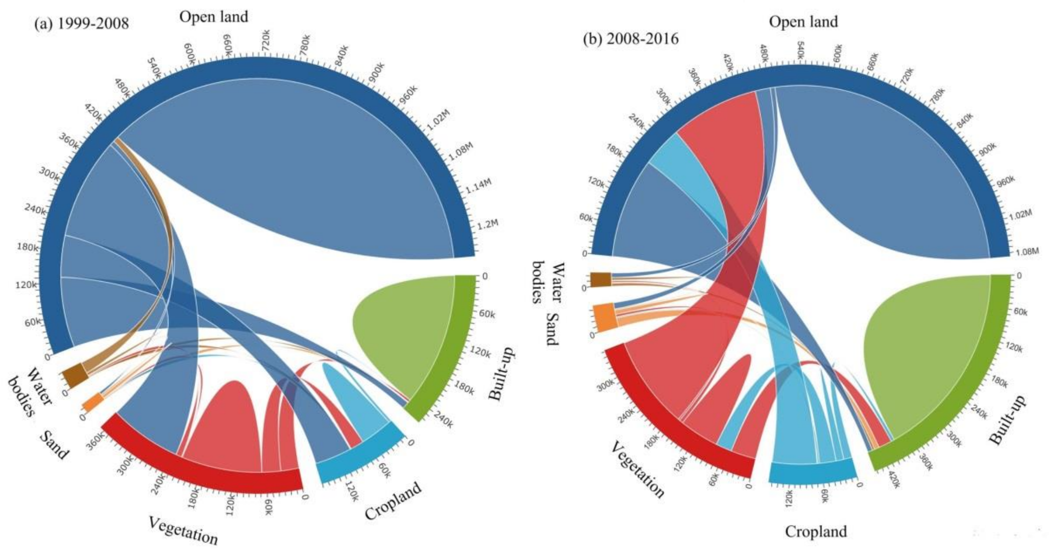

Figure 5.2: Markov LULC Transition for the periods of 1999-2008 and 2008-2016

Similarly, the compact model efficiently avoided 81% error of LULC level, whereas urban growth suitability confirms the good improvement of factor space (AUC=0.85). Environmental scenario show improved performance compared to trend scenario (AUC=0.84). While at LULC level, environmental scenario (Kstandard=0.81) and compact scenario captured the residential development efficiently. Overall, factors that are used to generate the compact suitability model to some extent replicate the past LULC change scenario. However, other alternative suitability models are also useful to understand the location-specific advantages of urban growth driving factors.

5.2.3 Future changes

All the scenario models are supplied with transition demand model. The single land demand model is applied for all scenarios (Figure 5.2). Seemingly, only land supply is allowed to vary. Future LULC scenarios are developed for the year 2031 (Figure 5.3-5.6). Future changes are mostly based on proximity factors, whereas actual changes are observed through current incentives and restrictions. Across the scenario models, up to 5 Km^2 areal variations are accounted for built-up, open lands, water bodies, and sand, whereas pattern varies significantly. Open

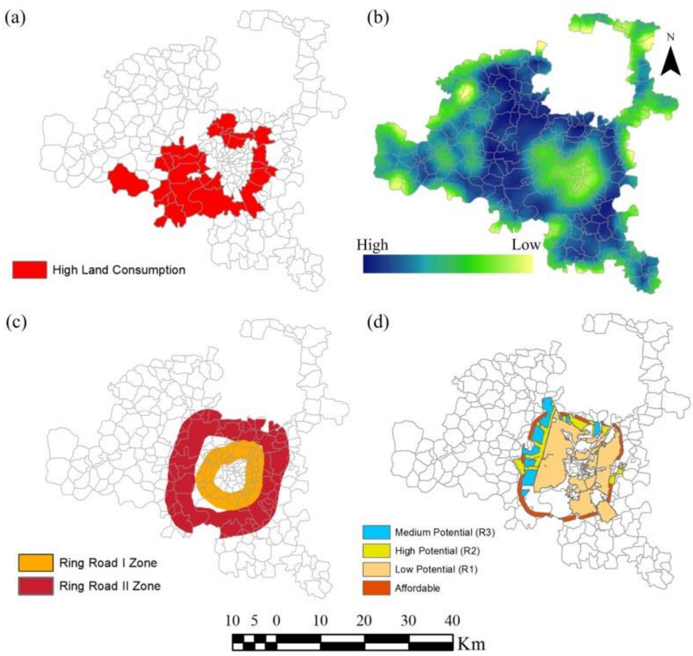

Figure 5.3: Incentives for the sprawl and compact scenarios. (a) land consumption zone, (b) USPI, (c) Ring road buffer, and (d) Residential zones

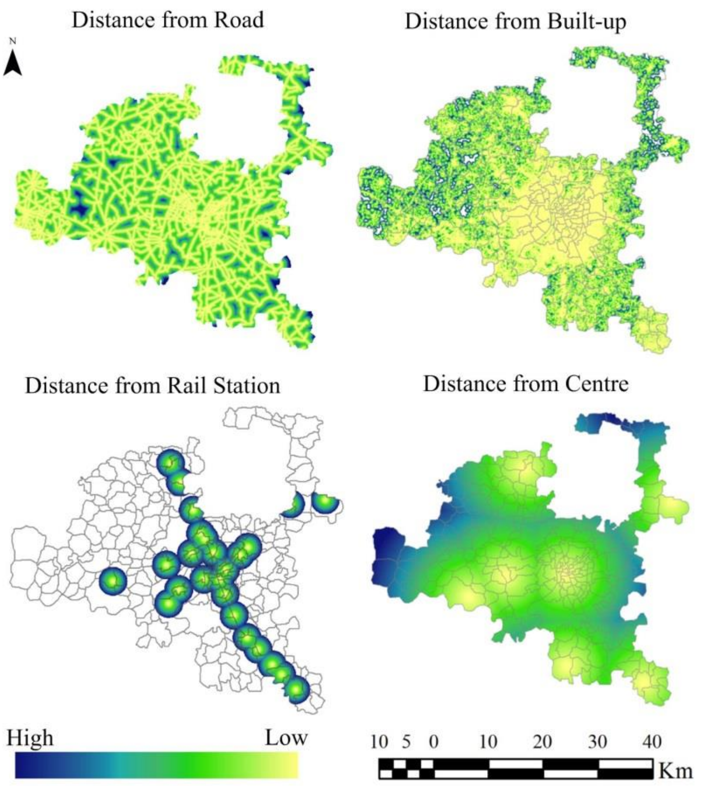

Figure 5.4: Common factors use in four scenarios (Trend, Environment, Sprawl, Compact)

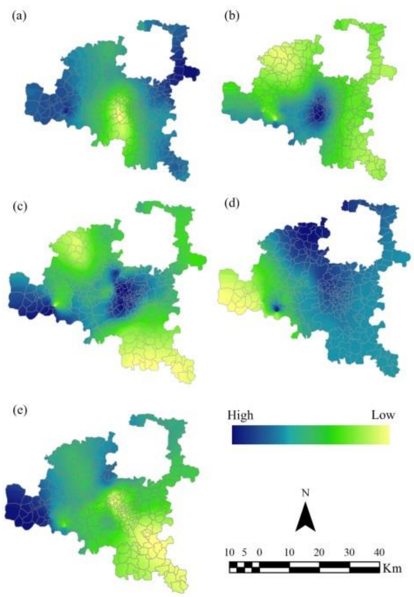

Figure 5.5: Environmental incentives to simulate environmental scenario. (a) Coefficient of LST, (b) Coefficient of NDVI, (c) Coefficient of Air quality, (d) Coefficient of Open space, and (e) Coefficient of Tree cover

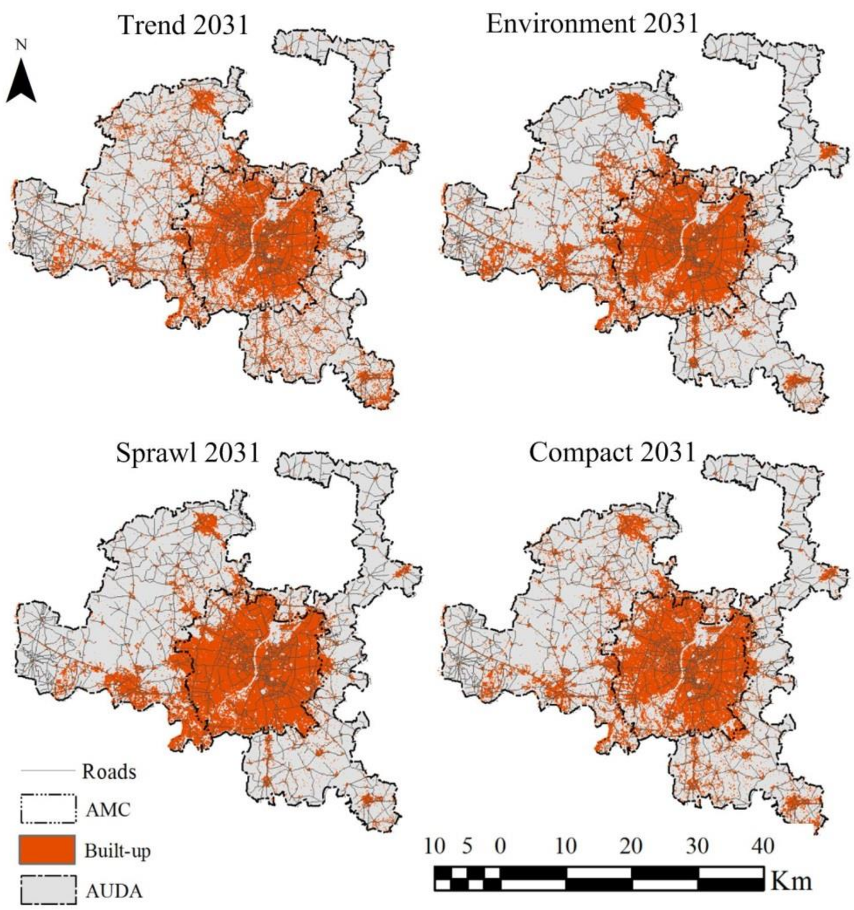

Figure 5.6: Simulated built-up scenarios.

land will reduce to almost 806 Km^2 (with an average loss of 12 Km^2/year), while built-up area will increase to 595 Km^2 (average increase of 14 Km^2/year). Cropland area loss will increase to 19 Km^2 during 2016-2031. Vegetation loss will also significantly decrease (31 Km^2). Though the amount of loss will decline, conversion of cropland to open land and vegetation to open land will increase significantly. Out of 142 Km^2 area, 56% area will be converted to open land, and 21% area will be transformed into green spaces. Similarly, out of 318 Km^2 vegetation area, 52% area will be converted to open land by the year 2031. However, only 11% cropland, 14% vegetation and 18% open land will be converted to built-up. While it is evident that effective policies can restrict the natural space to man-made conversion, the problem is different in reality. The authority approves open lands to built-up conversion, but cropland and vegetation to the built-up area are restricted. There the transition pattern shifted from cropland to open land and open land to built-up. Scenario assessment shows the sprawl model will gain the highest built-up area (236.84 Km^2) at the cost of open land (159 Km^2), cropland (12 Km^2), and vegetation (32 Km^2). Also, it is accounted that cropland and vegetation loss is highest if sprawling will dominate in the AUDA region. The compact model shows loss of open space, vegetation and green space are least compared to sprawl and environmental models. While, the trend scenario shows that in future cropland and vegetation loss will reduce. Sprawl scenario also shows the highest open land gain (almost 131 Km^2), whereas environmental model accounted for the highest gain of cropland (41.91 Km^2) and vegetation (128 Km^2). Overall, scenario models explain the current situation and to some extent underestimate the transition, whereas the sprawl scenario explains that the loss of natural space will increase in the future. Similarly, the compact model efficiently captures the transition in the Western Sabarmati riverbank where natural space loss will minimise as compared to the sprawl model.

5.3 Discussion

This study accounted for urban expansion patterns according to different development scenarios. As we have used a single land demand strategy for four scenarios, areal allocation is almost similar. However, growth pattern significantly varies across the AUDA region. For example, urban sprawl was extensively active in the eastern peripheries of AMC during 1999-2008. After 2008, the entire scenario has been changed; sprawl has shifted to the Western peripheries of AMC. It is also accounted that availability of environmental amenities significantly improved after 1999 in the Western AMC. At the same time, the new economic corridor (Sanand-Sarkej) encouraged urban sprawl development in the Western AMC. To observe changes that resulted due to the implementation of certain policies, this study developed three major urban development alternatives viz. compact, sprawl and environment sensitive development. A recent study by Troupin & Carmel (2016) clarified the benefits of growth measurement strategies are regulated and unregulated, in the conservationist point of view. The regulated scenario is pronounced to safeguard the environment. Similarly, Abo-El-Wafa et al., (2017) show green infrastructure as well as high central city densification policy can be a useful strategy to develop a holistic land use policy. This study summarizes a few facts that emerged from the scenario assessment as follows: (i) current trends shows development of low-density settlement in the suburban area will increase if containment policy is not implemented properly; (ii) urban sprawl in the suburban area is a major problem, which will become more pronounced in the South Western area. Economic opportunities and environmentally sensitive development powered township development or sub-centre development in the Western peripheries, and (iii) local authority to some extent increase density in central city through zonation and transportation system. However, compact development shows decreasing trends of urban sprawl in a suburban area. It is evident that control measures are competent to control environmental degradation and urban fragmentation. However, control measures also highlighted several issues viz. the rise in housing price, urban spill-over and scarcity of environmental amenities.

5.3.1 Urban development scenario and planning

Future extrapolation based on past changes witnesses the process of urban changes. Efficient transportation, sub-centre development, housing price affordability and available green infrastructure played a major role in the emergence of uncontrolled urban expansion. AUDA already have a comprehensive land use control plan (i.e., AUDA Development Plan 2021) to manage urban growth. Major aspects of land use control mechanism of AUDA can be identified as follow: (i) inclusive compact development to restrict urban sprawl, provide high quality of life, and efficient high end transportation and communication system, (ii) green or eco-city development through green corridor development, natural space redevelopment and conservation, and (iii) housing and residential development for all sections of the society and specifically create space for economically weaker section through zonation scheme. Our estimation suggests sprawl along the transport network in the form of radial expansion is a dominant character of AUDA urban growth. The present suburban development pattern of AUDA can be categorized as urban sprawl. Trend scenario highlights that in the future, urban sprawl will increase significantly. Housing demand, economic opportunities, and out of zonal speculation are the major hindrances to compact development. This study accounted for large-scale urban expansion beyond the pre-defined residential zones of Gamtals and GCs. GCs shows high future potentiality due to the new economic opportunities and domestic migration (Brussel, Zuidgeest, & Maarseveen, 2018). Specifically, Sanand shows unexpected future growth in the form of urban sprawl. Present residential zones are not enough to carry the future population influx, whereas Gamtals shows a more compact form of growth compared to growth centres. However, urban growth pattern in GCs neither witnessed compact sprawl scenario exactly nor extensive spill-over. According to the sprawling scenario, the affordable zone will face widespread sprawling due to housing price, environmental benefits, proximity to the ring road, and transit service. Almost, 24 Km^2 new built-up area will add to the affordable zone in the form of sprawling. However, efficient regulation can restrict the urban expansion in the affordable zone. Future housing market dynamics and the environmental situation can restrict the growth to only 13 Km^2. Overall, this affordable zone can gain 13 Km^2-24 Km^2 new built-up area in future. Sprawl scenario shows future expansion dominates in the residential Zones III during 2008-2016 through TOD and transportation development. It is also accounted by Adhvaryu, (2011) that due to private transport and housing affordability people prefer outer AMC. This study accounted that in future compact development also prevails in the Zone III zone. Almost, 26 Km^2 and 27 Km^2 areas will be converted to urban according to the compact and sprawl scenario. The environmental scenario also suggests high built-up development (23 Km^2) will emerge in the Zone III area. Similarly, compact policies densify Zone II and Zone I area and minimise sprawling event. However, the environmental situation significantly improves the urban expansion rate in a few specific locations. Indeed, housing price and infrastructural development force people to choose a new home outside the planned zones. Therefore, sprawling event will be pronounced in the outer AMC residential zones. Overall, AUDA is not an exception in respect to typical expansion stages: (i) Economic and demographic densification (industrial specialization and densification), (ii) segregated and garden city development (urban expansion based on economic class), and (iii) planned central densification and suburban sprawling (Spodek, 1980; Adhvaryu, 2010). Moreover, the three scenarios highlighted the different outbreaks of the urban expansion process. Compact policy in the form of residential zonation and green network development will not guarantee complete control on urban sprawl and availability of affordable housing. It is a difficult task for AUDA to encourage green network, urban compactness, and residential quality simultaneously. However, environmental safeguard is ineffective since sprawl dominates the region. Compact policy to some extent prevents the loss of natural space, but at the cost of land value. Trade-off task needs to be re-evaluated from the consumer point of view and from the planner point of view. Consumers will always try to trade-off between affordability and infrastructure, in these conscience planners should trade-off between environmental sustainability and sprawl. Besides, planners should revisit the local land market regulation and mix residential use, but the most difficult task is to control the housing price as well as social segregation (Munshi et al., 2014) to achieve the inclusive compact development in AUDA region.

5.3.2 Ecological safety and urban scenario

Besides urban planning, local authority also focuses on food security and green, healthy city environment. The environmental quality in AUDA area was undeniably degraded. Even in 1999-2008 agricultural to non-agricultural conversion is a serious issue. In India, urbanization pressure on agricultural land, the shift of agricultural labour to other sectors, and rural to urban migration is a common phenomenon (Acharya, 1988; Nandi & Gamkhar, 2013; Das, Ghate, & Robertson, 2015; Abhishek, Jenamani, & Mahanty, 2017; Natarajan, 2017). Ahmedabad is also a typical example of such transformation. Our estimation suggests cropland is the most vulnerable land use due to the multidirectional conversion. Therefore, cropland is a most useful LULC type, which demands sustainable use and conservation (Kindu et al., 2018). In this study, we have identified agricultural lands that are utilized in winter crop. All the other agricultural tracts are considered as open land or current fallow. Therefore, we have found that the rate of durance of cropland has declined in the recent period (2008-2016) compared to 1999-2008. However, the open land conversion rate has increased over the period. It is clear that cropland is the most vulnerable land use which has been faced three type of conversion, viz., cropland to open lands, cropland to built-up, and cropland to plantation.

Loss of vegetation, croplands and open spaces increases due to the requirement of land for development. The domestic land market, less profitable farming practices, and livelihood insecurity in rural areas (Nandi & Gamkhar, 2013; Narain, 2009, 2017) force people to sell their land to developers for healthy compensation (Chakravorty, 2016). This acquisition embraces bundles of issues in the land development process, which is beyond the scope of this study. However, our assessment accounted that local authorities have initiated several policies such as prime agricultural land identification, park, garden and water bodies redevelopment to utilize the natural resources efficiently. As our future trend scenario shows, urbanization pressure on croplands and open lands in proximity to the developed area are high compared to the isolated croplands. In fact, croplands and open land areas are extensively affected due to the urban sprawl. Unregulated urban sprawl scenario shows urbanization pressure will increase on open lands and croplands around the growth centres and outer AMC area in future, which can also reduce the availability of environmental benefits. For example, high NDVI, open space and water bodies will convert to built-up in future. Consequently, AUDA will lose extensive environmental commodity. Sprawl also creates an extensive loss of livelihood in the sub-urban village population. If sufficient jobs will not be created in the urban area, then a serious issue of unemployment will prevail. Besides, dependency on food products import from surrounding region will increase significantly. The urban, regional agricultural base will worsen if urban sprawl is not checked. However, the compact policy can restrict the loss of agricultural land but is unable to provide sufficient green space in the central city area. Densification of urban land quite efficiently restrict sprawl, but the city environment will be worsen (Sridhar, 2010; Sridhar & Narayanan, 2016; Sundaresan, 2017). The compact form also raises the issue of the protected area near the developed area. In reality, the compact policy creates zonal functioning and conservation issues in the long run (Troupin & Carmel, 2016). Environmental sensitive growth to some extent shows less fragmentation of croplands, green spaces and water bodies. However, sprawl is dominant in the rich environmental amenity locations. It is accounted that loss of economic benefit is small compared to complete sprawl outcomes. Sprawl, environmentally sensitive and trend scenario show ecological risk in the South Western peripheries of AMC. A natural space is under threat if urban growth follows trend, sprawl, and environmental scenarios more specifically in the hinterland area. However, sometimes-remote hinterland areas are converted to recreation places, which invite high-class township without understanding the benefits and risk of natural space transformation. For example, Sola-Science City development along with high-class township for new business professionals is the new form of hinterland development or peri-urban change. It is clear that implementing strict boundary or regulation to control the natural space is no longer an effective solution to save the environmental health of the city. Local authorities must formulate a holistic and integrated approach in which potential sprawl area and ecosystem loss area should be managed effectively to unleash economic development along with ecosystem health. Most importantly, development form should not act against the urban locale.

5.3.3 Limitation of scenario development

Despite a few advantages of simulation-based modelling in policymaking, there are certain issues that need to be considered. There are a few major limitations of scenario planning which have been discussed in the existing literature, i.e. data, land allocation, land supply mechanisms, and reliability. The present study was also affected by data limitations. Land supply and demand were computed using MCE and Markov transition process, which is a data-dependent process. This estimation was primarily based on LULC map, prepared from Landsat 30m x 30m data which is considered as efficient to compute land use change (Corona-Núñez, Mendoza-Ponce, & López-Martínez, 2017; Ghosh et al., 2017). The accuracy of land use transition is of vital importance for future scenario planning which is easily achievable with high-resolution data. Error in LULC can lead to change in actual land demand system. As our LULC estimation observed the accuracy of 80%-90%, indicating 20-10% error in the land demand data. Similarly, the land allocation system also depends on the LULC data; therefore, the same error persists. Scenario modelling for the single LULC class is relatively more reliable than entire LULC. LULC scenarios need large groups of explanatory factors, which is difficult when we study on an Indian city. Although, this study simulated LULC scenario, yet the major focus is embedded in urban growth pattern. The absence of data may increase the uncertainty. Despite such limitations, our scenario models replicated the actual urban growth trends efficiently. Scenario models competently captured the effect of containment policy, constraints, and environment. Spatial allocation rule and single demand function sometimes lead to areal uncertainty. For example, sprawl scenario and compact scenario possibly create different built-up area but in this study, the built-up area is almost same. A few scholars also prefer more sophisticated mechanism instead of simplistic CA rule (Li & Gong, 2016). However, to find out a suitable model for future simulation is beyond the scope of this study. Indeed, accuracy of this study is well above the critical limit. To reduce the model uncertainty, this study followed a rigorous sensitivity test for the entire scenario.

5.4 Conclusion

This chapter successfully estimated the urban growth scenarios of AUDA. A major aim of this study is to evaluate existing land use regulation and future potentiality. It also accounted for future potential issues and possible flaws of existing policies. Although there is a significant number of studies available that deal with planning vision, the present study is unique in terms of comprehensive spatial assessment using scenario tool and, in that, it efficiently assessed the future threats to croplands and green spaces. Scenario selection process of this study is comprehensive with respect to urban sprawl and environment. It is also well acquainted with socio-economic and people perceptions. Sprawl matrices, TOD, and potential land consumption area successfully demarcate the potential sprawl area and associated issues such as open land fragmentation, green space loss, and unidirectional urban expansion. Similarly, environmental amenities are significantly lost during future transition, whereas compact scenario identified densification process as well as indicated the future environmental crisis in the central city. By promoting compact form, AUDA can proceed for natural space preservation. However, preservation itself introduced housing affordability and supply crisis. The local authorities need to look at these critical issues for sustainable urban development. Undoubtedly, MCE-CA successfully presented the future issues of the existing plan. This integrated modelling framework can be used as a reference tool for other Indian cities. This model easily interprets local policy, socio-demographic status, and provides a range of decision-making alternatives. MCE-CA is highly beneficial for high growth active medium to the higher order cities to capture the different expansion pattern. This assessment highlighted branch of information that is valuable for future policymaking. Local governments can use this information to alter the growth path. It can be useful to create space for affordable housing and to regulate the existing housing market. Adequate responsibility is also essential for environmental health in central city when local authorities promote densification policy. The disappearance of green space and water bodies in the central city is a fact due to the high demand for land.

To develop an environmental resilient, efficient compact city, integration of resource sensitive land use planning is essential. Besides, understanding of mix-use zones, the effectiveness of conservation plan assessment is a valuable addition to the urban planning. Most importantly, future work on stakeholder-based land use allocation system and socio-demographic integration are helpful for scenario development, as well as strengthen the LESS framework.

Appendix

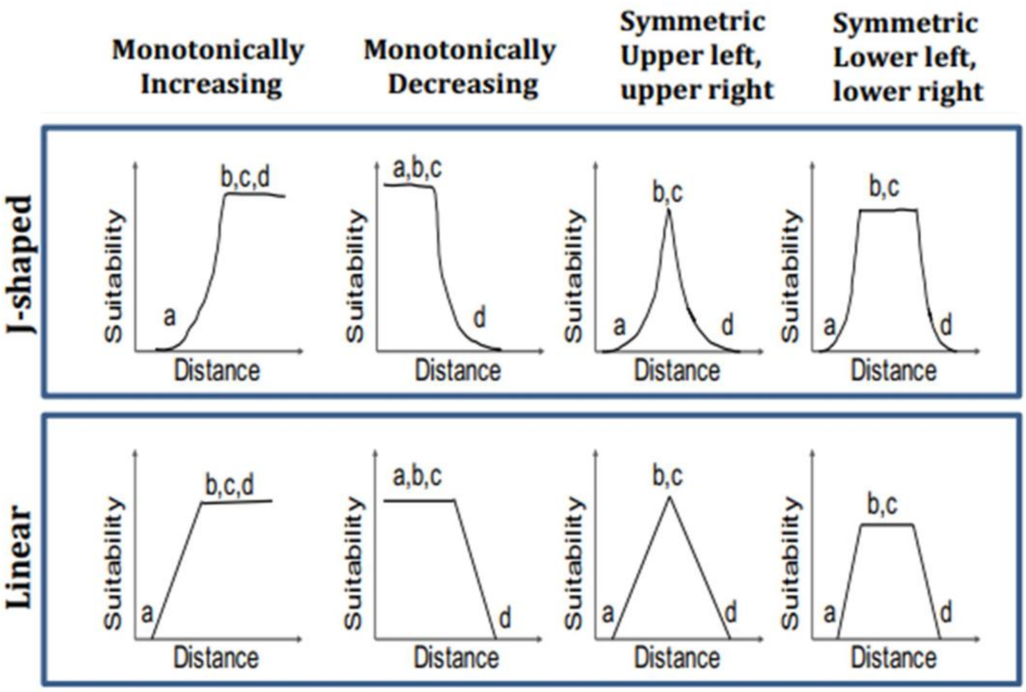

Figure A5.1: Different membership functions of fuzzy logic (*Source: Idrisi Manual 2012*)

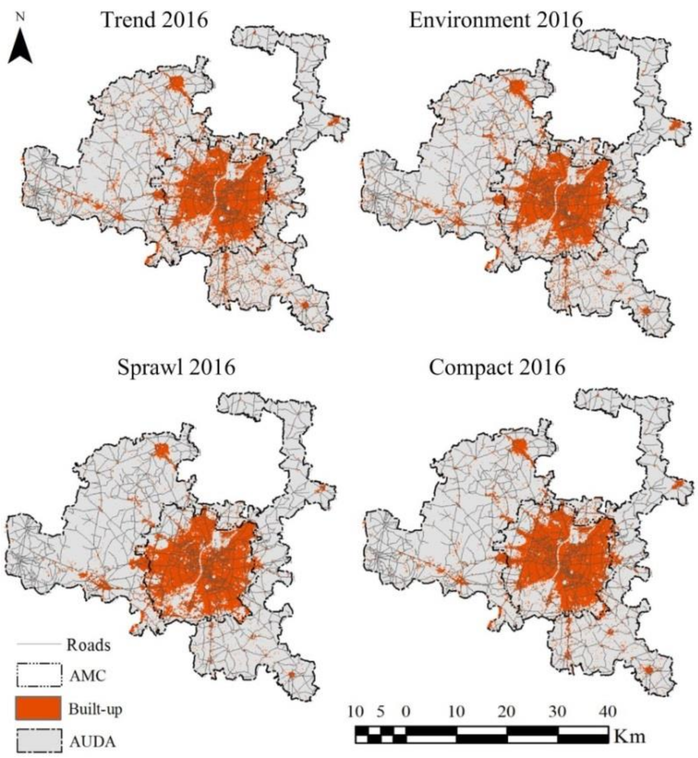

Figure A5.2: Simulated built-up 2016 of different scenarios

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Chapter 6

Summary and Way Forward

Land use policy in India is a highly debated aspect of urban planning in recent times. India does not have any comprehensive national land use policy. India has undertaken urban land policy since 1989. The most controversial land acquisition, rehabilitation and resettlement act 2014 (LARR) is now implemented after several levels of assessment. Still, there is a gap of national-level land use policy, which is useful to regulate loss of natural space, land transformation, and environmental degradation. One of the major constraints to implementing national land use policy is a diversity of city size in terms of demographic, economic, and areal coverage. Single land use policy for all city classes may increase the arbitrary land use allocation mechanism. Proposed LESS framework can be used to assess the across the all size class cities. As land consumption pattern significantly varies across the size class, therefore a single policy would be unable to restrict the land utilization and urbanization process. At the macro level (national level), LESS can be used to prepare the development zones as well as the reserved area. It is also useful to target the urban sprawl and environmental safeguard, along with the generation of time-efficient residential zonation system. Indeed, one can use this LESS framework to prepare a resource-sensitive land use plan.

LESS assessment on Ahmedabad brings forth a few new insight of land use maintenance system and has identified some unique advantages. The suburban land transformation from natural to built-up area indicates uncontrolled expansion and inefficient land utilization mechanism. From the methodological point of view, the proposed framework is unique as it integrates several major aspects of land use planning. Firstly, land change system is used to explore the past trends; also, we have identified potential local land consumption zones. This study uses spatial GWR model to quantify the value of natural ecosystem and level of urban fragmentation through common sprawl metrics and measures the local cost and advantages of sprawl through the GAM. Finally, CA-MARKOV model is used to set the alternative scenarios. Several most popular tools GAM, GeoSOM, GWR, and CA-MARKOV are combined in this LESS framework. Any time one can incorporate more sophisticated and robust spatial model instead of the above models. The limitations of these models have been already highlighted in the previous chapters. As a whole based on several previous approaches to land use change assessment, this research proposed LESS framework. From an environmental point of view, LESS is efficient to allocate land for development where simple simulation models only considered past trends, but neglect the land utilization process. Although there are several advantages, two major strengths are (i) effectiveness of residential zones and associated environmental amenities, and (ii) future policy direction based on local perception and government incentives and constraints. In general, LESS framework is to some extent open system, where multidimensional modifications are always adjustable.

However, the major four components are the heart of this framework. Land change system was first used to access the past trend, potential local fragmented and land consumption zones. This integrated system systematically synthesized the challenges and strengths of urban expansion in the single monitoring system. Each of these models is well equipped with several advantages, although not free from structural limitations. The base of this study depends on the LULC, Population Census of India, and field survey data. Although, 30 years span of LULC data have been used, yet the integration of socio-economic data is limited to 2001 and 2011 population Census of India. Land change situation is not well regulated in AUDA. Sprawl and land use fragmentation have resulted because of the unidirectional planning. Major factors that are responsible for LULC change are employment, transport, population and infrastructure. In fact, these factors are inseparable from LULC policy assessment. Land change assessment is the first aspect of LESS framework, which explain domestic demand and supply of land for development. LULC change assessment summarizes the land consumption process, which is not adequate to undertake resource sensitive decision-making. Potential land consumption zone has been identified, which is not mutually coexistent with the residential zone. The estimation shows that land consumption rate is declining in the central city area and suburban area gaining. Land change assessment highlighted two trends, (i) land consumption rate has increased in the Western peripheries in the form of linear expansion and development of sub-centre, (ii) redevelopment and insufficient vacant land stabilize land consumption rate in the central city area. Available regulation and zoning scheme are not enough to restrict the suburban land consumption without LULC fragmentation. GeoSOM optimizes five different clusters, in which one cluster accounted for unexpected natural space fragmentation, built-up expansion, high employment rate, and low population density. Nevertheless, time series assessment may help to understand the process of mismatch between the master plan and land consumption zones.

This study aims to explore the benefits of environmental amenities to achieve sustainable residential development, besides LULC assessment. Valuation approach is used to capture the locational advantages in the context of the environment. Economic valuation is useful to trade-off between natural amenities and development should be the crucial aims of local land use policy. Our findings suggest green space, water bodies, temperature, and quality of tree cover shows a significant effect on residential development pattern in the Western peripheries. In fact, LULC change, environmental amenities, and urban expansion are mutually inclusive event seen in the Western peripheries. Existing studies on USA, Europe, and China have shown increasing influence of natural amenities on housing choice. The present study is unique in terms of amity based residential pattern extraction, also identified the demand mismatch between eastern and western riverbank. In the present context, the urban eco-social environment gained significant attention to improve the residential quality. It is beyond doubt that urban environmental amenities can be considered as a component of local residential quality differentiation. This study accounted for the inequality of available natural resource accessibility. Findings are highly useful for local policymaking. This assessment is valuable to identify the most expensive location-specific environmental amenities and efficient way to its sustainable and equitable use. Sustainability of these resources highly depends on the market dynamics, the efficiency of the local institution and the land use regulation. In this context, land allocation and land demand system based on environmental amenities shows promising outcomes in the long-run.

Delineating land use policy without acknowledging urban sprawl may lead to unproductive utilization of a parcel of productive land. Considering the previous literature, several issues associated with urban sprawling have been identified. In fact, cost of urban sprawling is much greater than the benefits. In the case of Ahmedabad, this study found some perennial issues such as the increase in average travel time, consumption of fuel, and loss of environmental amenity. However, local authority deliberately ignored all these issues and focused on compact growth policy. Interestingly, compact growth initiative in the forms of the ring road, floor space ratio, and residential zones mix use system itself fueled the urban sprawling in Ahmedabad. It is also found that environmental amenities are also associated with burgeoning urban sprawl. In general the findings can be summarized into three major segments, as follows: (i) urban policy cannot be restricted through containment policy if local market dynamics actively mishandle the local land use rules and regulations, (ii) people's perception on local situation highly affect neighborhood satisfaction; locational development potentiality is highly associated with environment, which is significantly influenced by people perceptions and (iii) the benefit of urban sprawl on the other hand significantly associated with affordable housing environment. If the city vision is concerned with the inclusiveness then the sprawling pattern is effective, otherwise, the majority of citizens are excluded from the better housing. In fact, compact growth is useful to restrict CO_2 emission; however, exclude the majority by densification policy.

Further, without an understanding of future alternatives blind formulation of plan and policy may mislead the vision. The inclusion of alternative assessment mechanism greatly helps to initiate a long-term policy resolution. In this context, LESS framework is not away from any ideal policy assessment tool. LESS framework included scenarios to identify the effect of different land use policies. This study estimates four alternatives and its effects on urban expansion pattern. Also, the present study highly focuses on the comparative estimation of the effectiveness of residential zones. This study found that if local government strictly implements the compact policy, then sprawl could be minimized.

Similarly, accessibility to environmental benefits can significantly differ away from the current trends, sprawl, and compact policy-induced expansion. Two major findings are (i) socially inclusive compact city is automatically becoming a distant dream for AUDA as long as affordable housing, and residential zonation is exclusive content of planning (ii) urban beautification, and green corridor planning came as a safeguard to the environmental sensitive places at the same time accessibility of such natural places reduces gradually for the majority. Scenario planning has shown four different future situations, which can help to adjust the issues of any specific local zoning policy. Scenario building based on the aspects of Development Plan 2021 may increase the acceptability of the LESS framework. Moreover, this approach addresses the local issues that cannot be handled through the current development trends. The local authority should promote compact policy only if in the long-run containment policy will be beneficial to the majority. Otherwise, the current policy scheme needs to be given a thought on.

Urban land development in entire Gujrat is done using the Gujrat urban development and town planning act 1976 (GUDTP Act). Town planning scheme is generally used for local and macro level planning in Development Plan scheme. Like other Indian cities, Ahmedabad also emphasized two aspects of land regulation viz., urban land ceiling and floor area ratio (FAR). Population projection and density criterion are also incorporated to delineate development zones. The urban land (ceiling and regulation) Act 1976 mentioned the threshold size of prime land. Beyond the threshold, the land is distributed for public development. FAR highlights maximum possible human density. Previously, AUDA DP 2011 emphasized on (a) compact urban form, (b) urban environment to restrict the urban sprawl and LULC fragmentation. However, existing studies condemn success of proposed green network in the master plan, but unsuccessful to initiate such pan-city green development measures. Based on the finding, we believe only population projection based visionary plan is not beneficial in the development plan. Similarly, the zonation system is not at all efficient. AUDA considered only employment and population density criterion. Most importantly, AUDA have not taken any alternative measures of compact urban development. Considering all these issues AUDA Development Plan 2021 carefully considered the weaknesses of their previous plan, which can be summarize as follows , (i) affordability of housing is serious concern due to the large mismatch between housing demand and supply, (ii) provision for economically weaker section is not adequate, (iii) assumed development and built-up expansion rate of growth centre exceeds the threshold limit, therefore quality of urban services deteriorated, (iv) despite green initiative, large-scale development outreached the environmental sustainability, (v) vacant land utilization system is inadequate, which encourage urban sprawl, (vi) significant growth spread outside the regulatory system, which has fueled the loss of natural spaces. AUDA Development Plan 2021 proposed a comprehensive framework, which incorporated CBD and TOD plan for urban densification and outer ring road development to optimize the outer AMC development zones. Nevertheless, AUDA Development Plan 2021 is dysfunction as significant sprawl and LULC conversion has been accounted. We found LESS framework is worthwhile to account for the issues related to land use policy. To address the uncontrolled expansion and develop a resource sensitive urban land use policy, LESS can be a suitable tool. LESS is more efficient to decode any development framework. It can easily identify the flaws and advantages of the existing plan. LESS shows some flaws of AUDA Development Plan 2021, like, (i) residential zone demarcation based on density is seriously problematic. Yet, density, employment, accessibility clusters used in LESS, are more promising. Most importantly cluster-based approach will include the non-regulatory outside AMC area, which is helpful to control informal rural land transactions, (ii) to preserve the environment compact and green road corridor is not fruitful until now. We observed that environmental amenity valuation should be a beneficial step to demarcate the rich urban ecosystem area. Presently, Western peripheries is the most environmentally attractive location and need careful investigation of natural resources, (iii) sprawl should not be treated as an evil, but can be treated as a planning 'informality'. Containment policy and strict regulatory framework need to be revisited to minimize commuting time, LULC fragmentation, and fuel consumption. In the local context affordable and mix-use, zonation with high public transportation can reduce the urban sprawl. Finally, AUDA should focus on alternative strategies rather than a single suitability measure. Alternatives are extensively used to understand the potential threat of planning. It has emerged from the present study that LESS framework can be used as a guideline to evaluate the land use policy. This approach is highly suitable for cities in the developing countries, more specifically Indian cities where environmental degradation and urban sprawling has always challenged the deliveries of basic urban service. Seemingly, this framework covered wide areas that are associated with land use planning. Nevertheless, show some scope to improve the capability of LESS to monitor the master plan through the inclusion of eco-social understanding.

Questionnaire

PhD Survey Questionnaire **Phase 1: Geospatial Approach to Urban Sprawl and Environmental Amenities**														
Surveyor:												**Date:**		
Location no	**Latitude**	**Longitude**	**Ward/Village/Town Name:**	**Income categories** (1=<10k 2=10k-50k 3=>50k)	**Admin Unit** (1=core, 2=semi-urban, 3=village, 4=town)	**Housing Price (unit)**	**Land Price (unit)**		**Lot Size (unit)**	**Home Age** (e.g., 1990)	**No. of Room**	**Type of house** (1=2BHK 2=3BHK 3=Personal 1 floor 4= Personal >1 floor)	**House Condition** (1=Bad, 2=Average, 3=Good)	
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Neighbourhood Variables															
Location no	Dist to CBD	Neighbour Unemployment (High=1, Low=0)	University Education	Dist to Nearest Road (m)	Dist to Highway (m)	LULC Diversity (r=500m)	Public Transport (Available=1, not available=0)	Dist to shopping centre (m)	No of Educational Institute (r=5000m)	No of Health centre (r=1000m)	No of School Present (r=2000m)	Distance between dwelling Unit	POP density	HH density
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Neighbourhood Variables									
Location no	Ratio of Built-up and Non built-up	Built-up Change (Phase 1)	Built-up Change (Phase 2)	Neighbour Land Use change(Water bodies)	Neighbour Land Use change(Transport)	Neighbour Land Use change(Cropland and openland)	Neighbour Land Use change(Vegetation)	Building Shape	Transportation Condition (Score based)
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25									

Environmental Variables														
Location No	Lake Dist (m)	Park Dist (m)	Forest Dist (m)	Water bodies (m)	Open space Dist (m)	Open Space (r=1000m)	Impervious Surface (r=500m)	Tree Cover (r=100m)	Tree Cover (r=200m)	Tree Cover (r=300m)	Tree Cover (r=400m)	Tree Cover (r=500m)	Significant Environmental Area	Ecosystem Fragmentation (r=1000m)
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25														

Sprawling Variables												
Location No	Plot Plan Present (yes=1, no=0)	Environmental Disamenities (factories per 1000m radius)	Average Dist to Factories	Entropy (r=500m)	Patch Density 9r=500m)	Fragmentation of green space (r=500m)	Urban Density (r=500m)	No of trip to Centre	Time Spent in travailing	Energy Use (Electricity)	Energy Use (Cooking)	Energy Use (Transport)
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Market based variables										
Location No	Job Centre Address	Dist to job centre (m)	Nearest Development Project (Yes=1, no=0)	Nearest Township (Yes=1, no=0)	Land Value Change due to any speculation (y=1, n=0)					
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Phase 2: Score based Assessment (1=Strongly Bad, 3= Bad, 5=Moderate, 8=Good, 10=Enough)																		
Location No	**Air Quality**	**Water Quality**	**Noise Quality**	**Temp**	**IMS**	**Quality of Garbage Disposal**	**Viability of local Service**	**Neighbour Interaction**	**Recreation Environment**	**Resource Accessibility**	**Cultural protection**	**Regulatory Environment**	**Market Environment**	**Credit System**	**Profit**	**Industry Setup**	**Labour Force**
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Phase 3: Sustainable Urban Plot Index (SUPI):
Land Use

Location No	Single Family HH/1000	HH in Apartment /1000	Per capita residential land	Gross Residential Density	Per capita commercial land	Per capita green land	Per capita open land	Per capita Road	Area with environmental fragmentation	Environmental significance					
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Sustainable Urban Plot Index (SUPI): Amenity													
Location No	No of University or institution facilities (r=5000m)	Nearest bus stop distance	Health centre service (Score based)	Nearest Railway	Proximity to super market	Energy Consumption	Govt. Service (Score Based)	Water Quality (Score Based)	Electricity (Score Based)	Sanitation (Score Based)	No Hi tech industries (r=1000)	Hotel business (Score Based)	E-governance system (Score Based)
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Sustainable Urban Plot Index (SUPI): Smart															
Location No	Age of the respondent	Is it Second Home? (y=1,n=0)	Any govt. facility taken (y=1,n=0)	E-billing (y=1,n=0)	Recreation time	Internet Banking (y=1,n=0)	Computer Skill (y=1,n=0)	Graduation and above (y=1,n=0)	Cinema attendance (y=1,n=0)	Foreign language (y=1,n=0)	Expenditure on education	HH with Internet access (y=1,n=0)	IT employee (y=1,n=0)	E-gov use (y=1,n=0)	Renewable resource use (y=1,n=0)
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