URBAN GROWTH MODELING AND ASSESMENT USING AGENT-BASED MODEL

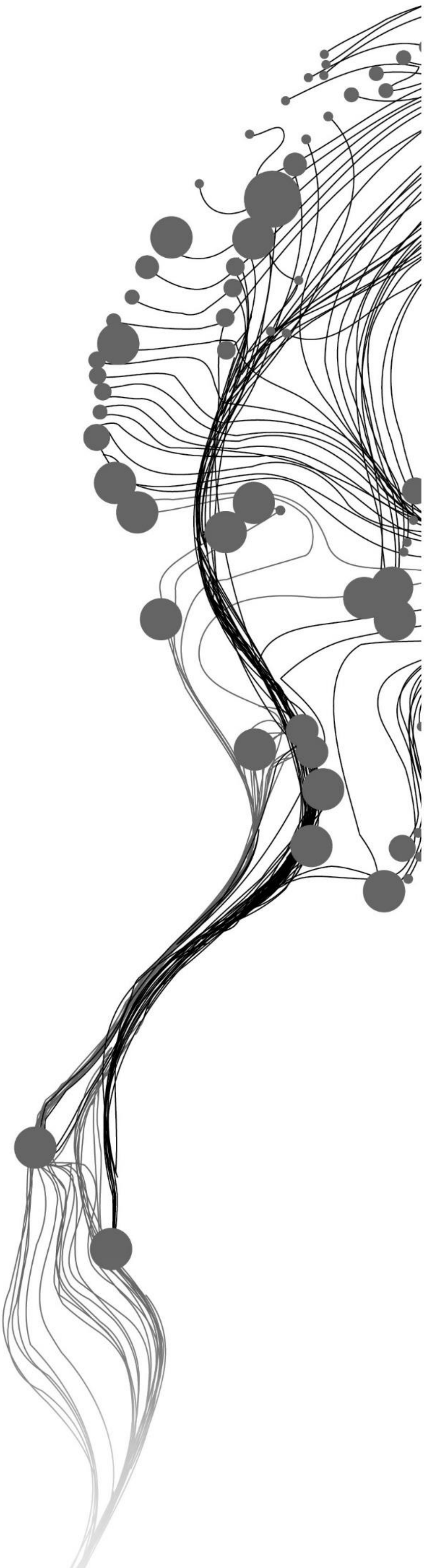
BADRI GARI ROHITH

[November, 2022]

SUPERVISORS:

Mr. Ashutosh Kumar Jha

Dr. J.M. Morales Guerin



URBAN GROWTH MODELING AND ASSESEMENT USING AGENT-BASED MODEL

BADRI GARI ROHITH

Enschede, The Netherlands, [November 2022]

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.

Specialization: [Geoinformatics]

SUPERVISORS:

Mr. Ashutosh Kumar Jha (IIRS)

Dr. J.M. Morales Guerin (ITC)

THESIS ASSESSMENT BOARD:

prof.Dr. R. Zurita Milla (Chair)]

Dr. Nitant Dube (External Examiner, Group Head MRG/EPSA,SAC-ISRO]

DISCLAIMER

ABSTRACT

Municipal development authorities, primarily in metropolitan areas, used statistical based urban growth models, guidelines, drivers-based approaches to prepare perspective plans and other development plans for future prediction, and the result was allocation of proposed land use, population projections, and policy recommendations, but some were not focused on intersection of population distribution, housing parcels, location of proposed housing parcels and land use changes. Gaps in the planning and implementation process, such as these deviations, the importance of small scale changes, and decision making during policy preparation, can be addressed with urban growth computational models in this era.

Decision-makers such as urban planners, policymakers, and others require urban growth models. Decision-makers must apply these growth models to future growth using dynamic and static drivers in order to plan development and manage haphazard growth. Bottom-up modelling heralds the start of a new era in urban planning, with the ability to understand the impact at a small scale made possible by growth models.

Cellular automata is a technique for putting this theory into practice and the spatial growth elements, such as buildings and roads, and their measures, was handled using rule-based modeling because it is possible to measure, update, and test different scenarios by the regulations of that specific area and agent-based modelling as a part allows for the examination of how various individual interactions affect society's general behaviour in spatial and non-spatial terms, as well as potential scenarios at a very small scale that visualize how changes in quantitative and qualitative terms affect current land use. The small interactions have a big impact on how that area develops.

This research is limited to the eastern part of Hyderabad(zone-1), which consists of 17 wards and five circles. Aim was to setup a methodology and develop a decision making system for proposed land use and land cover in urban cities. Rule-based modelling technique was used to create building parcels using OSM (road network datasets) data, municipal data, local government planning guidelines, building and road bylaws, and neighborhood parcel characteristics and status in Gis softwares. Surrounding behaviour, such as neighboring parcels' land use and land cover using sentinel-2A satellite imagery, neighbouring parcel's status,physical characteristics, demographics and drivers such as accessibility based are investigated, in order to know the impact on created parcels for the development. To understand the behaviour, impact, and potential development of created parcels, various model approaches such as hexagonal, planning-based, computational, and statistical approaches are used. Various suitability scenarios (maps) for the development of different land use and drivers (variables) were created with the help of logistic regression to estimate the relationship between dependent and independent variables. These suitability maps of different land use classes created the suitability score for the created parcels. These parcels with the suitability scores and other required vector-attributes are participated in agent based model. With all these parameters ,agent-based model discovered the interactions within the neighborhood and decided the growth potential for future years.

The agent-based modelling achieved 60% accuracy in predicting the future development of parcels in terms of location and land use. It has been observed that the impact of various drivers on various land use classes varies. Future development potential locations for various land use classes were obtained using agent-based modelling, which assists decision makers in framing policies or initiating short-term action plans to control the deviated-growth direction.

Key words: Urban planning, Perspective plans and development plans, Land use, Urban growth modelling, Municipal data and Sentinel-2A satellite imagery, Suiatbility maps, Agent based modelling.

ACKNOWLEDGEMENTS

First and foremost, I would like to praise and thank God, the Almighty, for the numerous blessings, knowledge, opportunity, and capability that have enabled me to work on and complete this thesis.

I would like to express my heartfelt appreciation to Mr. Ashutosh Kumar Jha, my IIRS supervisor, for giving me the opportunity to work on this project and for his support and guidance not only as a supervisor but also as a mentor. I'd like to thank him for his invaluable advice and knowledge sharing throughout this project.

I would like to thank Dr.Javier Morales Guerin, my ITC supervisor for his wise advice, knowledge sharing and continous support in helping me complete my thesis..

I also want to thank Dr. Sameer Saran, the head of the Geoinformatics Department at IIRS and course co-ordinators Dr.Sander Oude Elberink and Kapil Oberai for giving me the chance to learn through this thesis project and complete the MSc course smoothly.

I would also like to thank thesis committee,the chair prof.Dr.R.Zurita Milla, External Examiner Dr.Nitant Dube for their critical comments and feed back.

For providing the necessary data as well as their encouragement and support throughout the project, I would especially like to thank the Town Planning and IT sections of the GHMC, Hyderabad.

For their encouragement and support throughout the project, I would especially like to thank my team members Manivannan, Priyadarshini, Margarret Ashmita, Neethu Narayanan, Gautamee Baviskar, Shivang Pandey, Aravind, Prateet Tiwari, Omkar Jadav, and Ketaki.

I also want to thank my friend satya priya for her continuous support in all ways throughout my project.

I sincerely thank my parents and brother for their unwavering support.

I want to thank everyone whose assistance was essential to completing my project.

TABLE OF CONTENTS

LIST OF MAPS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Background and Introduction

Disregard for rules and regulations has consistently encouraged haphazard growth in metropolitan areas. According to World Bank estimates, just one-third of the world's population has access to official land administration systems for registering and protecting their land rights. Any land administration system must incorporate cadastral maps since they provide the location, value, and property ownership details. Additionally, they are used to create and amend land records ((D. Kohli, E.M. Unger, C.H.J. Lemmen, R.M. Bennett, M.N. Koeva, J. Friss, 2018) . Not Computerizing and updating the land records creates the possibility of increasing haphazard growth in urban areas (Abu, 2015). Urban and Regional Development Plans Formulation and Implementation URDPFI Guidelines, India (MOUD, 2014) for the approval of land; improper land use, overexploitation of resources, and finances have been a massive bane for planned urban development. Built-up regions change and increase all the time. Clear and comprehensive property records have several far-reaching benefits, including ease of searching titles, a transparent taxation system, more straightforward dispute resolution, reduction in fraudulent transactions, and facilitating upcoming developments in urban areas. (IIHS).

While ground surveys gather data on land use and urban growth, traditional methods for detecting changes in the land's cover rely on comparing successive land-cover maps obtained through remote sensing (Jain et al., 2016). Due to institutional difficulties and time constraints, it is impractical to conduct ground surveys quickly; as a result, the city planner cannot produce the necessary time-series data. Master plans or other long-term plans are revised and prepared every 20 years. Asper the MOUD guidelines, the master plan will be reviewed every five years; long-term perspective - ignoring short-term actions and goals, Monitoring and review mechanisms are inconsistent and ineffective. (MOUD, 2014).

However, (Madhavi Jain, 2016) states that utilizing remote sensing data in planning can help overcome the process gap. Without the aid of satellite remote sensing, it would not have been possible to continuously observe, quantify, and precisely track LULC changes over such a wide variety of spatial and temporal scales in a short time. When it comes to putting the plan into action and gaining access to data, the lack of connections and communication in planning, land resources, and other administrative departments causes delays, poor decisions, and information gaps. Linking the properties with the geospatial database is required for land planning to monitor and fulfil the data requirement gaps.

1.2 Rationale

Land use monitoring is necessary for plan implementation to detect change between the years of development in physical-real time and take action according to the plan at the early stage(Wang et al., 2020). Regular monitoring of goals will limit the amount of time needed to analyse and formulate annual plans. (MoHUA, 2014). GIS is mostly used in land-use monitoring to support user analysis, visualisation, and mapping needs. Since it is generally understood that data utilised in GIS applications lacks the rigours necessary to satisfy accuracy criteria, therefore data would only be used as a source of reference (GFDRR, n.d.). With the assistance of modelling techniques like the Land Change Modeler, maximum likelihood suitability generator, agent-based modelling, and other machine learning techniques such as SVM, Random Forest, and others, we can obtain a better result of changes and indicators of drivers. The impact of reviewing the implementation of the plan can be very beneficial for policy formation. These factors and indicators help evaluate and predict future growth. The evaluation's primary goals are assessing progress and identifying areas of success, failure, and conflicts to direct or correct the future course of action. This is a crucial stage in the dynamic planning process that hasn't been appropriately applied until now. This process should become mandatory under TCPO acts.

Bottom-up modelling heralds a new era in urban planning. Cellular automata is a technique for putting this theory into practice. The model's principal purpose would be to explore the future. This entails an awareness of the implications of various alternatives under diverse external factors. (Lahti, 2008). CA, Logistic Regression (LR), Agent-based, Rule-based modelling, and weights of evidence were used to evaluate and simulate LULC changes and predict the zones and areas that needed to be planned and executed.

As a result of this research, a model, design, system approach, data handling, and management are created. Accounting changes in Land Use and Land Cover are derived by employing various classification schemes and computational models; these changes can be used to frame public decision-making policies.

1.3 Study Area and Location Characteristics

1.3.1 Study Area

The study region is Hyderabad, and the study area Zone 1(East zone) comprises an area of 650 km^2 under GHMC (Greater Hyderabad Municipal Corporation).

1.3.2 Location characteristics and History

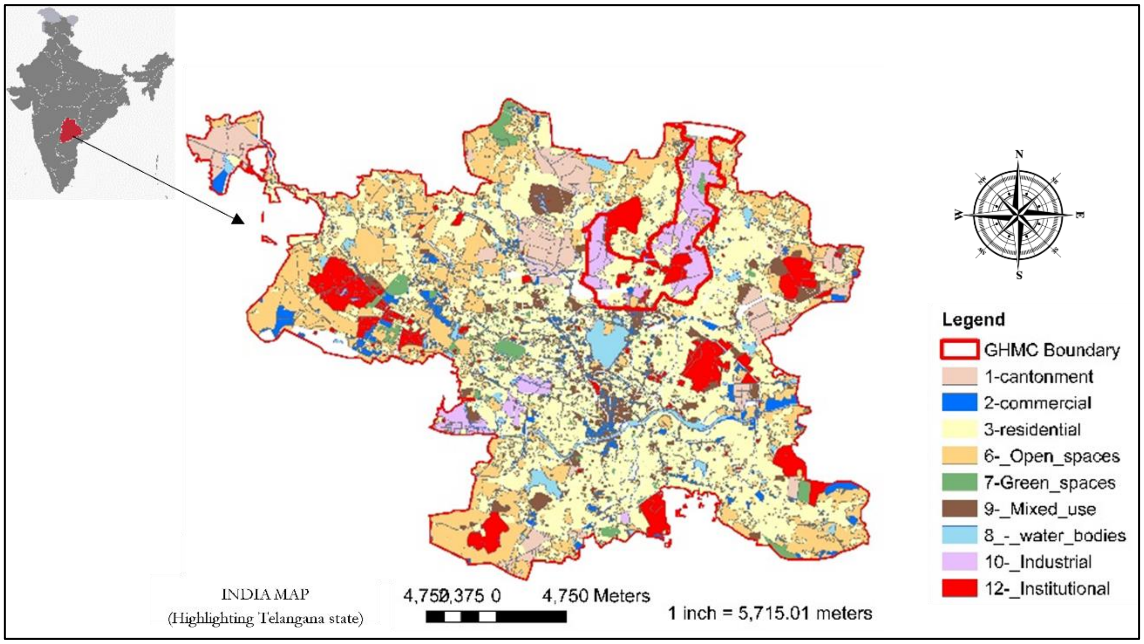
To comprehend Hyderabad's urban morphology, it is necessary first to grasp the history of Islamic geography, cartography, and cosmology. Hyderabad was known as the Isfahan-I Nau, or "New Isfahan," and its architect, Mir Momin Astarabadi (1585-1624/5) modeled his design on Isfahan, Iran, which was also erected at the same time to commemorate the Islamic millennium. The fifth sultan, Muhammad Quli Qutub Shahi, founded Hyderabad in 1591. The city is named after Caliph Ali Ibn Ali Talib, the fourth caliph of Islam and his son-in-law.(Kevin B. Haynes, 2020)

After the adjacent Golconda Fort settlement became outdated, Hyderabad was created in 1501. During this time, urban settlements grew along an east-west axis. The Secunderabad British military cantonment was established in 1806, and urban development began to grow along a north-south axis. Since the establishment of the Hi-tech city, the urban settlement has reverted to east-west urban settlement expansion. (Kevin B. Haynes, 2020).

The analysis also uses official Nizam papers, HUDA master plans, and Hyderabad Municipal Development Authority (HMDA) master plans to assess the spatial patterns of change and the pace of development in urban area extent and form across the study period(Kevin B. Haynes, 2020). HUDA Master plan is prepared to provide or make available housing for all kinds of section people under the state government act 1975. It was covered up to 1348 sq. km. It was also formed for the revision of masterplan and zonal development plans. Later as the city grew, it transformed into HMDA in 2008.

According to HMDA(7257 sq. km)(*HMDA*, n.d.), Hyderabad (HMDA core area) is 2,500 sq.km and GHMC is 650 sq.km in size and is located in central Telangana. The city is situated on the Deccan Plateau, with an average elevation of 536 meters above sea level, centered at 17.366 degrees north latitude and 78.476 degrees east longitude. The study areas are notified as zone-HUDA and HMDA Zone vide G.O 805 MA, dated 15.09.1and. Vide G.O 518 dated 1.08.80(*HMDA*, n.d.)

According to the setup of the administrative and planning organisations, municipal corporations are divided into city level, zone level, and ward level. Analysis was carried out at the zone and ward levels in accordance with methodology and process. , Hyderabad city (GHMC) administrative boundaries have divided the city into six zones. These zones are Charminar, L. B. Nagar, Serilingampally, Kukatpally, Secunderabad, and Khairtabad make up Hyderabad. Each zone has subdivided into circles. There are a total of 30 circles. Zone 1 is the study's primary area of interest.



Map 1 HYDERBAD MUNICIPAL CORPORATION LANDUSE MAP-2018

As part of the development and growth in developing countries, Hyderabad city is changing rapidly with significant momentum in terms of Infrastructure and the economy in India. The city has attracted investments in the IT sector, further fueling growth in the residential space and other asset segments. With

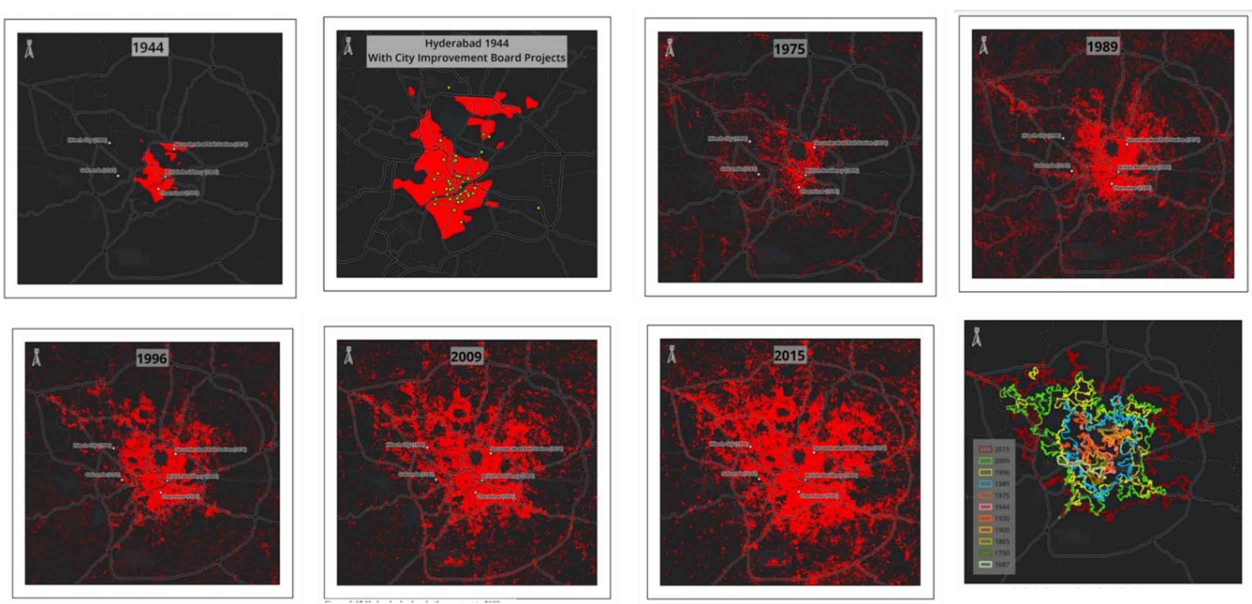


Figure 1 Spatial Growth of Hyderabad over the years. Source:(Haynes, 2020)

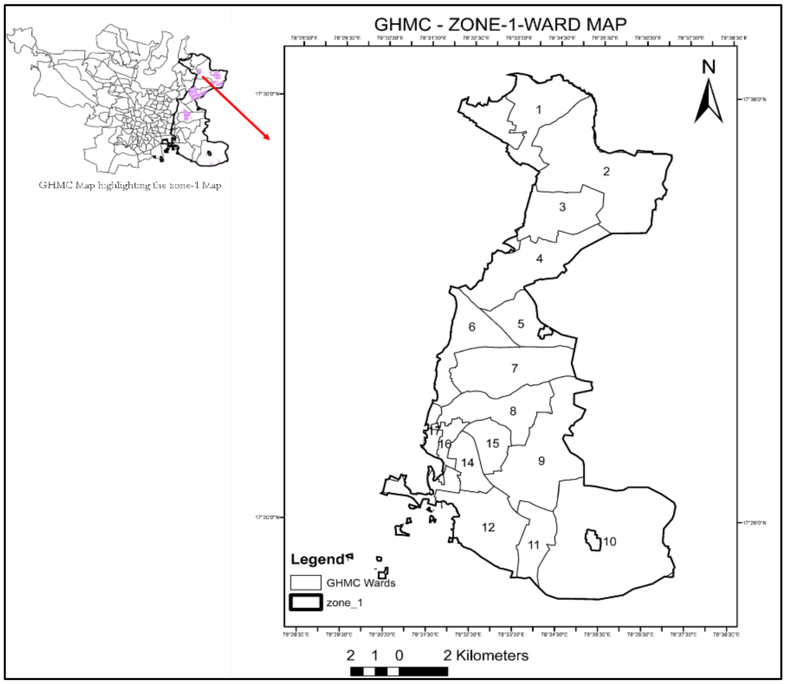
large e-commerce companies setting up their centers in the city, the warehousing sector is also growing gradually. Telangana government is making the State a significant investment destination for the manufacturing sector. The proposed Hyderabad Pharma City will become another important driver for office and residential space, leading towards effective governance. It has attracted investors.

Built-up infrastructure is expanding as part of urbanization, and resources are running out. Global firms have begun to invest in, build, and run the city's technical, industrial, and service facilities. As a result, the Demographic profile, Economic profile, and Living profile are all out of balance. Job prospects are expanding, as is the population. It continues to change to accommodate and balance the population profiles. As a result, its land-use dynamics has resulted in unorganized and biased growth, ignoring the master plan objectives. The master plan fails because of implementation and execution lack data-driven monitoring and the time necessary to study and update the relevant data. The plans/projects should be monitored frequently to reduce the time spent reviewing and developing the yearly plan.

Particularly when working with informal settlements, those in charge of mapping and maintaining building definition layers in GIS databases encounter a challenge (cdema.org, 2016). Differentiating between permanent and temporary features that can serve as references in spatial analysis is crucial. In light of this, it is widely accepted that data used for GIS applications may not adhere to strict accuracy standards (cdema.org, 2016); instead, the data would be used for reference purposes. Urban planning with guidelines and regulations is like a plan without life in it as reality is different from a master plan with primary data. Maps and data updating are required for all sectors of the development of the city of Hyderabad. As a result, the Hyderabad government might fall behind in its planning for future growth. The use of high-resolution satellites, up-to-date data collecting, and data storage aid in the preparation of base maps and comprehensive databases for improved master plan development and decision-making for the government and the people.

Study area-Zone-1-East zone

LB Nagar Zone (Zone-1) has been selected for the study, which is located on the east side of Hyderabad and has diversified land use such as residential, industrial and commercial use. Zone 1 has 17 wards are spread across an area of 128 sq.km within GHMC (as shown in Map 2). The zone population was 7,22,935 as of 2016. It is home to many manufacturing industries. Figure 2 shows the zone-wise breakup of different land uses. As per the 2016 estimate total land-use is classified into Residential as 18%, Industrial as 28.24%, Waterbody as 2.21%, Greenspaces as 1.05%, Open spaces as 15.27%, Institutional as 8.86%, Commercial as 3.07, Transportation as 23.3%. As per URDPFI, 2014 Guidelines, Residential and Industrial land use of Zone 1 can be developed further.



Map 2 the study area with 17 wards (Zone-1), GHMC. Source: GHMC

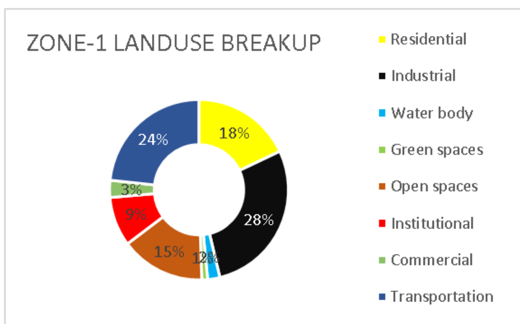


Figure 2 Zone-1-Landuse-Breakup Source GHMC

1.4 Objectives and research questions

This research intends to setup a methodology to monitor urban city growth at various zones and ward levels and develop a decision-making system. It envisages using computational methods to integrate agent-based spatial growth modelling tool, spatial data and their attributes, satellite imagery, land change models, statistical methodologies, and planning standards. Future scenario maps and zonation maps are generated using various forecasted growth models based on cellular automata. All these maps are supported with both static and dynamic drivers. Land-use growth model provides a detailed view at the ward level so that a clear understanding of every ward and zone helps us plan for the whole city. Based on this, the bottom-up approach can be followed; this helps in decision-making while preparing master plans and other development plans. Due to this approach, it can be ensured that decisions made for one part of the city have known implications inside and other parts of the city. The overall objective is to design and build decision-making, analytical, and monitoring system for existing and proposed land use and land cover in urban cities.

1.4.1 Sub-Objectives

1. Integration of spatial (GIS) and non-spatial data to identify driving factors of eastern zone of Hyderabad city.
2. To develop a computational model based on real-world master plan data with satellite imagery to provide future land use trends and show usage of it monitoring planning deviation.
3. Build and use urban dynamic modelling and algorithms (Vector-CA) to forecast future LULC change in Hyderabad east zone.
4. Calibration of Agent-based modelling parameters on various scenarios and factors.
5. To evaluate urban growth zonation maps, LULC maps and depicting zones of urban growth potential at an ordinal scale.

The advantages of having such a system are as follows:

6. Data acquired from satellite imagery will help make flawless data for providing infrastructure services and future LULC prediction.
7. It reduces the time and effort to reach data.
8. A centralized database for getting and updating the data. (Ozdilek & Seker, 2004)

1.4.2 Limitations

1. The study area is limited to the eastern part of Hyderabad, which consists of 17 wards.
2. The research focuses on a few parcel attributes and parameters such as height, ownership, area, land use, development status, accessibility parameters, Neighbourhood effect, and planning guidelines. However, no data is available to analyze land value, urban sprawl boundary, or income groups.

1.5 Research Questions

1. How can we keep track of how things are progressing? What are the prerequisites for monitoring LULC on a city scale?
2. Which approach and method are optimal for evaluating the city's development and growth momentum and indicators?
3. How to optimize the parameters for future potential land-use models of a particular region or zones with immediate updating as real-time data?
4. How can planned and unplanned growth scenarios are created and used to evaluate policy options?

1.6 Conceptual framework

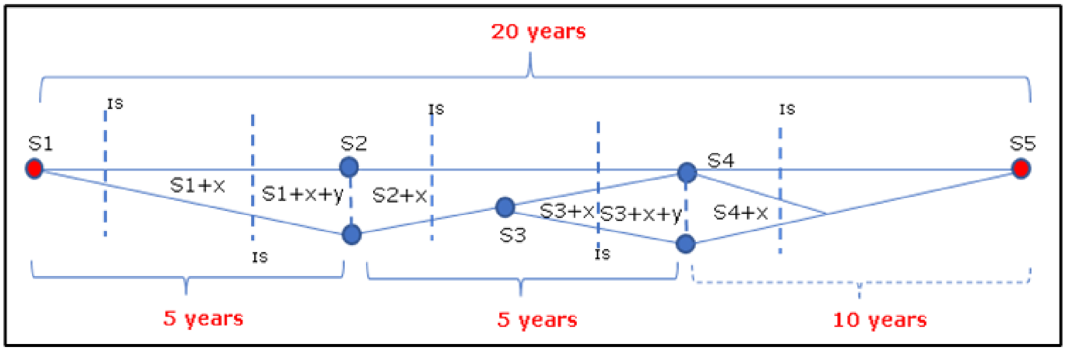


Figure 3 Existing Land use Master plan process. Source-Author

Figure 3 explains about the existing land use master plan process of Hyderabad. Span of the Master plan is 20 years and every 5 years, it is reviewed. S1, S5 are the starting time and ending time of the plan. S_i indicates Stages (x, y) which are changes or deviation indicators in plan. The IS-Intermediate stages (events) measure deviation from the proposed plan within the specified years (Time span) such as for every 5 years the plan is revised until the plan completion at 20 years which is followed by new Master plan.

Monitoring, updating, and predicting will help narrow and bridge the gap between the proposed development plan and reality. As the study region is a metropolis, it experiences rapid growth.

Hexagonal LULC Change Model Approach in Planning can be followed to build and maintain the planning system. The approach divides LULC into two parts, i.e., one for LULC for Existing Place (or) Planned (or) Occupied and Built-up area. Second is LULC for Planned place, proposed place (or) Developing phase place (or) Unoccupied and open space. The different major tasks in this approach have been grouped in measurement or evaluation based (left part) on which planning and prediction is carried out (right part).

Hexagonal LULC Change Model Approach	
Left part	**Right Part**
1. Existing LULC map done with ground truth. GIS map-Land use-ground truth	1. Existing LULC map done with ground truth. GIS map-Land use-ground truth
2. Planned (HMDA)or any other development plans-LULC Maps	2. Master plan-LULC-Proposed
3. Satellite data map –LULC. Satellite data can be used for digitization, site analysis, and reference datasets to know the growth pattern in occupied places. (Past – present)	3. Satellite data map-LULC The pattern of Housing and other LULC characteristics analysis. Development momentum. Future predictor LULC maps as per algorithm, parameters, and regulations.
4. In the present change in LULC momentum and Housing structures, to suggest redevelopment and other infrastructure development plans (GIS and Satellite imagery)	4. Change prediction and analysis. Land transition potential modelling. Future potential areas mapping.

Table 1 Approach of LULC Change model

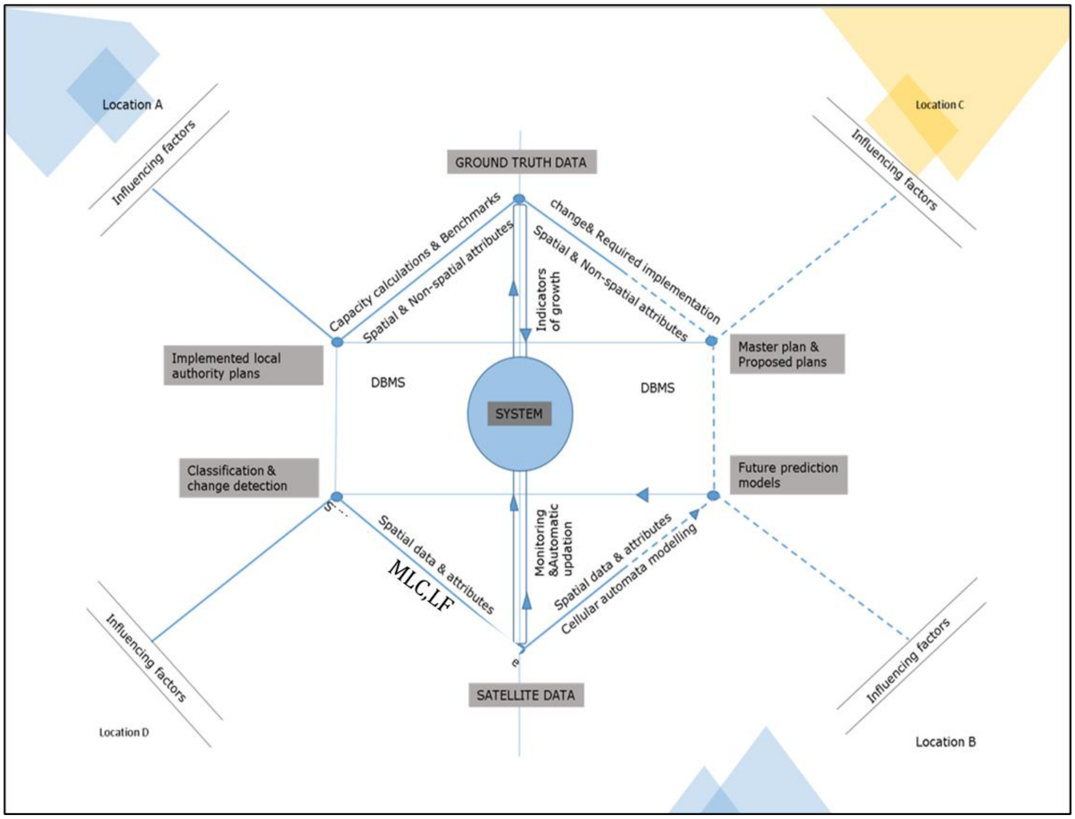


Figure 4 Hexagonal LULC Change Model Approach and Conceptual framework

Explanation of the Conceptual Framework

The Figure 4 depicts the hexagonal approach based on the conceptual framework. It has four quadrants. It can also be viewed as upper and lower halves. The center represents the interaction of the four quadrants as part of system. The system is anchored on plan inception and implementation based on future requirement identification of observed changes. The upper and lower halves of the figure represent the interaction of satellite dependent spatial process modelling and ground truth and based on requirement and deviation as part of whole planning approach.

Collecting primary and secondary data (ground truth) from the research region, such as land use categories, base maps, cadastral maps, and other non-spatial attributes, and maps used for analysis, linking, and setting up attributes with Georeferencing to the location datum. High-resolution satellites will determine the growth trend regarding spatial attribute changes in the study location context and monitor compliance with recommendations. A database management system stores, retrieve, and updates all geographic and non-spatial data (DBMS). Datasets (implemented, current, and anticipated land use from GT and satellite) are compared to the current master plan, local development plans, laws, regulations, and guidelines developed and implemented during the area's establishment and development. Because of the comparison and links, the indicators of growth drivers and land use changes can be found. Decisions such as issuing a new land use development or modifying a specific region are feasible. A future prediction model will be built using the vector-based-cellular automata model.

2 LITERATURE REVIEW

This chapter describes the urban planning approaches, plans and guidelines formulated in India, implementation processes, and significant shortcomings. Various urban growth models developed are explained and discussed to understand their usage, importance, and support in urban development. The chapter concludes with datasets used in the current research.

Section 2.1 discusses the city's complexity and its relationship to urban planning. Understanding city dynamics through urban modelling, where this urban modelling process be a single decision-making process rather than a separate step while preparing any development plans. Section 2.2 discusses guidelines, their importance, formation, implementation, and land use structure according to urban settlements classification. Section 2.3 discusses the master plan's importance, objectives, gaps, drawbacks, and shortcomings. Section 2.4 discusses the urban systems and early urban models, the history of urban models and the purpose of developing these models. Section 2.5 discusses the static urban model, such as a rule-based model, where urban elements such as buildings, open lots, and roads with their geometrical characteristics are generated using rules. Section 2.6 discusses dynamic modelling and its evolution over time, such as the cellular automata model, GIS-based model, open land use land cover dynamic model, agent-based model and agent-based model tools. Section 2.7 discusses the datasets that are used for this research.

2.1 Introduction

City complexity and its relationship to urban planning

The components of the city are dynamic, making it a complex system. A city is made up of several static elements and their interaction with social and human dynamics. For example, although a site is a static element, the character of the site is always impacted by its social aspects, such as residential, industrial etc, and surrounding land uses. In this case, urban modelling is essential to understand the dynamics of a city, including the setting of physical infrastructure components such as roads, buildings etc., to various locations and their importance/relevance to the static element. Urban modelling provides abstraction reality to simplify the demonstration, classification, and explanation of urban functions.(Wolfel, 2021).

Detecting, monitoring, and managing urban growth has emerged as the most pressing current in urban planning and development to achieve the desired outcomes, which may serve as a solid foundation for policymakers to steer policies in the right direction. It can help comprehend the complexity and control growth and development goals according to policies and planning guidelines. It can also help monitor growth and provide accurate insight into predicted future growth. These two phases, i.e. planning and monitoring, should no longer be considered separate steps but a single decision-making process.

2.2 Guidelines of Urban Development and Plan Formulation and Implementation

2.2.1 Importance of Guidelines

We needs guidelines to be followed while planning development in urban and peri-urban areas to deal with the complexities of a city. Managing resource utilization in the face of changing dynamics is only achievable through planned growth and continual monitoring.

If cities and towns could develop sufficient resources to support themselves, the planning process could be improved even further. This will only be possible if deliberate development and transparent governance are ensured. Any city or town should aim for inclusive growth in its master plan by minimizing levels of inadequacy and working to provide amenities for the physical and social infrastructure for all facets of the population. In the era of globalization, urban areas should be transformed into Smart Cities, which should be the Ministry of Urban Development's top priority. (MOUD, 2014)

The improvement of planning can be facilitated by the incorporation of (GIS) and remote sensing. During the preparation of the plan, detailed evaluations of the spatial expansion of cities and towns, the scope of unapproved and haphazard growth, and the construction of physical infrastructure facilities can be made for the projected population growth. Currently, out of a total of 7933 cities and municipalities, about 2100 Master Plans have been notified. All cities and towns across the nation are anticipated to receive statutory Master Plans due to the 2014 URDPFI Guidelines".

2.2.2 Guidelines Formation and Implementation

The rise in application in terms of technology and the spatial growth of towns and cities served as the inspiration for the 2014 "Urban and Regional Development Plans Formulation and Implementation (URDPFI) guidelines." Since initial guidelines were created in 1996, there have been significant changes in the use of cutting-edge technology, the geographical expansion of cities and towns, and urban dynamism, all of which have influenced their planning and development. It is required to design a City Regional Plan because the provision of infrastructural facilities extends beyond the municipal boundaries of cities and towns to ensure the balanced growth of all regional settlements. As a result, the Guidelines provide a foundational methodology for creating regional plans.

These guidelines establish the necessary framework, norms, and standards and offer options for resource mobilisation, such as methods for putting together land and development polices. These rules would need to be altered and adopted under local conditions, perceived requirements, and technological advancements for the planning process to function as an efficient and dynamic tool because situations vary from location to location and can be modified even based on a settlement.

The URDPFI guidelines have their nomenclature of human settlement classified according to population range for planning towns and cities. The URDPFI guidelines-based adopted classification is given in Figure 5. The category and sub-categories with their population range are shown indicated.

S.No.	Classification	Sub-category	Population Range	Governing Local Authority	Number of Cities as per Census of India, 2011
1	Small Town*	Small Town I	5,000 - 20,000	Nagar Panchayat	7467
		Small Town II	20,000- 50,000	Nagar Panchayat/ Municipal Council	
2	Medium Town	Medium Town I	50,000 to 1,00,000	Municipal Council	
		Medium Town II	1 lakh to 5 lakh	Municipal Council	372
3	Large City	--	5 lakh to 10 lakh	Municipal Corporation	43
4	Metropolitan City	Metropolitan City I	10 lakh to 50 lakh	Municipal Corporation/ Metropolitan Planning Committee	45
		Metropolitan City II	50 lakh to 1 Crore	- Same -	5
5	Megapolis	--	More than 1 Crore	- Same -	3

Figure 5 classification of urban settlements as per URDPFI guidelines

There are four types of urban centres: small, medium, large, and metropolitan. These classifications are based on geographical area and population. In the 74th CAA, if a Nagar Panchayat (a municipality) is to be constituted for an area migrating from a rural to an urban environment, small towns are referred to as "transitional towns." Metropolitan cities II (such Chennai, Bengaluru, Hyderabad, and Ahmedabad, Delhi, and Kolkata) and

Megapolis are currently exhibiting urban nodal agglomeration combined with its peri-urban and rural areas.(MOUD, 2014).

As per the settlements classification (Towns and cities) that was mentioned in figure 5, the land use structure was formed for different levels of areas (Table 2 can be referred for the land use structure).

Land use structure for developable areas in urban areas

Land use category	Percentage of developable area (%)			
	Small	Medium	Large cities	Metropolitan
Residential use	45-50	43-48	36-39	36-38
Commercial use	2-3	4-6	5-6	5-6
Industrial use	8-10	7-9	7-8	7-8
Public-Semipublic use	6-8	6-8	10-12	10-12
Recreational use	12-14	12-14	14-16	14-16
Transportation	10-12	10-12	12-15	12-14
Agri/special use	*Remaining %	*Remaining %	*Remaining %	*Remaining %
Total	**100**	**100**	**100**	**100**

Table 2 Land use structure for developable areas in urban centres. (MOUD, 2014).

* Remaining % indicates that there is no fixed percentage assigned to the category.

Table 2 provides the land use structure for a developable area in urban centres in terms of percentage. Here the amount percentage is determined based on the requirements as per ground truth data availability. Under the simplified urban land use classification of the URDPFI urban area planning approach, nine land use categories exist. (MOUD, 2014). The green area with natural, agriculture and special categories are combined. Further, at the Development Plan level, these nine land use categories have been divided into 43 sub-categories under the perspective plan level.

Under this research, based on the availability of data, we took only eight land use categories mentioned in Table 3 out of nine categories. Hyderabad city falls under the metropolitan category as per the 2011 census of India. The study area falls under the industrial area as per local municipal authorities. As a result, the industrial area planning land use structure and percentages were followed in this research.

Land use structure for industrial areas/towns.

Land use category	**Industrial (percentages)**
Residential	20-25
Commercial	3-4
Industrial	30-35
Pub-Semipublic	6-8

Recreational	12-15
Transportation	10-12
Agri/special/natural	* Remaining %

Table 3 Industrial area Land use structure

Land use refers to the manner of land utilisation, including its allocation, development and management. Table 3 shows the land use structure of an industrial area. The land-use is attracted to different physical, locational and institutional characteristics. Conversion from one land use to another reveals the dynamic transformation in terms of quality and quantity influenced by drivers. The sector distinction mentioned here assists in understanding the relationship between land use and characteristics (measurable terms) of land use. The characteristics of the industrial area land use are based on the following broad land use sector requirement given below.

Residential-For this residential category income, place of employment as person(individual) spatial data is required and as a measurable parameter such as no. of dwelling units, population, area, density percentage and other socio-economic data are required for planning residential area.

Industrial- For this Industrial category, manufacturing, IT and different types of industries and their locations as spatial data and population around that industry, area, density percentage and other socio-economic data are required for planning industrial area.

Commercial- For this commercial category, region serving centres, convenience goods centres, dedicated Markets data with their location data as spatial data and market oriented dedicated area, population, employment and services profile, density percentage, real-estate information, land values, property ownership and other socio-economic data are required for planning industrial area.

Institutional- For this Institutional category, administrative blocks, (C-I) buildings, educational institutions and other public related buildings along with their location information (spatial data)-No of Institutional Units, area, population, cluster IU, density percentage and other socio-economic data are required for planning Institutional area.

Open spaces-For the Open spaces category, public open spaces, commercial open spaces, barren lands with their location and area and other land use locations and accessibility data to other land use locations (spatial data) and population, density change percentages, buffer zone data and other socio-economic data are required for planning Opens spaces

Greenspaces- For the Green spaces category, public open spaces, commercial, Green spaces, Parks along with their location and area (spatial data) population, density change percentages and other socio-economic data are required for planning Green spaces.

2.2.3 Addressing the importance and shortcomings of Master plan process

This section explains about the master plan, its importance, objectives, gaps, drawbacks and, shortcomings.

What is a Master plan?

The development authorities follow the Master-plan prepared by decision-makers and policymakers to achieve desired outcomes. A Master Plan is a statutory plan designed within the framework of an approved perspective plan for guiding the sustainable planned development of the city. The Master plan is the most important and primary tool in providing detailed land use allocation for urban areas. It is prepared for 20 years, and it will be reviewed every five years. The need for the master plan is for development control, to reduce unplanned growth, to prepare for future development, to reduce overcrowding at a particular location, and to give us a holistic view of the city. The most important information for developing a master plan is an accurate and up-to-date A base map of the planning area shows the road, building layouts, spatial extent of development, and information on the use of each parcel of land, along with other information.(Terra Economics and Analytics Lab, 2019)

Importance of Masterplan.

The idea of a formal master plan had a definite influence on how cities and towns were supposed to develop and thrive. The master plan specifies the usage of all the lands included within the particular urban regions as well as the city-wide circulation pattern. The usage of a privately owned land was to be regulated by master plans as well. The founding principle and goal of a master plan is to improve and sustain quality of life for local residents.

A master plan of a city provides the foundation for:

1. Long-term investment strategies
2. The establishment of tangible assets
3. The assessment of standards, such as zoning regulations
4. Identifying areas in need of utility expansion or development
5. Acquiring and developing potential facility sites
6. The inclusion of sustainability and environmental conservation features
7. Setting overall needs in order of importance

The main objectives of master plan preparation are

1. The ideal form of a city
2. improved quality of life
3. An effective traffic and transportation system;
4. Rationale in infrastructure distribution
5. Good governance
6. Development that is sustainable
7. **Orderly developing undeveloped areas**
8. Rebuilding the developed areas and enhancing traffic flow
9. **Limiting haphazard and unplanned growth.**

However, monitoring and updating the master plan requires ground truth spatial and non-spatial information to achieve these objectives and to implement the master plan. The plan and ground truth should be reviewed every five years in the implementation and reviewing process. But due to a lack of resources, this is not happening. As a result, objectives are not met and desired outcomes are not obtained.

The Masterplan's drawbacks include a long-term perspective as well as a rigid and static nature. It takes a very long time to prepare and approve, so even before it is used, it is an outdated document. The efforts to plan financially and physically are not integrated. As a result, it ignores short-term goals and actions and is viewed as a final product rather than an ongoing process. Public involvement in the planning process is not practical because the norms and standards for land use and the provision of facilities are generally high and very challenging to achieve at the implementation time. Additionally, monitoring and review processes are neither consistent nor sufficient. Control is emphasised over encouraging development.

How to address these shortcomings

Urban growth models are efficient in carrying out these gaps and help interlink the internal process of master plan starting from the root level to the city level to fill this gap or complete the implementation process. The goal of urban growth models in this master plan implementation process is to help predict future growth areas while considering existing and potential future drivers, land-use land-covers, and non-spatial data. A few analysis are required, including land use analysis, socioeconomic survey, market, network, and swot analysis. The population, economic base and employment, transportation, social infrastructure, physical infrastructure, and land use are the primary requirements for developing a master plan. Land use as a requirement is essential because land-use planning of a particular region and monitoring the changes of land-use conversion helps us adjust the percentage of potential land-use development. The mathematical and other modelling techniques estimate the conversion rate and allocation percentage based on the ground truth and the influence of the neighborhood. This conversion rate helps us weigh proprieties according to the existing policies and create new policies. To carry out all of these analyses with these requirements, Data must be available and easily accessible. Because of lack of access, availability, and time constraints, only a few conditions are used and indulged in the present study's current growth model research for future prediction.

2.3 Efforts and History of understanding the Urban systems

Cities are a prime example of hierarchical complex structures. They do have various scales, each with a unique key attribute, specific questions related to it, and a small number of dominant mechanisms related to each phenomenon.

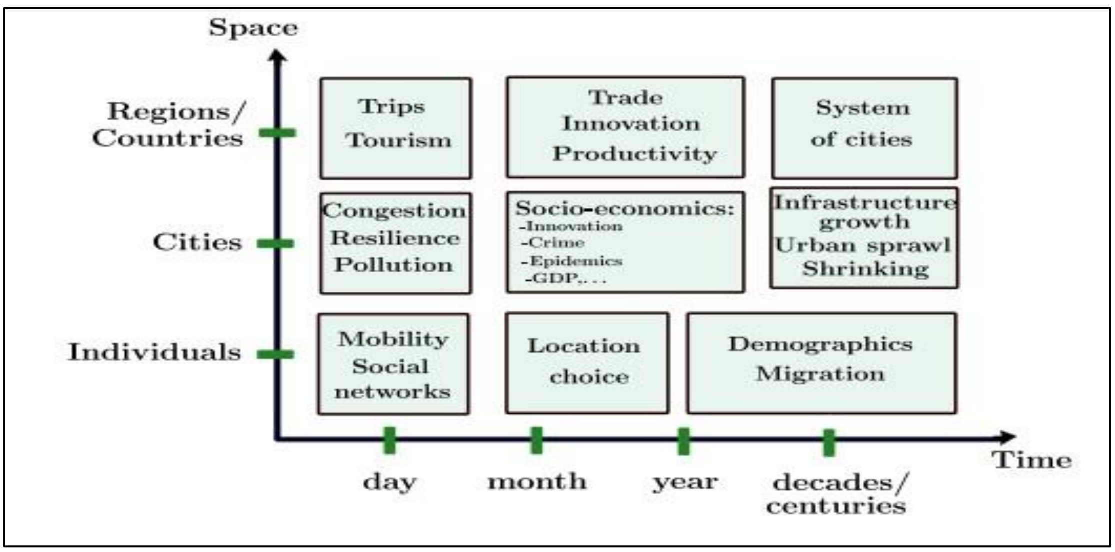


Figure 6 a list of the processes taking place in urban systems, organised by their spatial and temporal scales. Source: (Carra, 2018)

Understanding the behaviours of urban systems requires empirical analysis, but it also falls short. Without a theoretical framework for their interpretation, data can indeed be deceptive, so it is crucial to understand the interactions and processes that underlie the observations in order to inform and assist those responsible for developing urban policies. Therefore, we require models and empirical observations to constrain them and aid in the discovery of general patterns. In order to advance, data, models, and the feedback loop between them are required.(Carra, 2018).

2.3.1 Early Urban Models

Urban planners have discovered that spatial models are helpful for a variety of tasks, such as visualising potential future urban growth, identifying urban influences on the cityscape, and evaluating different urban policy scenarios. Some have criticised the use of dynamic modelling techniques in spatial models, claiming that they lack theoretical and conceptual underpinning and raise questions about how accurately they represent real urban systems. (Morgan & Sullivan, 2009)

There have been some attempts to lessen the amount of coding expertise required to develop a workable agent-based model. Net Logo is frequently used in educational settings and was " . subsequently to decrease the amount of programming required for model creation (Wilensky and Rand, in press). It offers a limited set of higher-level capabilities along with a graphic visualisation environment for quickly developing agent behaviours within the confines of a Euclidean space. Similar to Net Logo, Repast offers agents tools for reading GIS data by exchanging files from a GIS database. A common trade-off between case of use and flexibility limits ABM's ability to adapt.

2.3.2 Mathematical Urban Modelling

Planning to address urban issues must be found on a clear understanding of the urban system. Models serve as tools for comprehending city systems and planning the future city since they are condensed representations of reality (Prabhudesai & Viswanathan, 1978). Urban models operate as prediction models, offering quantitative analysis and assessment of the effects of actions and policies pertaining to the development of the city. Urban modelling often includes specifying the model's application, its underlying theories, its design approach, the selection of variables, calibration techniques for its parameters, and assessment of the model's degree of reality correspondence. Three main groups of models important to urban planning may be recognised within basic framework: descriptive models, predictive models, and optimising models**.** Among these predictive models are nearer to reality and shows us the consequences and development pattern. Since they are primarily relevant to the urban and regional planner, it would be good to summarise some of the principles and factors controlling the construction and development of predictive models.(Gross, 1982) All of the predictive models we select and use should be able to be tested by altering the dynamic parameters and incorporating other projection and forecasting models with the current data. (Kim, 2012)

The first stage of mathematical modelling in the field of urban studies used retrospective analysis to calibrate the model, and the second stage inferred the trend to predict the future growth. To match the land changes for the same pattern, urban growth models took mathematical help to construct again the land use in a retrospective study to the full extent. Using linear function , thinking that the trends would be the same all over the period ,having no change then the model infer the future prediction of land use (Prabhudesai & Viswanathan, 1978) (Bolman, n.d.)

2.4 Static Modelling

Static urban models are urban development models that include rules, regulations, and bylaws for static physical components such as roads and buildings that aid in the planning and creation of planned development for a city. The LULC of a region using proper guidelines and taking drivers with respect to unchanging components over a longer period of time provides with a future predicted map. These drivers are used as a constant driver for predicting future.

We seek to understand the range and relative importance of the different biophysical and socioeconomic factors that influence patterns of urban design and development. These days, LULC change models can take many different shapes. Some of the model types that are most used by the scientific community include the SLEUTH (Slope, Land use map, excluded area, Urban area, Transportation map, Cliffside region) model and the CLUE

(Conversion of Land Use and its Effects) model. Forecasting Scenarios Environment (Pratomoatmojo, 2018). These tools generate maps of LULC forecasts based on different scenarios.

Dynamic drivers are those that change over time, including population and other socioeconomic factors. Statistical drivers are those that remain constant over time. Static drivers include proximity drivers, distance drivers, and other types of drivers that do not alter over time.

The development of various kinds of suitability maps for potential scenarios is influenced by all of these aspects.

Rule-based modelling is also a component of urban growth modelling, as was previously discussed. This can save time and allow for expansion to be planned in accordance with the rules.

2.4.1 Rule Based Modelling

Rule based modelling provides a fast, flexible and responsive toolchain to increase the speed of developing different scenarios of urban area ranging from one unit of structure to n number of unit structures at neighborhood scale and city scale. Once the rules are applied to the structures or components then a large number of similar structures can be created quickly and easily. With the rule based modelling the level of details such as planning of administrative buildings in every zone specifying color to these structures all over the city creates uniformity of administrative buildings and applying different landscapes at different land use zones enhance the aesthetic sense of that zone. By changing the rule attributes at different times can prepare scenario mapping and these attributes can all be updated over an entire city at once.(Shi et al., 2021)

Adding more attributes (GIS)such as building height, building bye-laws (set backs) at their respective zones and all these details applying in CGA rules (computer generated architecture) makes these 2D structures to 3D structures.

There are software's such as Esri's city engine that can be used to explain rule-based modelling. A software programme for rule-based urban modelling is called City Engine. It offers a flexible technique for producing 3-dimensional urban models from 2-Dimensional data. Examples of common uses include handling 2D urban cartography geographic information system (GIS) data to generate an exhaustive three-dimensional model, generating an accurate depiction of a planned development, or examining the model structure of a potential project. Large cities may be developed just as easily as tiny ones because to Esri's City Engine's rule-based core, and the model quality is consistent throughout. This rule-based approach also enables rapid, interactive, and analytically contrasted exploration of large design domains. These advantages must be carefully evaluated against the longer construction and parameterization times for the rules.

For easily developing urban scenarios, including standard modelling, university design features, and simulation of towns and urban areas, rule-based modelling can offer a convenient, rapid, and able to respond toolchain. Large amounts of shapes can be quickly and effortlessly created again when the rules are understood. Real-time scenario alterations and adjustments are doable. A rule-based example is shown in the figure below.

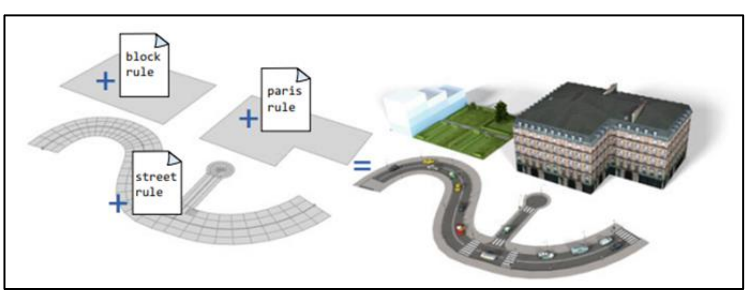


Figure 7 Creation of ruled based lots(Kelly, 2021)

Adding road network rules to the roads and building rules to building lots and green spaces rules to the open space lots and applying them on simple CGA rule file to create the associated 3D models (figure 7) on the right side. Here extrude rule to the lots are applied and these measurements are taken from local government regulations.

Algorithms in dynamic forms are applied for feature change. For instance, a city area having GIS data for the Roads and parcels can have dynamically created roads and parcels surrounding it. Additionally, it is possible to input road network from a GIS data source, and the blocks between them can be real - time change divided into space portions.

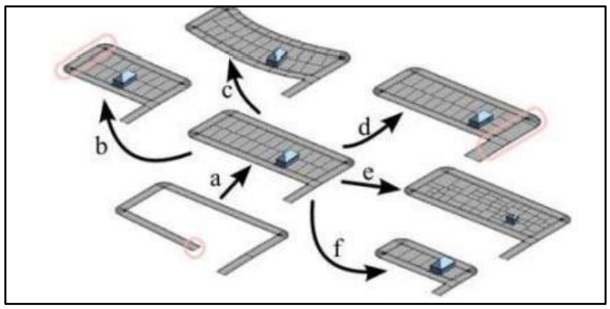


Figure 8 parcels Generation using the road network(Vanegas et al., 2012)

A road network can be changed in a variety of ways interactively (a-f). Various rules have been applied to the road network to locate parcels of the same size (a); move an edge (b); edit the curve of two edges (c); change the width of a street (d); change the subdivision style (e); or scale the street network (f) (Vanegas et al., 2012)

The roads of a road networks are graphically represented by a road graph. This graph (figure 8) creates dynamic road geometries for the actual path, pathways, and crossings.

Rules are used to divide the road into several sub parts such as right of way (it should include furniture zone with in it, pedestrian path), road width and other parts of roads (Kerbs, cycle tracks, median). These road parts have impact on constructing of building such as, As per Indian road congress standards, building height should not be more than 10m for 3, 5, 7m of road width and the plot size (building size) should not be more than 100 Sq.m.

Dealing with rules rather than physical manual models can result in a variety of fresh ideas for urban planning while also saving a great deal of time. The solutions are visible and can be statistically evaluated in real time. These developments allow for quicker user feedback and a more thorough understanding of the problem and solution domains.

2.5 Dynamic Modelling

This section explains and discuss about urban growth dynamic models such as cellular automata, open land use dynamic model, agent-based model and also the tools used to perform these models.

The model which considers time factor at the time of simulation are said to be dynamic. The dynamics of urban systems attempt to represent the cities evolution of patterns over time and space. As urban systems are very complex in nature, with the help of these dynamic models such as cellular automata, ABM etc. it is possible to reduce uncertainty and increase understanding of the urban system(Abdul Hussein Bedewy et al., 2021).

Stochastic models use probabilistic functions to represent the random or semi-random behavior of phenomena. Whereas deterministic models rely on a clearly defined cause-and-effect relationship. Models of hydrological flow and pollution are examples of deterministic models, which frequently permit the "effect" to be represented using numerical methods and differential equations. Processes are handled by rule-based models using local (spatial) rules. Cellular automata (CA) are widely used for systems having local processes that are well known but typically poorly understood. For instance, a raster-based CA model may use the characteristics of nearby cells (such as wind speed and plant species) to reflect the direction of a fire's spread over a number of time steps.

2.5.1 Cellular Automata

The dynamic technique of cellular automata (CA) modelling was first developed in the study of biology to investigate the self-reproduction of single-cell organisms. Tobler used the concept of the CA earlier in the 1970s to illustrate the idea of cellular geography, showing the importance of neighbourhood and closeness (both geographical and temporal) in determining patterns in landscape changes.(Batty, 2009).

Cellular automata is characterised as a complex simulation technique that uses a two dimensional lattice model of the topography of Land and apply transition rules for every cell using inputs collected from the states of surrounding cells and its internal state.(Kim, 2012) Therefore, the standard Cellular automata structure includes the following four fundamental components: I cell, (ii) state, (iii) transition rules, and (iv) neighbourhood.(Batty, 2009)A geographical depiction of the Cellular automata is shown in the cell. It possesses the spatial characteristics of a cell and is perfectly square in form (lattice). The lattice structure of Cellular automata is similar to raster-based input, making it simple to integrate into Geographic information system platforms. (Yeh & Li, 2002).

In CA-based models, the dynamic change is represented by a similar expression of

$$S_{ij}^{t+1} = f(S_{ij}^{t}, \Omega_{ij}^{t}, \mathrm{T})$$

Where S_{ij}^{t+1} is the status of the cell (*i, j*) at time "**t+1**", which is very nearly related to the current cell S_{ij}^{t} **;** the effect of the neighbourhood is Ω_{ij}^{t} and the change in rules by T by a particular linkage of f. by a specific connection of Neighborhood rules and change rules are two most useful elements in CA-based models.(Li & Gong, 2016).

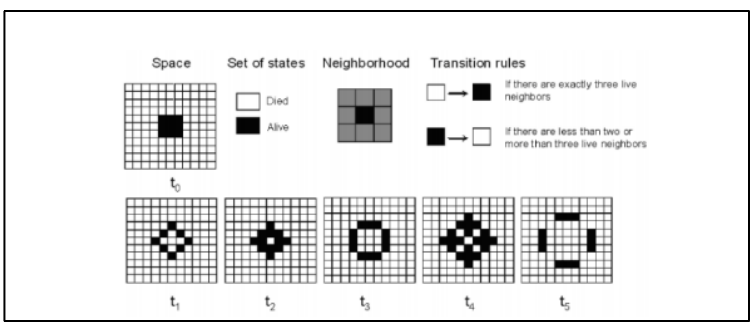


Figure 9 Element of cellular automata (CA) (top) with Conway's game of life as illustration-source- Wahyudi & Liu, 2015)

Figure 9 explains the transition of a cell considering it's status or state and also state or status of the neighbourhood shows the transition at different times according to the rules.(Wahyudi & Liu, 2015)

CA has developed in various stages and forms in the urban section, increasing the neighbourhood cells and making changes to transition rules and the relationship between rules and neighbourhood cells. As the urban system itself is complex in structure and needs to take into account not only the physical drivers but also the socio-economic data, CA alone cannot sustain in urban growth modelling. The complexity of urban systems is too great for CA alone to adequately represent in its formal structure. As a result, urban modellers must confirm the viewpoint and geographical scale at which the model will function and best achieve the modelling goal. Actors in urban systems make spatial judgments on the actual process of urban growth based on the anticipated economic advantage.(Tran & Tian, 2013).

However, the CA concept falls short of depicting the players and their actions in urban environments (for example, an increase in capital gain by developers as a result of new urban development)and as a consequence CA lacks the structure required for both the seamless portrayal of the interactions between human features and their environment in the model and the locational dynamics of urban development agents. (Torrens & O'Sullivan, 2001).

Figure 10 depicts full development tree that depicts the evolution of several urban growth models based on cellular automata research. It represents network of urban growth scenarios and concepts in development. On vertical axis, evolution of the model years are indicated. Each leaf of the tree represents a particular model, and each branch represents a certain CA-based model type. When building a model, a leaf's size corresponds to its value or contribution.(Li & Gong, 2016)

Scarcity of resources and raise on production demand, opportunities such as shifting markets, intervention of political views, loss in adaptive capacity and other attitudes and social infrastructure, combine to contribute to land use change(Lambin et al., 2003). The concepts of transition and complex systems can help us understand land-use change. For integrated, location-based research on changes in LULC, a combination of agent-based systems and descriptive comprehension methods would be needed. Basic rules that explain and forecast new land-use improvements can be found by carefully evaluating in our environment, land-use change research over a range of timescales.

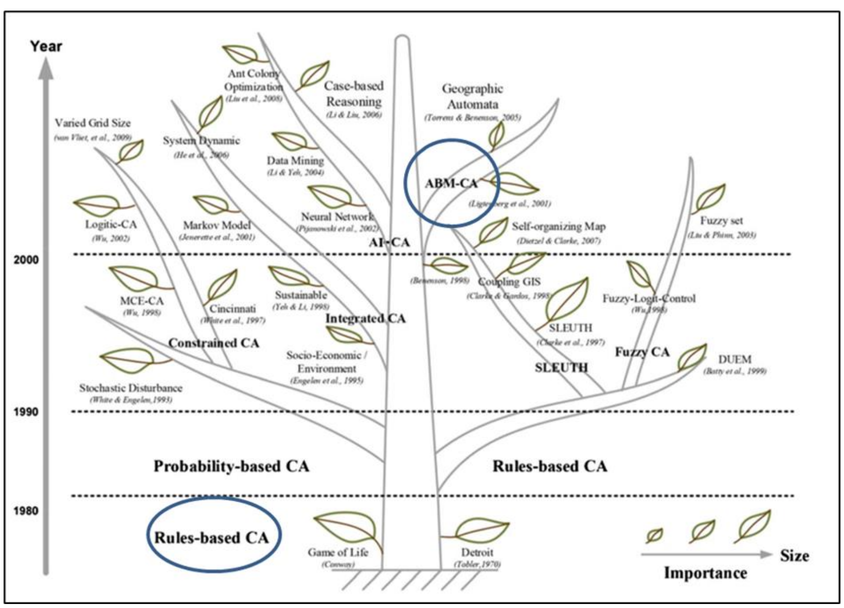


Figure 10 An evolution tree of CA-based urban growth models

2.5.2 GIS System dynamic modelling

GIS system modelling is a combination of system model with few characteristics that can relate and modify with spatial and non-spatial data (GIS). We figured out that five characteristics are important while developing a GIS based application or GIS based decision model. Examples include the model's goal, its technique, the scale at which it operates, its dimensionality—whether it encompasses geographic, temporal, or both—and its implementation logic, or how much the model draws on the knowledge already known about the implementation context. Stochastic models use probabilistic functions to represent the unexpected or semi-random behaviour of phenomena. Deterministic models, on the other hand, are predicated on a clearly defined cause-and-effect link. Deterministic models, which frequently allow for the "impact" to be represented using numerical techniques and differential equations, include models of hydrological flow and pollution. Local (spatial) rules are used by rule-based models to handle processes. For systems with local processes that are well known but which are usually poorly understood, cellular automata (CA) are frequently utilised. For instance, in a raster-based CA model, the properties of neighbouring cells (such as wind direction and plant type) may be utilised to represent the direction of spread of a fire across a number of time-steps.(ITC, n.d.).

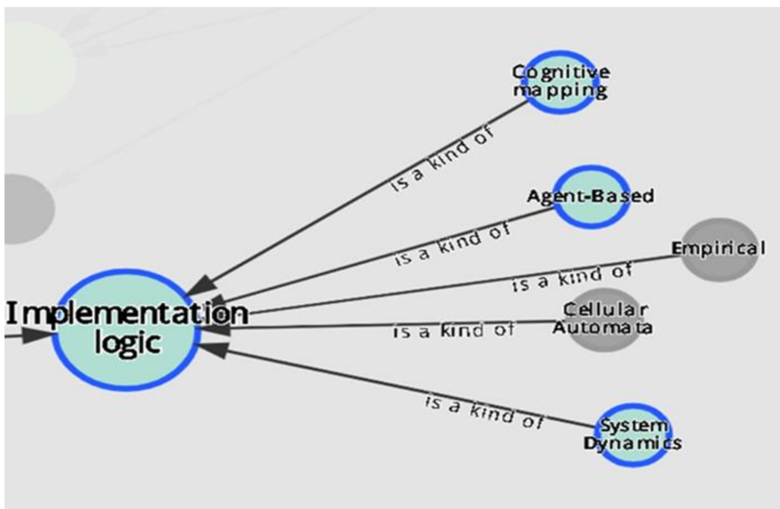


Figure 11 Urban growth models- Source of the image:(ITC, n.d.)

Figure 11 explains about different kinds of approaches to find the implementation logic in spatial growth pattern.

2.5.3 Open Land use Dynamic modelling.

The modeling tools provides dynamic modelling method to considers Land Classes as a noncompliant agent to create the functional relationship between the Land Classes and Drivers at base year Time period 1. The models features include selecting a model using available parametric and nonparametric techniques, developing a map of suitability, checking the accuracy, and visualising the outcomes and resource allocation. Techniques like regression (logistic and linear), ANN, RF, and manually controlled geographic context can be used to create

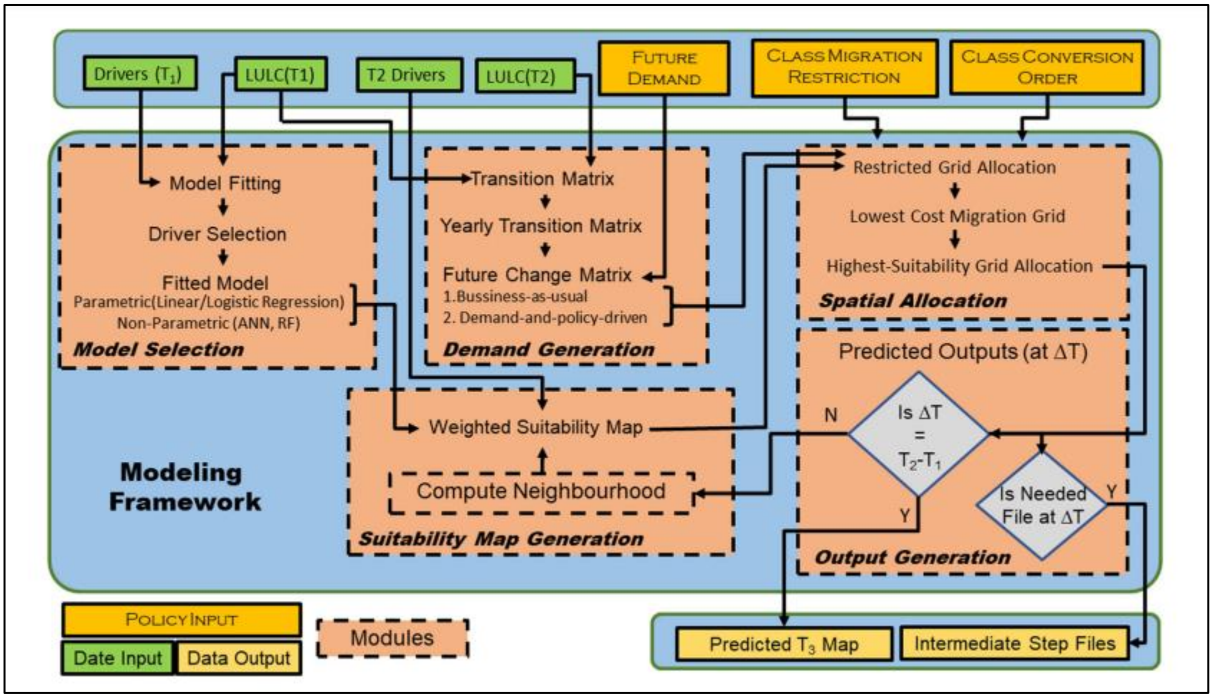


Figure 12 Modelling framework, inputs and outputs of Open- source Land-use Land-cover Dynamics Modelling platform (OpenLDM)-source-(Jha et al., 2022)

suitability maps for each class of land use and land cover. Statistical techniques made it easier to select the best drivers for each LULC class. To do the policy intervention base on demand of LULC and priority has approach are provided.

A suitability function represents the connection between causal factors (D) or drivers and a Land Classes. The scope and realm of such operations are the Land classes and drivers. The model build these relationship in a parameterized nature (such as those found in the families of linear or logistic regression algorithms) and a nonparametric nature (Artificial Neural Network or machine learning) techniques. It creates a linear sum of weighted drivers on a grid location to calculate the Land classes suitability function representing the projected strength of a particular Land Classes at each grid (x, y) based upon the input drivers on Land Use Land Cover The represent of these strength as the spatial distribution gives the suitability map.(Jha et al., 2022)

2.5.4 Agent Based Modelling

Since the 1980s, a group of agent-based models have been developed that rely on representing populations and objects at a fundamental or individualistic level in order to capture their behaviours over time and space. At higher aggregate levels, these models' bottom-up approach results in emergent spatial and temporal patterns.(Grant & Paterson, 2022).

“At its foundation, agent-based modelling is a method for determining probable system-level impacts of a group of people's actions”. It's not always necessary for agents to be completely independent of one another. Agents may interact with one another in considerable detail while surrounded by murky boundaries. ABM agents typically exhibit Herbert Simon's)(Barros, 2010) idea of constrained rationality. Bounded rational agents can only digest a certain amount of information at once and have a restricted amount of time to do so before making a decision.

Each agent has the capacity to: (a) have distinctive properties and states; (b) be built to follow distinctive rules; (c) be placed in a physical or relational environment that constrains its behaviour; (d) have its behaviour depend on that of other agents in its immediate environment; and (e) have a range of informational capabilities. (Manzo, 2014). ABM gives modellers the ability to describe an object's characteristics and environmental context, iterating through it repeatedly to forecast positive future growth. Simulating involves repeatedly asking each agent in a multi-agent system to carry out the rules that define them. During these iterations, the aggregated outcomes of the behaviour of the agents can be gradually determined and then re - injected into the behaviour of the same agents. Therefore, agent-based simulation enables the combination of "low" level entity behaviour to produce the desired macroscopic regularity through a dynamic chain of loops linking various levels of abstraction. It is useful to think of complicated events as (MASs) and use an agent-based modelling approach for modelling the societal behaviour. The visible world is defined by MASs in terms of actors (agents) that follow rules that depend on the surroundings, the agent, and the agent's geographical placement. Each agent is shown as a separate computational entity that may interact with other agents or operate locally in response to inputs. ABM works on the theoretical basis that you train virtual agents to communicate with one another. Agents can be distinct objects of any kind, including animals, tanks, parcels, and delivery vans. In space and time, patterns are produced as a result of the actors' decisions and actions. Agent-based models investigate the origins of patterns, as opposed to many other modelling approaches that quantify patterns before re-creating them. In agent-based models, patterns are emergent qualities that result from the individual actions of the agents.(Becker et al., 2015) Routines are provided to set up agent

Societies, and algorithms or structures are provided to carry out the connection between the environment and the agents. (ITC, n.d.), Decision makers contribute to the identification of the decision-making agents, their interactions with one another, and their links to their environment during a participative process. Many academics have considered a ground-breaking ABM adaptive approach over the years. Agents can also make use of local data, such as the socioeconomic and geographic status profiles of their neighbours. The decisions made by an agent may be supported by information from intricate spatial analyses that define spatial relationships.

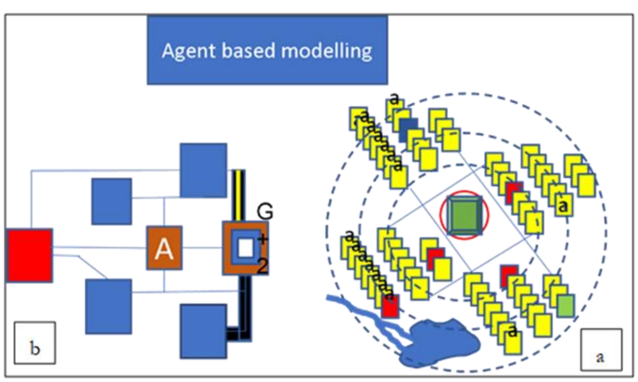


Figure 13 Conceptual figure of ABM-source: Author

Figure 13 explains the concept of agent (here agent is parcel) ,where agent interactions can be seen. Interaction with different land use, different structures of parcels, pattern on which it is located. This figure explains the agent undergo these conditions and makes decision.

a-Range values, rules, pattern, different land use.

b- The standardisation of density standards will be based on capacity studies, with a special emphasis on criteria such as space per person, access to facilities, and driving priorities.

When geographical data and agent-based modelling are used, a variety of issues may be solved, including the following:

1. constructing networks of communication along corridors for animal movement
2. Preparing for possible terrorist strikes
3. Creating evacuation plans or analysing traffic congestion
4. Preparing for the probable spread of diseases like the swine flu or avian flu
5. **Understanding of land-use change**
6. Improving the cutting of wood tracts
7. Examining the movement of energy through electrical networks
8. Conducting criminal analysis to minimise potential harm).

Difference between Agent based modelling and Cellular automata

CAs and ABMs are quite different yet similar in case of driver induced land change simulation. Cells are static, and the status get change as per neighbourhood cell status and itself status. The other transition rules of changing cell states from one to another is performing upon the continuous surfaces such as rasters, whereas in Agent based model, in our case agents were house parcels, which were ready to change their state as per the rules. In our case even though parcels are static like cells in cellular automata, but the rules and neighborhood which were affecting the agent are discrete objects as well as continuous surfaces. As parcels itself is discrete object(vector) having different attributes and characteristics interacts with another vector agent having different attributes and characteristics changes the behavior of simulation and patterns and this affects the outcome.

2.5.5 Agent based modelling tools

GIS software's mimics the design of ABM tools and make use of similar architecture. The agents can be used as separate entity or individual while interacting with environment. (Becker et al., 2015) levels of combining the GIS and ABM is increased as ABM is working well with both raster and vector datasets. This shows ABM is spatial dynamic model when compared to CA. Integration of GIS and ABM is required when the model is developing with more dynamic approach, such as inputting raster datasets like slope, aspect and distance to spatial features and to check the output after using such big datasets every time on the GIS display.

For variety of issues agent-based modelling techniques have been used to solve and their availability have increased significantly over the years. Since agents are capable of carrying out a wide variety of tasks, programming is still necessary to define those tasks. several tools like O-O languages helps us to create ABM model without GIS. (Matthews et al., 2007) Building on the success of Swarm, a number of other software libraries with preset functions have been developed specifically for use in agent-based modelling. These include the Java-based programmes MASON, Ascape, and Repast. Due to the O-O language approach, agent-based models can incorporate a wide range benefits, including those that provide GIS features.(Becker et al., 2015) . These tools also useful for "Monte-Carlo type techniques", and links to other programmes, can aid in the construction of various social or ecological systems (GIS, databases).

Repast tool

"The Recursive Porous Agent Simulation Toolkit" is one of the many agent modelling toolkits (Repast). Repast incorporates many ideas from the Swarm agent-based modelling toolbox. Repast is distinct from Swarm in that it provides a range of pure implementations in different languages along with adaptive features like evolutionary algorithms and regression.(Douglas Samuelson and Charles Macal, 2006). "Sallach, Collier, Howe, North, and others created the Repast toolset". The University of Chicago developed Repast. Since then, organisations such as Argonne National Laboratory have been in charge of its upkeep. Repast's goal is to move from the depiction of agents as discrete, individual entities. The Repast Organization for Architecture and Development (ROAD), a non-profit volunteer organisation, currently manages Repast. We want to assist the modelling of institutions, belief systems, and agents as recursive social creations.

Agent analyst

Agent analyst works on repast, an ABM simulation toolkit .The Repast ABM swarm and Esri ArcGIS software are connected by Agent Analyst via a middleware approach(Analyst, 2013) (specifically, the geoprocessing environment). Agent Analyst is open-source software that is compatible with ArcGIS software. Repast enables for the development of agent rules, scheduling and object support. The model developer can access the full range of GIS activities and incorporating them into the agent model by using ArcGIS Java objects with Agent Analyst.

The role of ArcGIS here is to generate the data, perform the spatial analysis and displaying the result of simulations. As new model tool in ArcGIS Geoprocessing for GIS analysis and simulation, Agent Analyst model can be used. The Agent Analyst tool was developed to provide a better user interface and to run the agent-based model while incorporating the GIS environment. It assists agents in making simple to complex decisions. Users can perform several models runs automatically using the batch run system. The model's fundamental operations, such as carrying out the agent behaviour rules and monitoring the states of the agents, are handled by the simulation engine.

2.5.6 ABM Structure of Agent analyst tool

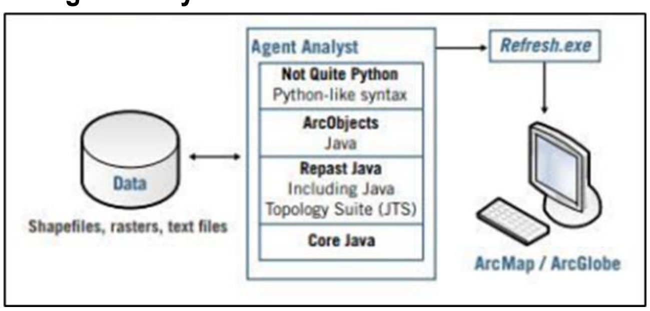


Figure 14 ABM Structure of AA tool- Source of the image : (Analyst, 2013)

The structure of the ABM of the agent analyst tool is shown in Figure 14 from input to output. The Not Quite Python (NQPy) programming language was used to create Agent Analyst. A powerful programming language that resembles Python is NQPy. It transforms Java functions from NQPy functions. This is more straightforward, Python-like syntax makes the majority of Java functions accessible (with Python being the preferred scripting language for ArcGIS software).

NQPy will significantly satisfy the needs of ArcGIS users; additionally, users can export their models to Java and continue to use extremely complex techniques. Arc Java objects are also taken care of by it. The results of the simulation were shown on the ArcGIS screen.

2.5.7 Best practices ABM in spatial studies

ABM is most effective in the following areas of spatial science: (I) policy analysis and planning; (ii) participatory modelling; (iii) assessing land use pattern hypotheses; (iv) assessing social-economic theories; and (v) simulating landscape functions. (Matthews et al., 2007). The changing urban aspects are covered by ABM. Changing the agent's spatial location constitutes a dynamic feature (i.e., moving). The agent can see various features of its surroundings and decide if it needs to adapt its actions (change), accept the current reality, or move on to locate another suitable cell because the agent's mobility is reflected in the model. Interactions between agents or between agents and their environments rarely follow a linear pattern in which system components affect an agent's decisions and behaviours uniformly regardless of the agent's location or the arrival of new information. When modellers believe that agent diversity provides a better explanation of system dynamics, ABM can mimic varied and individual decisions.

2.5.8 Summary

The theoretical and conceptual underpinnings for dynamic urban modelling are presented in this chapter, which also reviews revisions based on system, complex, and dynamic theory. Because ABM is effective at handling complex systems, including urban systems, it is a technology that could be used for urban models. ABM functions best when actors in urban systems engage in multidirectional interaction and display complex behaviours like learning and adaptation (Bonabeau, 2002).

3 METHODOLOGY AND PRE-PROCESSING

There are three significant subcomponents to the method which are Data preprocessing, Suitability score Generation, and Agent-based simulation to incorporate neighbor and other attributes of the empty parcels for the development. Figure 15 shows these three sub-components and their connection to each other. Here, the Footprints of buildings are considered parcels.

3.1 Methodological Flow chart

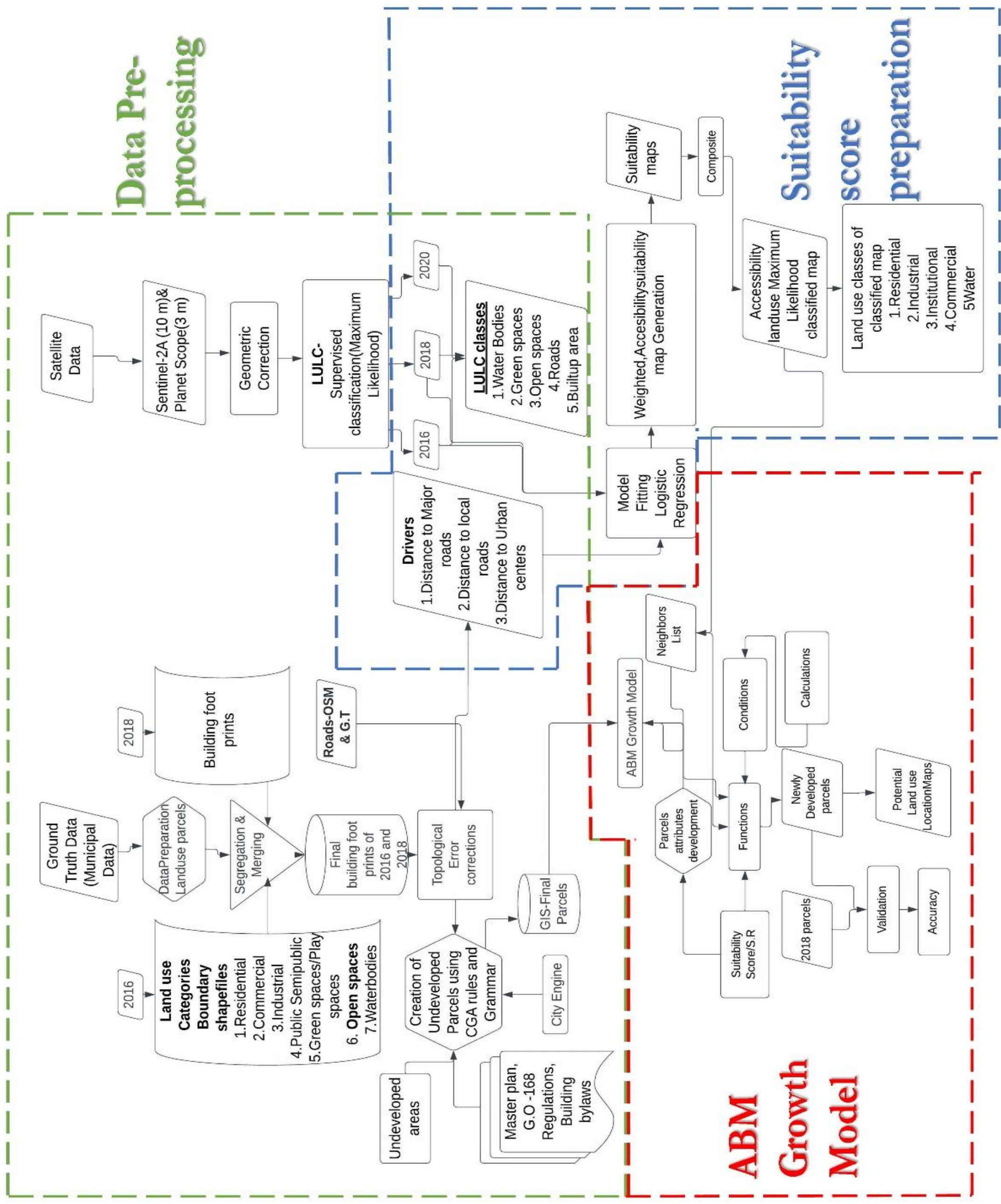


Figure 15 Methodological Outlining Three Major Subcomponents

3.2 Data pre-processing

Data collection

The data was collected as per the Growth model's requirements and LULC monitoring requirements. 2016 was chosen as the base year, and 2018 was the prediction year. The availability of ground truth data from the municipal corporation (Greater Hyderabad Municipal Corporation) drives the choices. The data for the base year 2016 contained the Land use Land cover classes of 7 categories, namely (i) Residential (ii) Commercial (iii) Industrial (iv)Public-Semi-public (v)Green spaces (vi)Open spaces and (vii) Water bodies boundaries. The data set of 2018 had attributes such as type of classes and sub-category classes at the building footprints level for the prediction year 2018. The second data set is the OSM Road data consists of a hierarchy of road networks such as Major roads, Local streets, Highways etc. The third set of data related to the estimated population growth for each ward from 2016 to 2018 was also made available from the same agency.

Data preparation

Data preparation is divided into Five steps: (i) Parcels segregation for 2016 and 2018. (ii) Undeveloped Parcels generation for 2018 based on 2016 land-use classes, (iii) Distribution of population over parcels, (iv)Categorization and Density defining of wards, (v)Preparation of LULC maps for the base year and the prediction year.

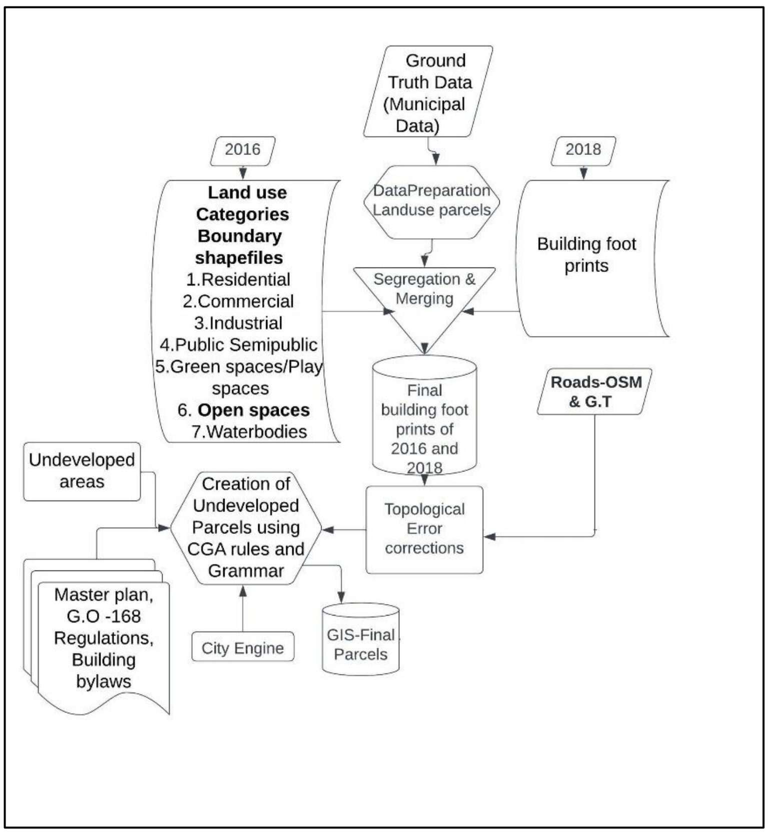


Figure 16 Parcels segregation and preparation flowchart

Figure 16 explains the data preparation for the growth model, which covers first two steps of parcel segregation and undeveloped parcel generation.

(i) Parcels data segregation

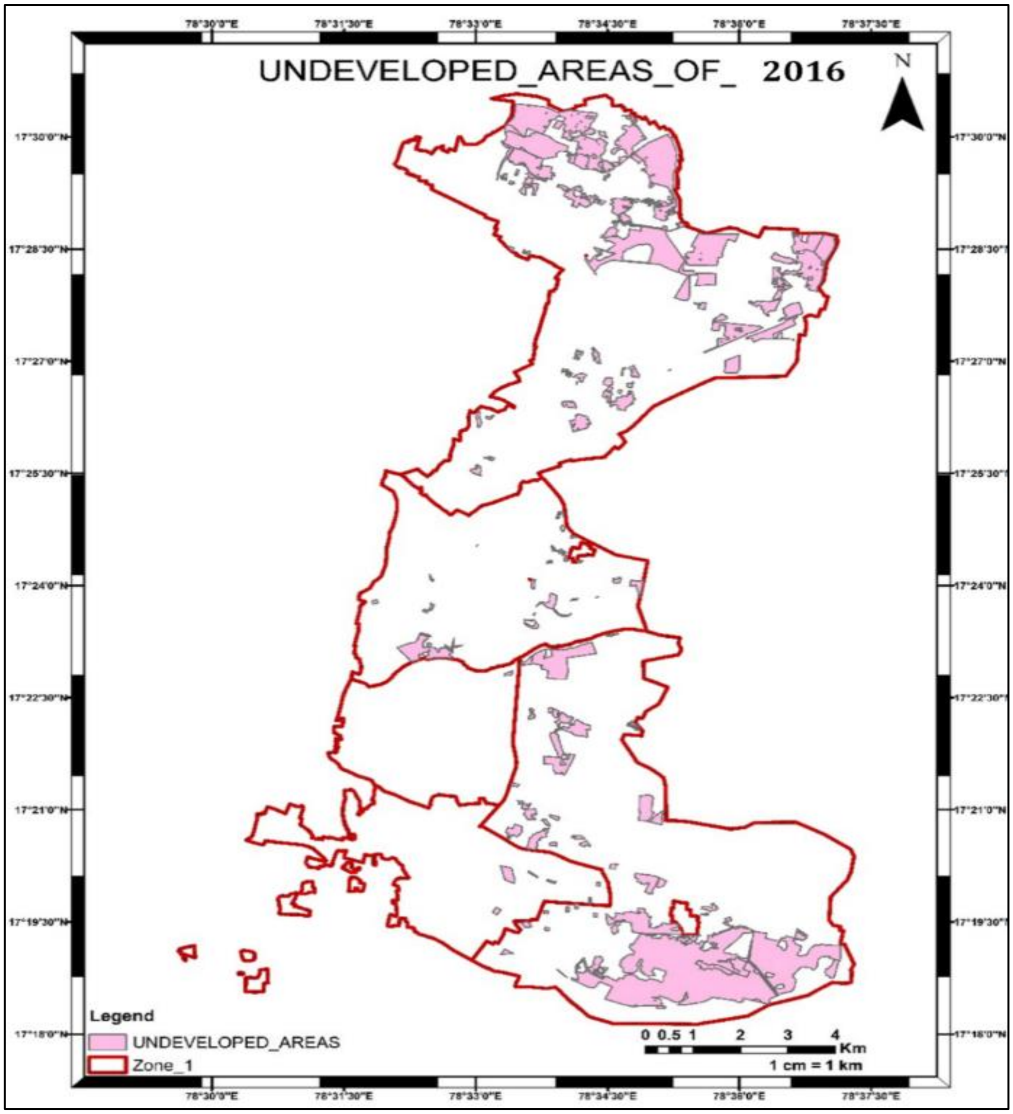
The field data only had land-use boundaries for 2016 and building footprints for 2018. All 2018 building footprints (Parcels) were overlayed over the land-use boundaries for 2016, indicating parcels developed till 2016 with the corresponding land use present in the 2016 map. The parcels outside the land-use boundaries of 2016 were taken as probable development parcels or areas for the year 2018. The area falling inside the 2016 land use extent with land use of type open spaces was taken as a probable parcel of development along with the parcel falling outside the land use extent in the 2016 map. All the probable parcel land-use will be assigned as part of the growth modelling steps.

(ii) Undeveloped Parcels preparation for 2018 based on 2016 open spaces land-use class.

To accomplish land parcel preparation for year 2018, undeveloped areas were used to prepare undeveloped parcels, these undeveloped areas were present within LULC class of open spaces as an attribute. These undeveloped areas (total of 184 count) were marked by GHMC from the ground truth observation. Road network was required to create undeveloped parcels in these areas and these road network data was collected from OSM were topologically corrected and the roads which were not present in the OSM were manually digitized and added to the road dataset such as service roads, mud roads, etc. The road network dataset containing road width, road-hierarchy type as attributes were used to generate undeveloped parcels. Road widths were manually assigned to the roads using satellite imagery (sentinel-2A, planet(3m)) in accordance with road hierarchy). Road widths were calculated because, it is required to create undeveloped parcels in undeveloped areas.

To create undeveloped parcels, road network datasets, local government planning guidelines, building and road bylaws, and neighbourhood status were considered. The status in terms of development of neighbouring parcels was referred to as neighbourhood status. Most of the neighboring parcels were base year (2016) parcels. All these base year parcels were considered developed because they have already been developed and obtained land use for themselves. are highlighting (pink in colour regions) in the map are undeveloped areas (184 areas total).

The prepared road network dataset mentioned above was used in a rule-based model to create undeveloped parcels in these undeveloped areas.



Map 3 Undeveloped areas of Zone-1(eastern zone) of Hyderabad.

Undeveloped Parcels Generation using Rule based Modelling

Rule-based city modelling enables us to create and design cities with rules and regulations that include application to open or undeveloped areas in this research (refer the literature review chapter for understanding the concept of rule-based modelling). Map 3 shows undeveloped areas of zone 1(eastern zone) of Hyderabad for the year 2016.

Undeveloped areas parcels Generation using rule-based model.

Figure 17 explains process of generation of undeveloped areas parcels. This has been done using rule-based city modelling in city engine software by following G.O 168 rules. Table 4 can be referred for G.O 168 rules.

Esri's City engine software was used to create new parcels according to customized rules. Roads have been used to further divide the whole block into several blocks. The capacity to easily generate large scale, models was a fundamental reason for the selection of interactive urban modelling.

A typical modelling effort (i) parcelizing the space in between roadways (i.e., blocks(parcels)).(Vanegas et al., 2012).

Building models in City Engine were described using Computer Generated Architecture (CGA), Shape Grammar based rules. Here, a CGA rule file was made up of several rules that define how the parcel (building) geometry was generated. The development of the construction model began after assigning the CGA rule file to a shape. As the ground truth roads (OSM roads) were available, the parcels were generated using these roads and ESRI library CGA rules.

CGA rule considered for the study was based on parcel's geometry such as plot area of parcels or blocks. These parcels were customised using the split and generate process and the parcel's average plot area of neighbouring parcels were taken into consideration to create undeveloped parcels plot area. Neighbouring parcel's average plot area was compared to standards such as building rules and abutting road width set by the standard guidelines (Government Order 168 of Andhra Pradesh, (Government of Andhrapradesh, 2012)). The height/plot of the buildings permissible in these undeveloped areas were subjected to rules specified in G.O 168.14,541 undeveloped parcels were created with these rules in these undeveloped areas.

Category status	Plot size in (Sq.m)	Height in (m)	Road width in (m)
Lower	Less than 50	7	3,5,7
Lower	50-100	7-10	7,9
Higher	100-200/200-300/stilt	10	9
Higher	300-750	10-12	9
More Higher	750-1000	15	12
More Higher	1000-2500	18	12
More Higher	1000-2500	24	18
More Higher	1000-2500	24	24
More Higher	1000-2500	45	30
More Higher	1000-2500&above	55	50

Table 4 Rules of Building with their abutting road width as per G.O 168. Source:(Government of Andhrapradesh, 2012)

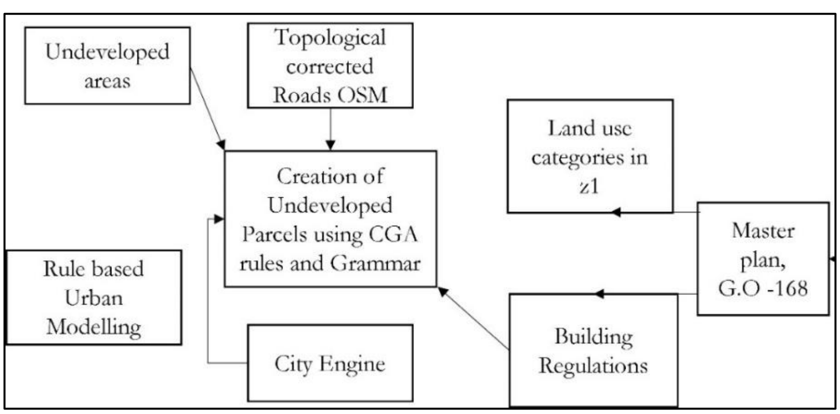


Figure 17 Undeveloped areas parcels Generation using rule-based model

Table 4 shows the building rules and road widths of (G.O 168) and status distribution based on their measurement values. 'H' indicates building height, Roads (m) indicates road width, and Plot (sqm.) indicates parcel/building plot area. Category status distribution column was discussed in the following paragraphs.

(iii) **Distribution of population over parcels**

The distribution of the base year 2016 population (7,22,935) over the parcels (1,10,411) of 2016 was done in accordance with the standard, i.e. (4.5 population size/ Household source: census of India and URDPFI (Urban and Regional Development Plans Formulation and Implementation) guidelines (MOUD, 2014)

The standard based parcels were generated by dividing the population by 4.5 to understand the spatial population distribution and the generated standard parcels were compared to the ground truth parcels to further understand the vertical population distribution. The height of each parcel (building) was further defined by the number of times standard based parcels exceed ground truth parcels and these multiples were considered as floors. Average height of each floor was considered to be 10ft (3.048 m) as per National Building code of India(NBC, 2016). Figure 18 explains the process of distribution.

For example, ward no.1 having population of 40,524 and as per ground truth 5,654 parcels were present. According to standard HH size method, 9,005 parcels should be present in the ward. However, to accommodate the population based on standard in parcels around 1.5 times of ground truth parcels were required. This 1.5 times is considered as 2 floors approximately. This process was carried out for all the 17 wards. (These floors indicate the height of the parcel).

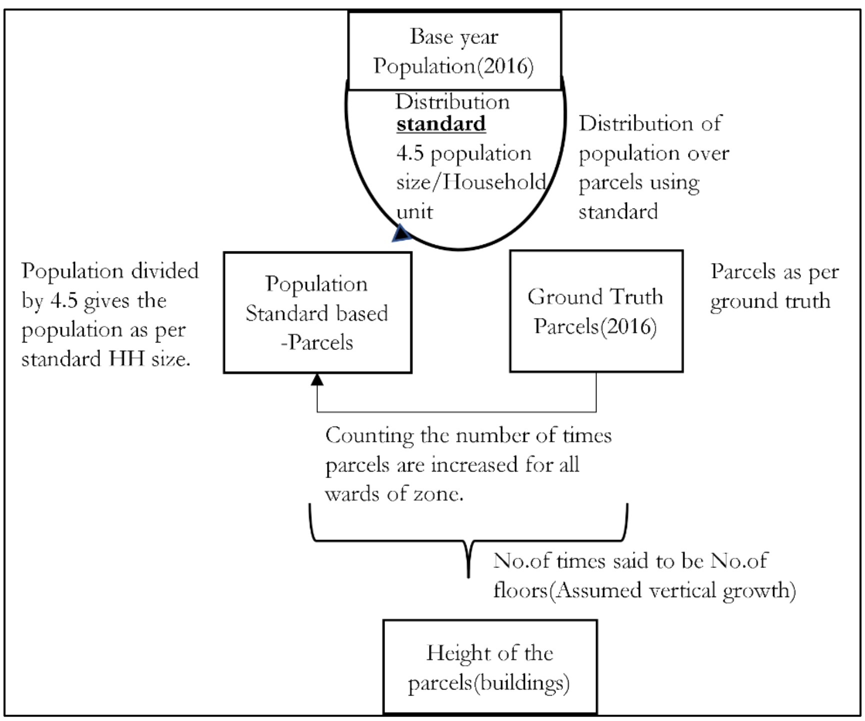


Figure 18 Distribution of the population of 2016 over ground truth parcels of 2016

Figure 18 explains the process of distribution of population over parcels of 2016, resulting height component.

(iv)Categorization and defining density for parcels and wards.

After including the height component in the ground truth data, it was compared to the rules along with area and road components. These three ground components were compared to building rules and road width to determine parcel density status. (For building rules and road width, refer Table 6). Building rules and road widths were assigned categories. Ground truth parcels are classified using these three categories: lower, higher, and more higher. (Table 6 can be referred for G.O 168 rules)

Table 7 shows the Height and Area status of 17 wards.

S.No Wards	STATUS	Height in meters (Avg)	Area (Avg)SQ.m	STATUS
1	H	7.5	130	L
2	L	3	152	H
3	MH	12	105	L
4	H	7.5	183	H
5	L	3	130	L
6	H	9	165	H
7	H	7.5	166	H
8	L	3	130	L
9	L	3	131	L
10	L	3	200	H
11	H	7.5	122	L
12	H	9	173	H
13	H	7.5	173	H
14	H	7	152	H
15	H	7.5	130	L
16	MH	12	158	H
17	H	7	143	H

Table 5 Category status of 17 wards. Source: Author & G.O 168

Table 5 shows the category status of 17 wards. The parcel's density status was determined by applying the logic that when the height of the parcel (floors of the parcel(building)) is higher and the area is less, the parcel is said to be high density. (According to population distribution mentioned above, when population increases, the number of floors increases, implying that the parcel's height increases). Density was calculated for wards by taking average of assigned categories of parcels within the respective ward. Nine combinations were developed to define final density status from the defined categories and logic.

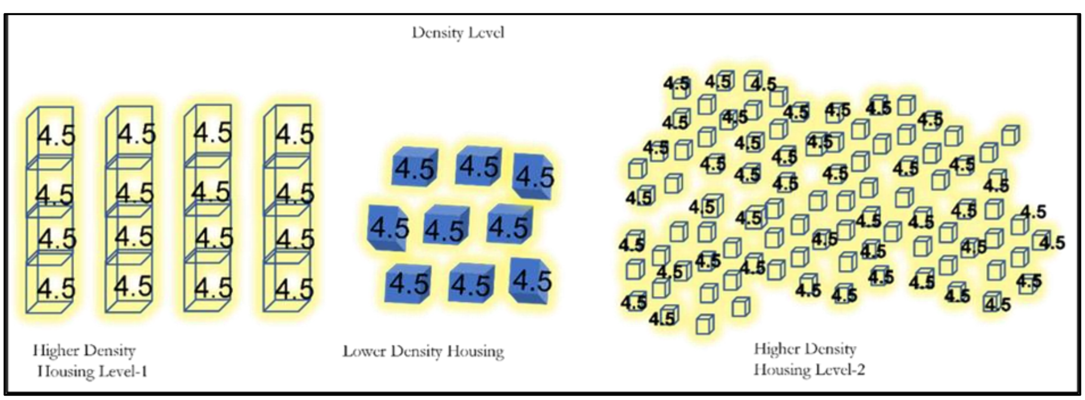


Figure 19 Density categorization process as per logic

Figure 19 represents the density division process as per logic. This figure supports the logic statement visually.

Height and area status are combined to define final density status.

Height status	Area Status	Final Status
L	L	L
L	H	L
L	MH	L
H	L	H
H	H	H
H	MH	H
MH	L	MH
MH	H	MH
MH	MH	MH

Table 6 Combining the status by 9 combinations and getting the final status

Table 6 represents the nine combinations, which were developed from defined categories and logic. Overall density status for the rules were assigned, from which parcels were again categorized into Normal density developed parcels and High density developed parcels. (Figure 20 shows the process of categorizing and density division process.).

STATUS	H(m)	Roads(m)	Plot (Sq.m)	Density status
Lower	10	3,5,7	<=100	More Higher density
Lower	10	9	100-200/200-300/stilt	High density
Higher	12	9	300-750	High density
Higher	15	12	750-1000	High density
More Higher	18	12	1000-2500	Low density
More Higher	24	18	1000-2500	Low density
More Higher	24	24	1000-2500	Low density
More Higher	45	30	1000-2500	Low density
More Higher	55	50	1000-2500 and above	Low density

Table 7 Rules of Building with their abutting road width as per G.O 168 and attained density status Source:(Government of Andhrapradesh, 2012)&Author

Table 7 represents the building rules and road widths of (G.O 168) and status distribution based on their values. H indicates building height, Roads(m) indicates road width, and Plot(sqm.) indicates parcel/building area and Density status is determined to the rules by combinations.

.

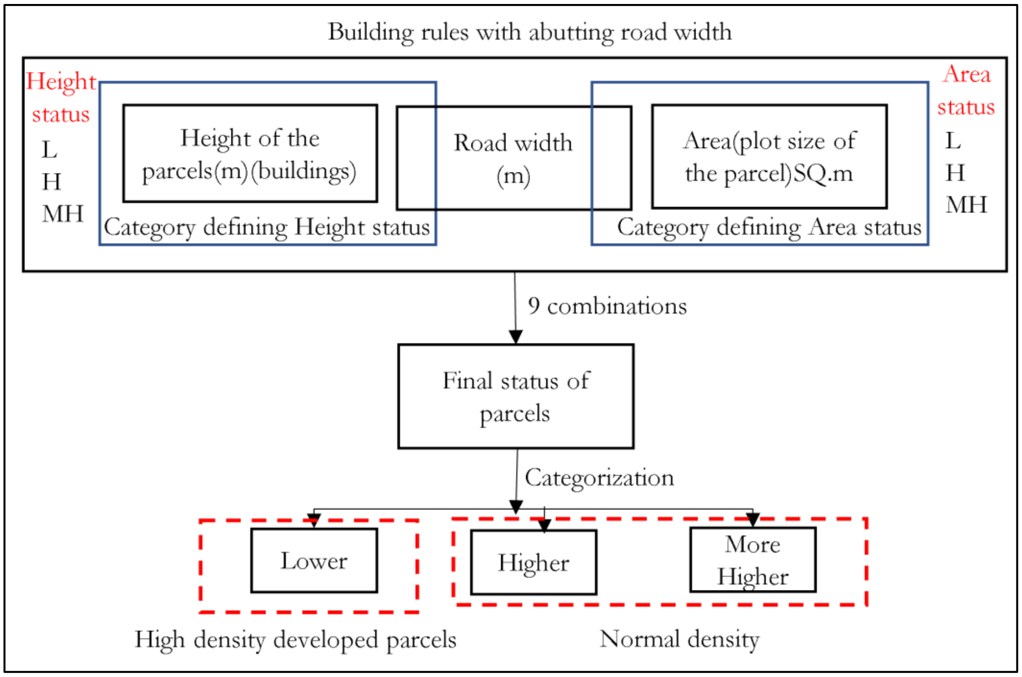
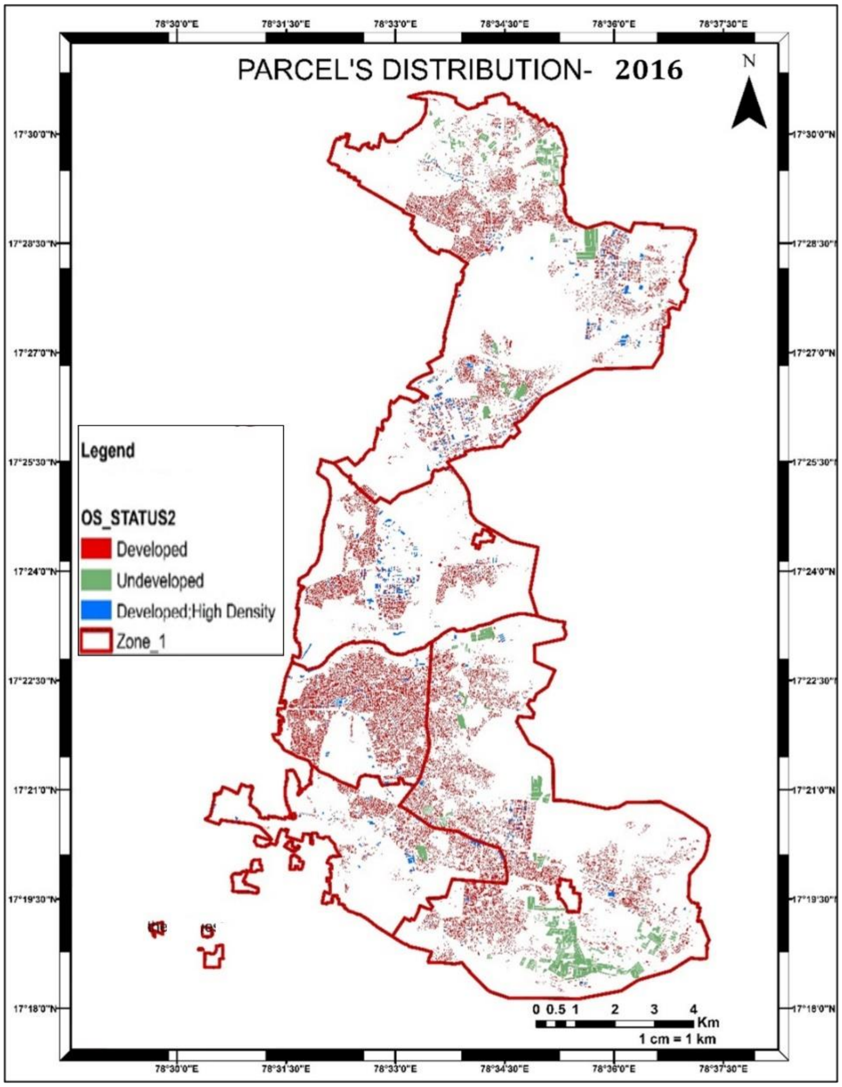


Figure 20 Process of categorizing the parcels and density generation process

Figure 20 explains the process of categorizing of rules and categorizing the density process. The 2016 developed parcels were finally classified as Normal density developed parcels and High density developed parcels. These parcels were combined with undeveloped parcels generated in undeveloped areas. All of these parcels served as input data for the agent-based model, in which they act as agents. The developed parcels act as neighbours to these undeveloped parcels, and these developed parcels density development status affects the growth of the undeveloped parcels. To differentiate the status between them, numbers were assigned to all parcels based on their density status.

The numbers 1,2,4 represent 1-Developed, 2-Undeveloped, and 4-Developed high density. These were the final parcels used in the urban growth model. Map 4 shows the parcels distribution over the zone.



Map 4 Parcel's development status distribution of zone-1 Source: Author

All these parcels were prepared for the ABM model with attributes like Area, Status, ID etc. These undeveloped parcels were of total 14,541. The green highlighted areas in the above map are the undeveloped parcels and the red and blue are Normal density developed parcels and High density developed parcels. All these parcels with their attributes were data inputs for the ABM growth model.

(v)Preparation of LULC maps and drivers for base year (2016) and prediction year (2018)

Sentinel-2A(10m) and planet(3m) satellite datasets were used to prepare LULC maps for 2016 and 2018 years with the help of maximum likelihood classification technique (supervised classification). These LULC maps were generated to monitor the growth of study area in different land use land cover classes over the years. The generated distance parametric drivers and LULC maps (considering these distance drivers as constant for both years) were used to generate suitability score for the above prepared parcels.

Monitoring of the LULC was required to know the changes from year to year, similar to the masterplan preparation process, monitoring of land use land cover is required and that is revived every five years, but it has limitations such as neglecting short term objectives and deviations from the process. These deviations are monitored using lulc maps from previous years. Drivers were prepared based on the changes and these drivers demonstrate the relationship between land use classes and their impact on one another. LULC induced factors affecting the LULCC are Push and pull factors of the region, table 10 can be referred for these factors.

Physical drivers	Location and accessibility drivers	Institutional characteristics
	Distance to roads and transit-oriented development.	Governmentally imposed boundaries and content of regulations
Distance and buffer water bodies and Natural features	Distance to Urban centers	Size of individual parcels under separate ownership
-	Population density.	Infrastructure services

Table 8 Push and Pull factors of the region

Type of Spatial data	Datasets	Source/ Preparation
Static	Distance to local roads	G.T/Euclidean Distance
Static	Distance to Major roads	G.T/Euclidean Distance
Static	Distance to urban centers	G.T/Euclidean Distance
Dynamic	LULC maps	2016, 2018, 2020/MLC

Table 9 Distance parametric drivers along with their source and preparation method.

Table 8 shows the few push and pull factors of the region. For the preparation of urban modelling, spatial characteristics provide a potential inventory of variables which can be hypothesized to influence land use changes. The location characteristics such as land use and accessibility drivers (refer table 8) were given prominent roles in operational urban growth models. However physical limitations can affect the landholding capacity and environmental impacts of any urban development. Location activity works, based on these settings. The datasets and types of spatial data are shown in the table 9, along with the source and preparation process. Drivers took for the study were distance to major roads, distance to local roads, distance to urban centres. Fundamental distance drivers were only used due to a lack of other drivers' data and also because of time constraint. These drivers were prepared based on the static components (roads, urban centres locations) of ground truth; distance parametric data sets were said to be static. The data for major roads, local roads, and urban centres that were spatially present until 2016 were only used for distance and accessibility parametric drivers. These distance drivers were fundamental to the region's development. According to guidelines, major roads and urban centres are given more importance in this kind of zone as the industries count in this zone were greater, it was designated as an industrial zone. Transportation (accessibility) for goods and materials should been flexible. Because this zone was primarily composed of manufacturing and service industries, adequate transportation facilities connecting to warehouses and highways were required.

LULC of 2016 and 2018 was prepared and these LULC was classified into 5 classes. Sentinel-2a satellite imagery datasets was used to generate LULC for the years 2016, 2018 for zone 1 by taking samples of 200-250 per class. Maximum likelihood classification (Supervised classification) was used to obtain LULC maps for the years 2016, 2018; LULC classes were Waterbodies, Greenspaces, Open spaces, Roads, and Built-up area .

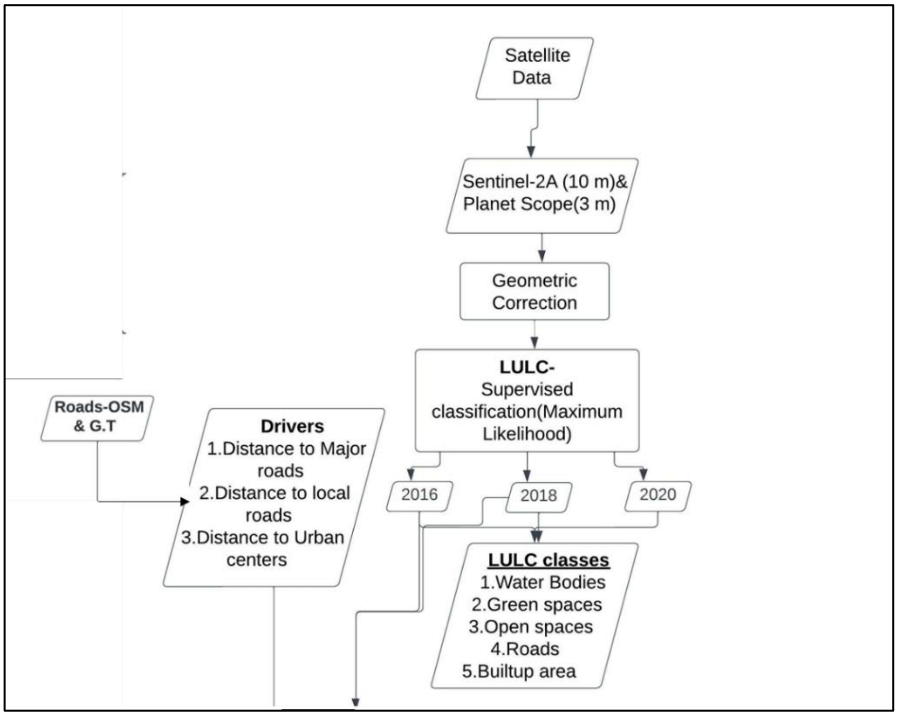
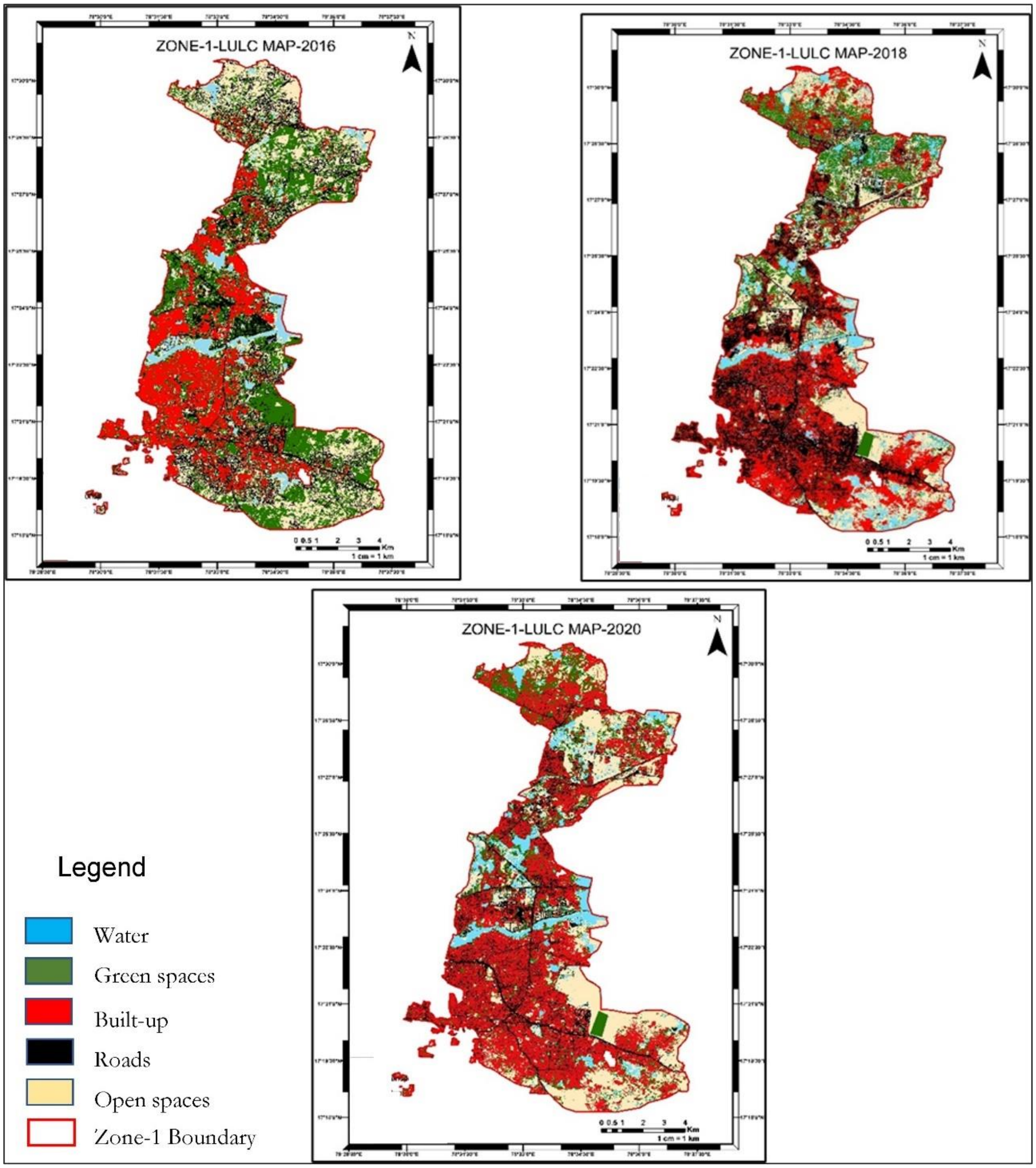


Figure 21 Flowchart for LULC and DRIVERS PREPARATION for 2016, 2018, and 2020 SOURCE: AUTHOR



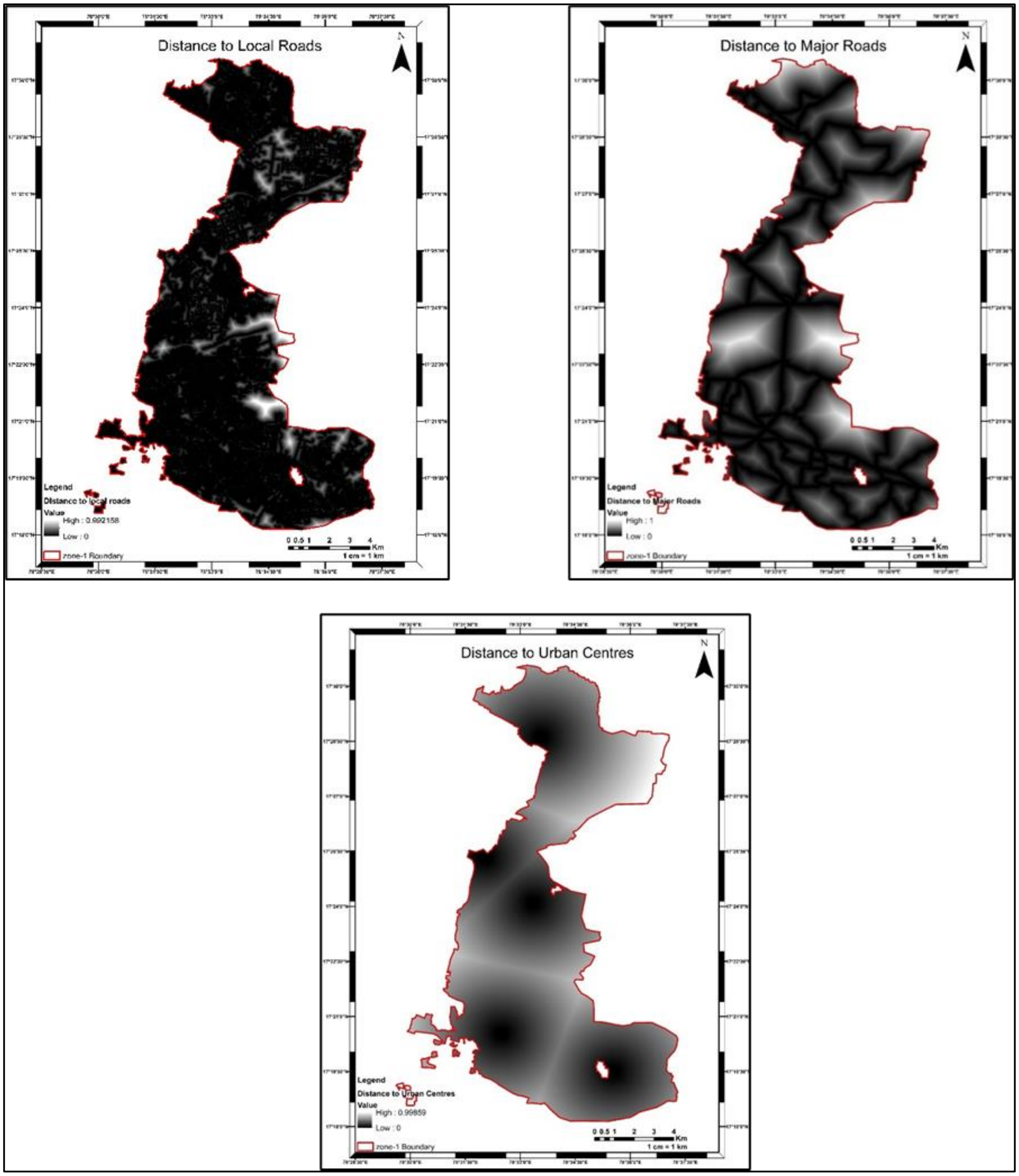
Map 5 LULC year wise DATASETS (2016,2018,2020)

Figure 21 explains the preparation process of LULC maps and drivers for 2016,2018, 2020.The above mentioned 5 classes were considered for preparation of 2016, 2018, 2020 land use land cover maps. Drivers considered were distance to major roads, distance to local roads, distance to urban centres. Fundamental distance drivers were only taken because of lack of availability of data of other drivers and due to time constraint. 2020-year LULC was also prepared in order to prepare prediction map for 2020, but it was not prepared due to time constraints.

These were LULC maps for the years 2016, 2018, and 2020. From 2016 to 2018 to 2020, a built-up class changes were seen. The built-up class percentage had increased by primarily reducing the percentage of open spaces and green spaces. This rapid growth of built-up classes was noticeable in previously undeveloped areas. The reasons for class conversion was due to impact of drivers and the neighbour class effect.

Preparation of Driver Datasets

Distance parametric drivers -prepared using Euclidean Distance methods.



Map 6 Distance parametric drivers; Source: Ground truth data of Zone-1 of year 2016

The distance to local roads, major roads and urban centers were distance parametric drivers of the zone. These drivers were assumed as constant and same drivers for all three years. The road hierarchy was classified according to IRC standards & G.O 168, with 3 to 12 metre roads classified as local roads and 12 to 50 metre roads classified as major roads. According to the primary survey, four centres play a magnetic focal role in the pull and push of various drivers, land use, and people's characteristic behaviour. All these maps were reclassified (normalize for model), and the values were in range of 0-1. These classes and distance drivers were input datasets for open- Land use Landcover Dynamic Model for suitability score preparation.

3.3 Suitability score Generation

Monitoring the lulc changes and predicting future lulc was required in master plan preparation and implementation process. Following the policy rules, standards and guidelines for different zones and preparing various suitability analysis was also one kind of approach for a part of preparation of master plan. Preparing with previous years lulc changes and drivers, making probability suitability score for each class with different dynamic drivers and classification techniques was another kind of approach. These suitability scores were appended to the parcels of 2016 already developed parcels and undeveloped parcels that were created in undeveloped areas. Suitability scores was part of urban growth model, which effects the behaviour of the agent or parcel at the time of decision making.

3.3.1 Approach-1-Planning based

The Suitability scores for the parcels for the potential growth are generated using planning-based approach. Industrial planning guidelines are followed.

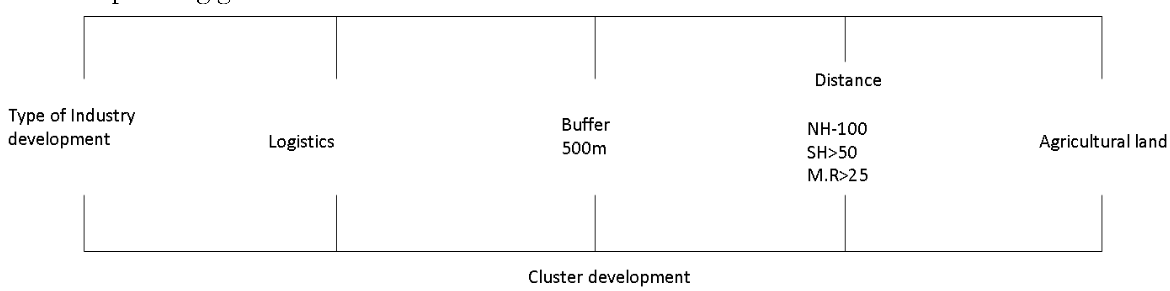


Figure 22 Suitability scores generation using spatial rules around the industries. (MOUD, 2014)

Figure 22 represents the elements and spatial rules to consider when designing an industrial zone. Industry type, the location of a logistic hub/warehouse, Buffer between industries, distance from industries to road network, i.e., National Highway, State Highway, Major Roads, and distance from industries to agricultural land ,Environmental rules such as distance to water body from different types of industries, buffer from water bodies, distance to green spaces from industries, buffer from green spaces, distance to open spaces from different types of industries to dump waste, and so on were used to consider. These spatial distance and buffer rules generate various suitability analyses and scores. After normalising the rasters and using the AHP or manual weightage, suitability scores for parcels are generated. Adding other land use rules makes the most suitable scores. Buffers were classified into three groups ranging from 150 to 500 m. For example, parcels in the buffer 150m and distance for SH - 50 m, categories were assigned with 0.7. These scores were given manually based on expert recommendations and the score ranging in between from 0 to 1. In terms of buffer and distance rules, the score decreases as the distance range between industries and parcels increases, as well as their sizes and other parameters. The newly developed parcels adhere to planning guidelines, whereas previously developed parcels have a score of 1 because they have already been developed.

0.7-150m,0.5-300m,0.3-500m---------Buffer Distance Suitability score

0.7-25m,0.5-50m,0.3-100m------------Accessibility Distance as per Road network

These suitability scores were used in the agent-based growth model as a parameter to make decisions about parcel potential for various land use development. As this was an industrial zone, the master plan and zonal development plan for this approach can prevent improper growth and protect people from a variety of threats.

The suitability scores (raster data) were used as input raster files or parcels attributes (vector data attribute) for the agent-based model. Agent-based modelling works on both vector and raster datasets. The other static drivers, LULC maps and neighbourhood status are also used as the input datasets for the ABM model.

However, this approach was not used for this research because the scores are given manually in this approach. Even though the scores are given by experts, the risk of this approach being uncertain is higher when compared to other suitability score generation methods. In this process, expertise such as decision makers should make decisions twice in the entire process, i.e., one step of decision making at suitability score time and one step of policy making from the growth potential areas at the end. Manual intervention may not always produce the desired results.

3.3.2 Approach-2-Open-Land use Dynamic Modeler

The logistic regression-based technique was used with these two years (2016, 2018) worth of land covers classes with drivers resulted to generate suitability maps for each of individual classes. These suitability maps display the likelihood of suitability of various land cover classes in their respective areas or locations, with scores ranging from 0 to 1. For this purpose, OpenLDM software was used. Land use map for the year 2018 was generated from these suitability maps using maximum likelihood techniques based on c 250 samples from each class.

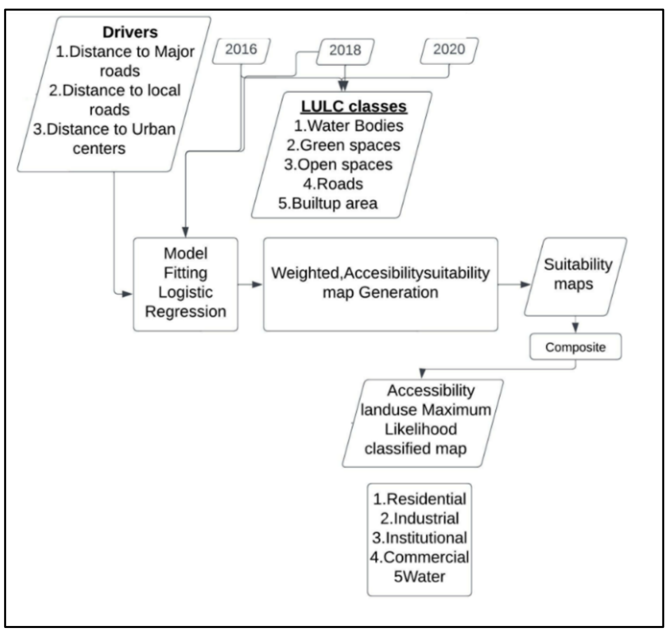


Figure 23 Process of OpenLDM

Figure 23 depicts the process of generating suitability maps using an open land use dynamic model. As these maps were created with distance parametric drivers and LULC classes, they were called accessibility-based suitability maps for each land cover class. Only fundamental distance drivers were used to prepare suitability scores, but other drivers such as slum location, traffic points or roads, infrastructure service drivers, environmental policy drivers, and so on could be incorporated into the model each year. Due to a lack of other drivers data and a time constraint, these drivers were not considered in this study. The scale of drivers in relation to the area produces dynamic results. These maps aid in determining the likelihood of each class of LULC at their respective locations.

These suitability raster datasets were used to assign the parcel's suitability score. From the suitability maps, composite map of all classes was created. Built-up class is predominant in the zone 1 as it is an urban area (city). The built-up class was sub divided into four classes: residential, commercial, industrial, and institutional, which account for a maximum percentage of the zone's land use. Physical feature such as waterbodies were also considered for land use classification map. As per primary collected data, there was no agricultural land, forest land, or other land types of data available to consider for the classification and one of the reasons to consider these land use classes was that they show an economic effect on socioeconomic elements like population, services, and building construction in urban area.

For the land use classification, the classes of land use are industrial, residential, commercial, institutional/public-semi-public, and water (land cover class) were used. Due to a lack of information or a very low percentage of data availability for other land use classes, only these classes were considered for classification. Land use classified map was created by taking training samples (250 samples from each class) and applying them to a composite map of LULC suitability maps, then applying the maximum likelihood method to obtain the likelihood classified land use map for the year 2018. This was referred to as an accessibility-based land use classification map because it was created using suitability maps (which were generated using distance parametric drivers).

These suitability maps and accessibility-based suitability land use classified map were input datasets for the ABM growth model. From these raster's data (suitability maps) suitability score of the parcel was created and append to themselves by using centroid of the parcel's geometry. The code has been constructed in the ABM model in such a way that it identifies the coordinates of the parcel by obtaining its geometry. Then it consults the rasters beneath it, append values to them, and compute overall scores or rating of parcels.

3.4 Agent Based Growth Model

The parcels generated during data preparation act as agents in the growth model. These agents are influenced by the prepared suitability maps, parcels attributes, and parcels' neighbours (8). Agents' decision was taken based on functions, conditions, and calculations.

Parcels of undeveloped areas were generated earlier by following G.O 168 building rules in city engine software by rule-based modelling. These parcels here acts as agents, these agents behave in accordance with their behavioural rules. The environmental factors helped to shape the behavioural rules in part. The agents' behaviour is influenced by the current state of the environmental factors, which can change periodically. The results of the agent's behaviour may then have an effect on environmental variables. At the level of the simulation model, the environmental factors were represented. The behaviour rules were also framed by the attributes of the parcels vector data (shapefile).

Agent-based model process

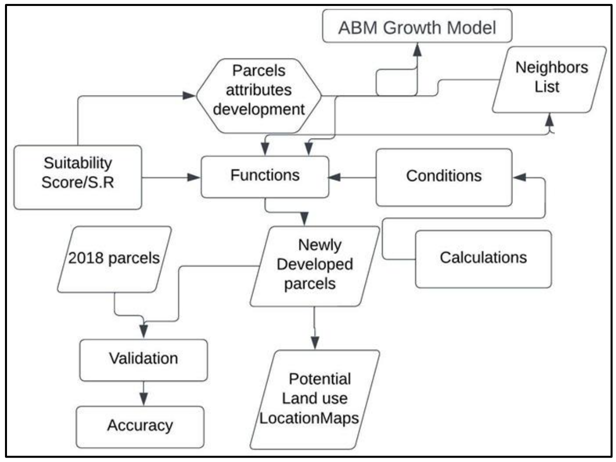


Figure 24 Flowchart of the ABM growth Model

The above flowchart figure 24 describes process of agent-based growth model. This process consists of parcels, parcels attributes, neighbours, functions, actions, conditions and their calculations. These were used and performed in the agent environment and growth model environment.

The ABM operates in two interdependent environments: the parcel environment and the growth model environment.

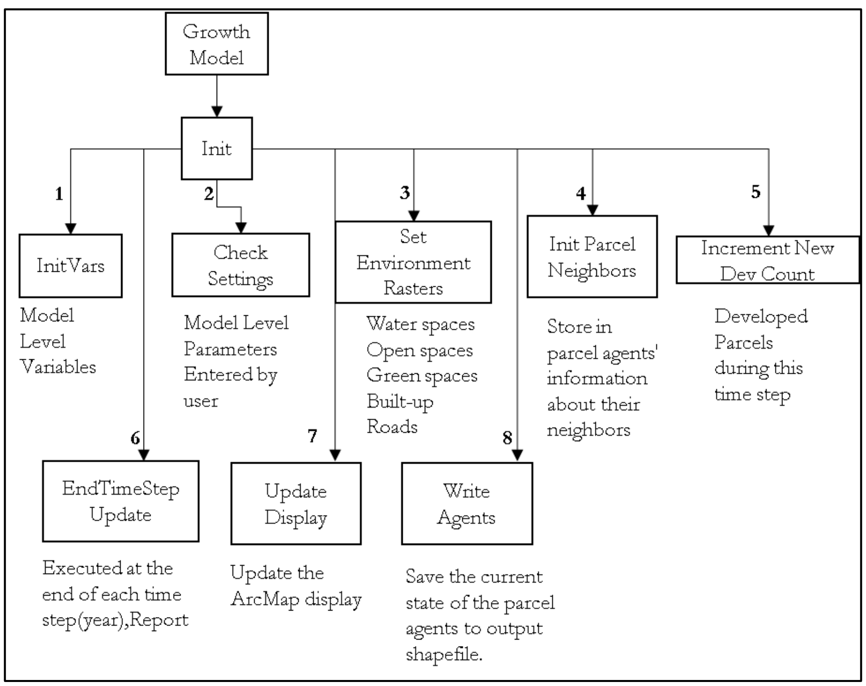


Figure 25 List of actions and functions of the Model environment

The above figure 25 explains about process, actions and functions of growth model and parcel-agent environments. Total of 8 actions developed for growth model environment. Each action has its own reason for the model development. Total of 20 actions developed for agent(parcel) environment. These actions were developed as per the conditions and requirements for growth model. In these actions several fields were added and used in both parcel and growth model environment as a supporting field for the agent's decision making.

3.4.1 Growth model environment

Below tabular format figure explains the meaning of actions that have used in Growth model environment.

Declared Actions	***Description***
Urban Growth Model	
InitAgents	Initialize parcel agents
InitVars	Initialize model-level variables
SetEnvironmentRasters	Set the environment rasters
CheckSettings	Check the validity of the model-level parameter settings entered by the user
InitParcelNeighbors	Store in parcel agents' information about their neighbors
IncrementNewDevCount	Called by parcel agents to increment the count of newly developed parcels during this time step
EndTimeStepUpdate	performed at the conclusion of every time step (year). Report on the development of the parcel in summary form, and change some threshold values for the following time step (e.g., relax the development suitability score threshold)
Update Display	Update ArcMap Display
WriteAgents	Save the current state of the parcel agents to output shapefile

Figure 26 Actions of Growth model environment and their description.

Figure 26 explains the growth model actions explain how they work with fields, data, and other parameters. Initiating agents in the growth model initialises the agents-data structures required for the aggregate's remaining computation, sets up the environment rasters for computation, checks the parameters and fields entered manually by the user in the model, initialises the neighbouring parcels information which lies in the parcel's environment, increments the newly developed parcels count, obtains the summary of parcel development, and relaxes the suitability score and thresholds. WriteAgents write changes in attributes to the output given layer.

In this action setting up the environment rasters means, setting up the suitability maps that are generated in the open LDM model. These were used to compute the suitability scores for the parcels. Initializing the neighbours of parcels for their status (status means whether that neighbouring parcel is accessible to road network, whether the neighbour is developed already, land use information and so on).

3.4.1.1 Neighbour's role in the growth model

Initiating the Parcels Neighbours in the Model.

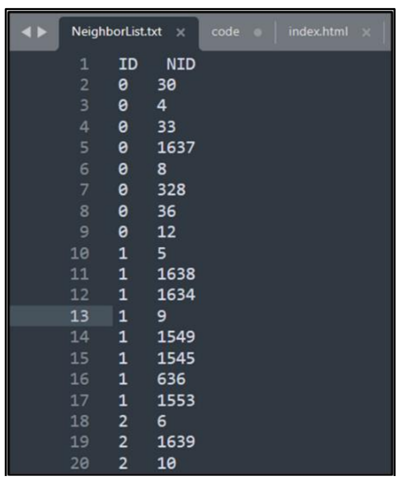
In this action, the model stores the following information about its neighbours in each (undeveloped) parcel agent for later use:

1. A list of undeveloped parcel agents in the area
2. The number of developed neighbouring parcels (currently, they are not agents in this model for performance considerations)
3. The total number of neighbours (developed and undeveloped)

For better performance, the neighbouring parcels that are undeveloped at the start of the simulation for each parcel agent were stored. Also, the track was maintained of how many neighbouring parcels had been developed before the simulation began.

This procedure reads a tab-delimited text input file containing information about the parcel neighbours. The Neighbour List File field of the model, which can be specified in the model's Fields Editor or change at runtime in the urban growth model settings window, on the parameters tab, specifies the path to this file. Each line in this file has the following format:

Where Parcel IDs were the ID String field of the parcel agents, Left Parcel ID, Right Parcel ID. The Right Parcel ID was the ID of a neighbouring parcel, and the Left Parcel ID was the ID of a parcel agent. One line represents each neighbour.




```
ID   NID
0    30
0    4
0    33
0    1637
0    8
0    328
0    36
0    12
1    5
1    1638
1    1634
1    9
1    1549
1    1545
1    636
1    1553
2    6
2    1639
2    10
```

Figure 27 Parcel's Neighbour's text FILE (8 neighbours for Every parcel/AGENT)

Figure 27 describes about the parcel's ID with their Neighbour's ID. For every parcel, eight neighbours were taken, these were generated using SWM weights with Nearest Neighbour and No standardisation.

To initialize the parcel, actions and supportive fields were required for the simulation. The number of developed neighbours and the development status of some will vary over time. The development status of the parcel changes during the parcel agent's step action, for example, which causes some dynamic changes to occur. The total number of developed neighbours for a parcel was one that needs to be calculated as part of a model action that was scheduled to run at the end of a time step.

3.4.2 Parcel's Environment

There are total of 20 actions developed in parcels environment, these actions include Functions, conditions, and calculations. Required datasets, attributes that were formed at pre-processing stage were used in these actions, Figure 31 depicts the datasets used in the model.

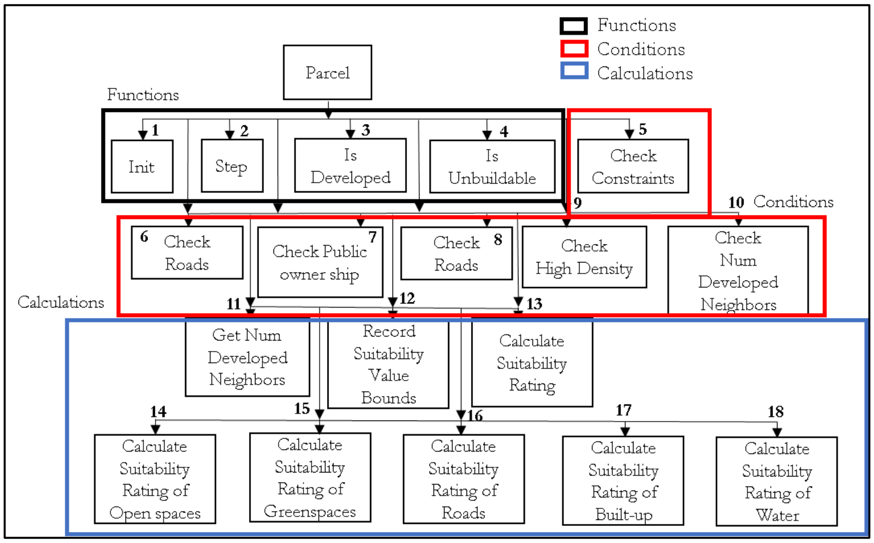


Figure 28 List of Actions, Functions, and conditions of Parcel's environment.

Parcel's environment actions were formed and framed into three groups, named Functions, Conditions and Calculations (Figure 28). Functions are for initiating the agents, calling up for the conditions and calculations/processing. Conditions group consist of Check constraints, Check roads, check public Ownership, Check Roads, Check High density, Check number of developed neighbours and calculations group actions consist of calculating Suitability rating overall and individually, Recording the suitability bounds that means, recording the check settings (model level parameters related to suitability bounds (lower and Higher bound)). Each group were interlinked and interdepended with growth model environments.

Parcel Agents	Description
Init	Initialize self, record relevant environment conditions
Step	Evaluate current conditions to decide whether self should change development status
Is Developed	Indicate whether self is already developed
Is Unbuildable	Indicate whether self is unbuildable
Check Constraints	Land use proper allocation.
Check Public Ownership	Evaluating the development probability of parcel in terms ownership.
Check high Density	Area of parcel less than the required size. (likelihood)

Figure 29 Actions Dictionary of parcels agent for the Urban Growth Model

Figure 29 depicts the actions of the parcel's agents and their descriptions, which could also be referred to as the reason for taking these actions for the growth model. The action's descriptions were described in detail in the following paragraphs.

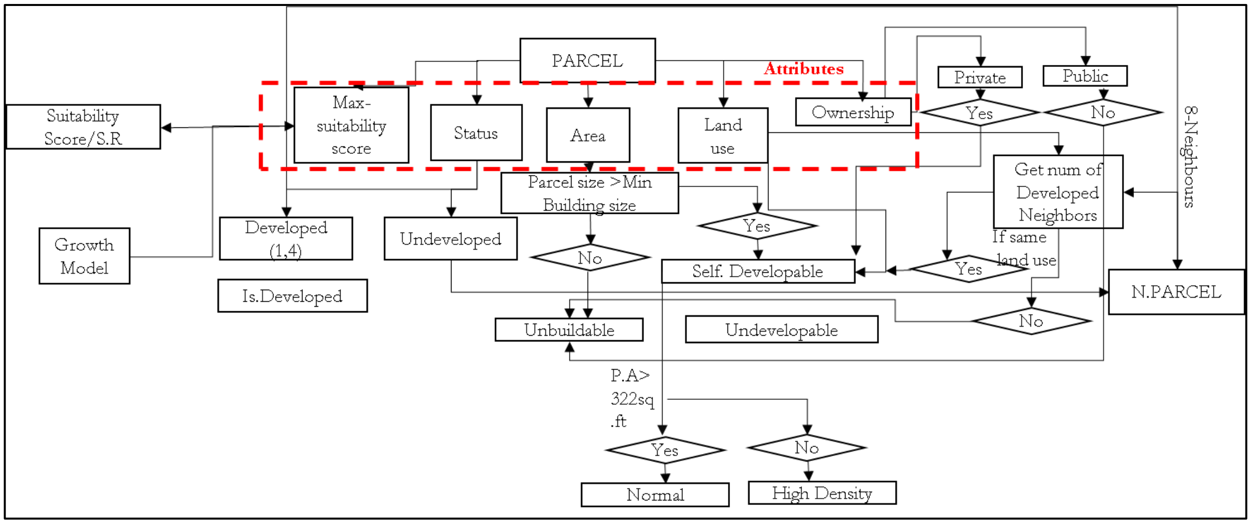


Figure 30 Parcel's role and Inside Function Mechanism Logic Flowchart

Figure 30 explains the internal mechanism and flow of the parcel's environment. Max of suitability scores (parcel centroid score from the raster datasets or mean values of each class), Status, Area, Land use, Ownership are the attributes of the parcel. These attributes are used in conditions action groups and were subjected to calculations. Processing of the parcel's agents, based on these group actions makes the decision for the development.

3.4.2.1 Parcel's Attributes, Conditions, and their calculations.

Agents' behaviour is dependent upon the conditions and their calculations. Main attributes of parcel were Area, status, Land use and ownership. Area indicates parcel's area size, which varies from ward to ward and due to neighbourhood effect also. The status attribute was used to determine the parcel's developed or undeveloped category it certainly applies to. The land use attribute was used to assign land use (Accessibility based land use) to parcels. Ownership is required to determine the parcel's private or public property (the development of the parcel was stopped in public property category),Getting suitability score by parcel's centroid.

1.Functions

Init

Initializing the parcel, such as the parcel agent consults the raster layers to obtain information about itself and, if needed, stores the information.

Step

The activities which were defined in this action were performed at every time simulation step and decides the status of development.

Is Developed

This action indicates whether the self-Parcel was already developed. The status attribute indicates, developed or undeveloped status of itself.

Is. Unbuildable

This function action indicates, the parcel's development decision based upon the conditions that have been applied, this action calls all other conditions and calculations that applied on the parcel's attributes to decide the buildable or unbuildable status.

2.Attributes

Attribute-1(status) and its relationship with functions and conditions group actions

Status attribute is given for a parcel according to the development status that had been carried from the parcel's density calculations and distribution section. Status attribute contains developed and undeveloped categories. The undeveloped parcel has undergone several conditions such as, getting know the status of itself and checking with the neighbouring parcel status for the future development decision making of itself.

This action indicates whether the self. Parcel is buildable. This decision reveals whether the parcel can be grown or not. Conditions play a role in this; in the current context, those buildings were stipulated and cannot be constructed in cells or suitability scores that are classified in water levels, as determined by the LULC and drivers, or in parcels that are smaller than the minimum building size because of uneven growth caused by development. As slums can grow along the nalas and is possible given the characteristics of the zone, it can be concluded that lots/parcels within this criterion are unbuildable.

Attribute-2(suitability score) and its relationship with calculations action group.

Suitability score appending to the parcels

Suitability scores were lies within the suitability maps of LULC classes that were generated using OpenLDM, the pixel values (suitability scores) are appending into the parcels through parcel' s centroid of x and y coordinate was the method used for the ABM model and other method also could be used that was taking mean of all the suitability scores(pixels values (values-suitability scores) with in a parcel following the same process for every classes .This can be accomplished by using zonal statistics as the input raster layer in the raster layer parameter and vector layer (parcel's vector layer) in the vector layer parameter and selecting the mean stat parameter appended to the parcels to generate mean values for the parcels of respective classes and finalizing the score by taking maximum mean value and appending that value to that respective parcels.

Like this attribute column was created with all the scores for every parcel. This method also could be used in abm growth model as suitability score for the parcels and continue towards decision making.

Average mean= sum of pixels values in a parcel geometry/no. of pixel values in a parcel geometry.

$$F.\ SS=S(P)/N(P)$$

Mean of the parcel was obtained by this formula, this mean is calculated to all the suitability maps (for all classes), the maximum of this mean values or scores of all the classes was taken the final score of the parcel or calculating the centroid(finding x,y co-ordinates by first getting the geometry of the parcel, once the centroid was found, the parcel consulted the rasters to get the value(score)) and taking it as suitability score for the respective parcel. This calculation was carried for all the rasters as these were having the same resolution i.e., 10m.This centroid method was used for the model as it takes less time to perform the simulation.

Overall Suitability Rating

As part of calculations, calculating suitability rating for each individual suitability maps created the overall suitability rating for the parcel. The suitability rating was calculated using below mentioned formula for every suitability dataset and calculating overall suitability rating was calculated based on suitability weights, Here weightage was given manually as per development priority.

Suitability rating of green spaces = 1 - ((self. Greenspaces - model. Green spaces Lower Bound) / model. GreenspacesTickValue), Here Tick value indicates the adjustment to use to normalize the parcel's suitability of greenspaces suitability rating to 0 to 1 scale.

The same formulae apply to all the classes rating. Here lower bound and upper bound indicates lowest and highest suitability score respectively.1 indicates the highest limit score of the class.

Assuming, S.R(suitability rating) =K

Suitability weightage is assigning weights to the rasters which can be more important (manual input) for the growth model.

Assuming, S.W(suitability weightage) =Y

Overall Suitability Rating = SuitabilityRatingOpenspaces(OSK) * model.SuitabilityWeightOpenspaces(OSY) + SuitabilityRatingBuiltup(BK) * model.SuitabilityWeightBuiltup(BY) + SuitabilityRatingRoads(RK) * model.SuitabilityWeightRoads(RY) + SuitabilityRatingGreenspaces(GK) * model.SuitabilityWeightGreenspaces(GY).

Or

Overall Suitability Rating = OSK*OSY+BK*BY+RK*RY+GK*GY.

Place-holder approach was used for the simulation in the model for the parcel's development decision eventually. The model employs a placeholder algorithm to simulate the reality that parcels with higher suitability ratings develop more quickly. Several dependencies were used in the model along and under the attributes, conditions and calculations for decision making of parcel's development. Such as Suitability threshold, Suitability Low stop threshold, Suitability decrement, Tick value etc. Required values were given to these dependencies for generating various situations of parcels decision making.

Dependencies usage for the parcel's decision making.

It Decides on an initial parcel high suitability threshold (parcels with suitability scores higher than given threshold will potentially be developed during the current time step), an ending low suitability threshold (parcels with suitability score lower than given threshold will not be developed during this run), and the suitability value decrement on each time step (the high suitability threshold will be relaxed at each time step so that parcels with lower suitability scores could be developed in later time steps).Various approach can also be used such as setting up a development target (a maximum number of newly developed parcels) for each time step based on population growth trend, economic growth trend, zoning regulations, etc., so that during each time step, the more suitable parcels will develop until given development target is met.

Suitability Threshold – Minimum development that parcel should have in its suitability score during the current time step.

After the parcel agent has calculated its own development suitability ratings (and has reported the low and high bounds of these ratings to the model), the model decides on a suitability threshold value for the current time step. Undeveloped parcel agents with a suitability rating less than the threshold were taken as the parcels were more likely to be developed parcels.

Assuming, S.T =Z

Suitability Decrements

The suitability threshold decreases with each time step, allowing less desirable parcels to become more desirable to develop as more desirable undeveloped parcel agents are developed. The amount to lower the suitability threshold each time step was controlled by multiplying the suitability rating by a decrement factor Suitability Decrement.

Suitability rating of Upper Bound (UB) - Suitability rating of Lower Bound(LB)/Maximum no of steps i.e., Parcels Development at n times of time intervals.

As, S.R=K

Maximum .no steps = N

$$S.\ D=(KUB-KLB)/N$$

Assuming, Initial Threshold of Suitability Decrement is I., This is first threshold of Suitability Decrement

Suitability Low Stop Threshold – Minimum ("low threshold") development of suitability score. If parcels score is lower than the threshold, it can't be developed during the model run.

Suitability thresholds of High and Low helps us to control, plan and develop the parcels accordingly over the period. Denoted as UB, LB.

$$S.\ T=KUB-(K*I)$$

Suitability rating Bounds of High and Low are the Highest and Lowest suitability scores among the parcels.

Record Suitability Value Bounds- This action records the suitability value bounds at every running step. The highest and lowest values of suitability scores are recorded in the model.

Attribute-3(Check Public Ownership) and its relationship with conditions group actions.

The ownership of the parcel was divided into two categories i.e., of private and public and parcel check's the public ownership status of itself and of the neighbours for the development. All undeveloped parcels are categorized into private status for the development as this attribute acts as condition and stops the parcel to develop ,when it was in public category as it was secure and illegal for the development.(policy interventions, public lands can be added in this). For example, Institutional structures like administrative buildings and other level institutions are categorized into public for already developed parcels. While the other parcels are categorised as private because the ground truth data does not include adequate information about the parcel ownership.

Attribute-4(Area) and its relationship with conditions and calculations action groups.

The attribute area was a parcel area. The size of the parcel also acts as a condition for the development. Areas of undeveloped parcels were assigned as per local guidelines and were based on neighbourhood parcels area. Area acts as a condition, such as a minimum given size was required for the parcel to be developed. Minimum parcel size requirement to be considered in High-density development and large parcel size development probability.

Conditions

Check-High Density

After the parcels were developed by getting ahead of all conditions and calculations. Then this area condition was applied, whether the area of the developed parcel was less than 30m or 322sq.ft, then it was considered to be a high-density parcel.

Minimum Building size area

The minimum size of the building for the development does not mean the smallest area or of all the parcels. It is varied as per the divided land use development. As per planning guidelines and housing regulations, the minimum housing area is 30 sq.m or 322 sq. ft., called "low-income housing." The parcels that will be developed in the future should not be less than the specified standard area, otherwise, they might be categorized as High-density development housing or slum housing.

Larger Parcel size Development

The parcels are categorised as per the status, so there were parcels that have a large area (sq. ft.), A random number s created if the parcel size exceeds a specific region, specifying the size of a parcel that is too large to develop. The random number was compared to the predetermined probability value for big parcel development. This variable (Large Parcel Size) can be changed in the fields of the urban expansion model.

Large parcel size development is the minimum size of the parcel is said to be large enough for the delayed development. In the study context, large parcels are allocated for the growth of industries based on the standard and percentage of industrial land use restrictions.

If self. Area (parcel' s area) > x, it is said to be unbuildable or delayed for development.

For already developed parcels of industry, the mean site area is 2239 sq. ft., the maximum site area is 196526 sq. ft., and the minimum site area is 13 sq. ft.

For undeveloped parcels, the mean site area is 3114 sq. ft., the maximum site area is 43596, and the minimum site area is 701 sq. ft. The parcels that are under 3000 sq. ft. are allowed to be developed as residential areas, and the area above that was for industrial development. Changing the variable to the lower limit of the large area parcel as the highest limit of the parcel's area for other land use growth. As a result, industrial areas and other land use classes have a chance of developing.

Checking and getting the number of developed neighbors for parcel's development.

This action provides the total number of developed neighbor parcels. As development depends on infrastructure, this activity aids in finding the developed neighbors from the list of neighbors. For undeveloped parcels, neighbors need to check their development status. This action was used here as kind of cellular automata method, that defines the future possibility of the development of undeveloped parcel based on the neighbouring parcels.

Number of Developed Distant Neighbours

Another random number was used in a similarly to determine whether the parcel would be developed based on how many of its second-degree neighbours (neighbours of immediate neighbours) have been developed. In this instance, a random number is compared to the parcel's total number of developed distant neighbours (if (random int (numDevelopedDistant Neighbors / 8).

Isolated ParcelDevProbability

When a parcel was isolated from all neighbouring developments, a third random number was utilised. Because no neighbouring parcel or second-degree neighbouring parcel has been formed in this situation (for the "leapfrog" pattern of development), Isolated ParcelDevProbability has a low probability value specified in the model later.

Data table of GIS Datasets

	Data Type	*Description*
Devpotential.shp .shp	Polygon	Parcels in entire study area. All the parcel data used in this model is real data.
Undeveloped. Shp	Polygon	Undeveloped parcels in the study area.
Streets. Shp	Polygon	Streets of the study area
Green spaces-ASM	Raster	Raster which says the suitability areas for the green spaces.
Open spaces-ASM	Raster	Raster which says the suitability areas for the Open spaces
Built-up-ASM	Raster	Raster which says the suitability areas for the Built-up spaces
Roads-ASM	Raster	Raster which says the suitability areas for the Roads spaces
Water-ASM	Raster	Raster which says the suitability areas for the Water spaces

Table 10 Data table of GIS Datasets Source: Author & Agent analyst

Fields	Data type	Description
Urban Growth Model		
Max Num Time Steps	Int	No. of time steps specified for a model run
Timestep	Int	The num of the current time step.
TotalUndevParcels	Int	Total num of undeveloped parcels at a given time.
TotalUnbuildableParcels	Int	Parcels which can't be build due to constraints
TotalNewDevelopedParcels	Int	Total num of parcels developed during the entire model run
NumNewDevThisTimeStep	Int	Num of newly developed parcels during this current time step.
Neighbor List File	Int	Neighbors of the parcels List (8)-N-Neighbor
Test-Output	String	Path to output shapefile. This will be overwritten at the end of each time, reflecting current status of the parcel.
Environment path	String	Path to environment layer folder.
Min Building site	int	Min size of the building site
Large Parcel Size	int	Min size of parcel which is said to be large enough for the delay development.
Large parcel size for other land use other than Industrial	int	Min size=2000(considered as large development)
Industrial land use size	int	(701-43596) size
Large parcel DevProbability	int	Large parcel probability to be developed.
MinParcelSizeHighDensityDev	int	Minimum parcel size requirement for parcel to undergo-High density development.
Suitability Threshold	Double	Minimum development suitability score for parcel to develop during this time current step.
Suitability Low stop Threshold	Double	Low stop threshold of development suitability score. If parcel suitability score is less than this, then it will not be developed during this model run.

Suitability Rating	*Double*	*Suitability score of parcels*
Suitability Rating Upper Bound	Double	Highest suitability score among all parcels.
Suitability Rating Lower Bound	Double	Lowest suitability score among all parcels.
Suitability Decrement	Double	Periodic relaxation on suitability Threshold of parcels after every run. Giving chance for low suitability thresholds to develop in next step.
Suitability weights	Double	Weights for the required datasets.
Open spaces Tick value	Double	The adjustment to use to normalize a parcel's open spaces suitability rating to 0-1
Open spaces Upper Bound	Double	Highest suitability rating or score among parcels of Open spaces
Open spaces Lower Bound	Double	Lowest suitability rating or score among parcels of Open spaces
Greenspaces Tick value	Double	The adjustment to use to normalize a parcel's green spaces suitability rating to 0-1
Green spaces Upper Bound	Double	Highest suitability rating or score among parcels of greenspaces
Green spaces Lower Bound	Double	Lowest suitability rating or score among parcels of green spaces
Built-up Tick value	Double	The adjustment to use to normalize a parcel's Built-up suitability rating to 0-1
Built-up Upper Bound	Double	Highest suitability rating or score among parcels of Built-up
Built-up Lower Bound	Double	Lowest suitability rating or score among parcels of Built-up
Roads Tick value	Double	The adjustment to use to normalize a parcel's Roads suitability rating to 0-1
Roads Upper Bound	Double	Highest suitability rating or score among parcels of Roads
Roads Lower Bound	Double	Lowest suitability rating or score among parcels of Roads
Water Tick value	Double	The adjustment to use to normalize a parcel's Water suitability rating to 0-1

Water Upper Bound	*Double*	*Highest suitability rating or score among parcels of Water*
Water Lower Bound	Double	Lowest suitability rating or score among parcels of Water
Debug	int	Whether the debugging is turned on during the model run.
Test Parcel	Int	Testing of some parcel with ID on few functions
Abort run	Int	Whether to abort the model run because of some predefined error conditions.

Table 11 Fields of urban growth models

Actions Dictionary for the Urban Growth Model

CheckNumDevelopedNeighbors	*Checking about developed neighbors for parcels.*
GetNumDevelopedNeighbors	Return the no of developed Neighbors parcels
Records Suitability value Bounds	Record the highest and Lowest values in data in model for those suitability criteria with weights.
Calculate Suitable Rating	Calculates self's development
Calculate Open spaces S. R	Check development suitability in terms of Open spaces
Calculate Green spaces S. R	Check development suitability in terms of green spaces
Calculate Roads S. R	Check development suitability in terms of Roads
Calculate Built-up S. R	Check development suitability in terms of Built-up
Calculate Water S. R	Check development suitability in terms of Water.

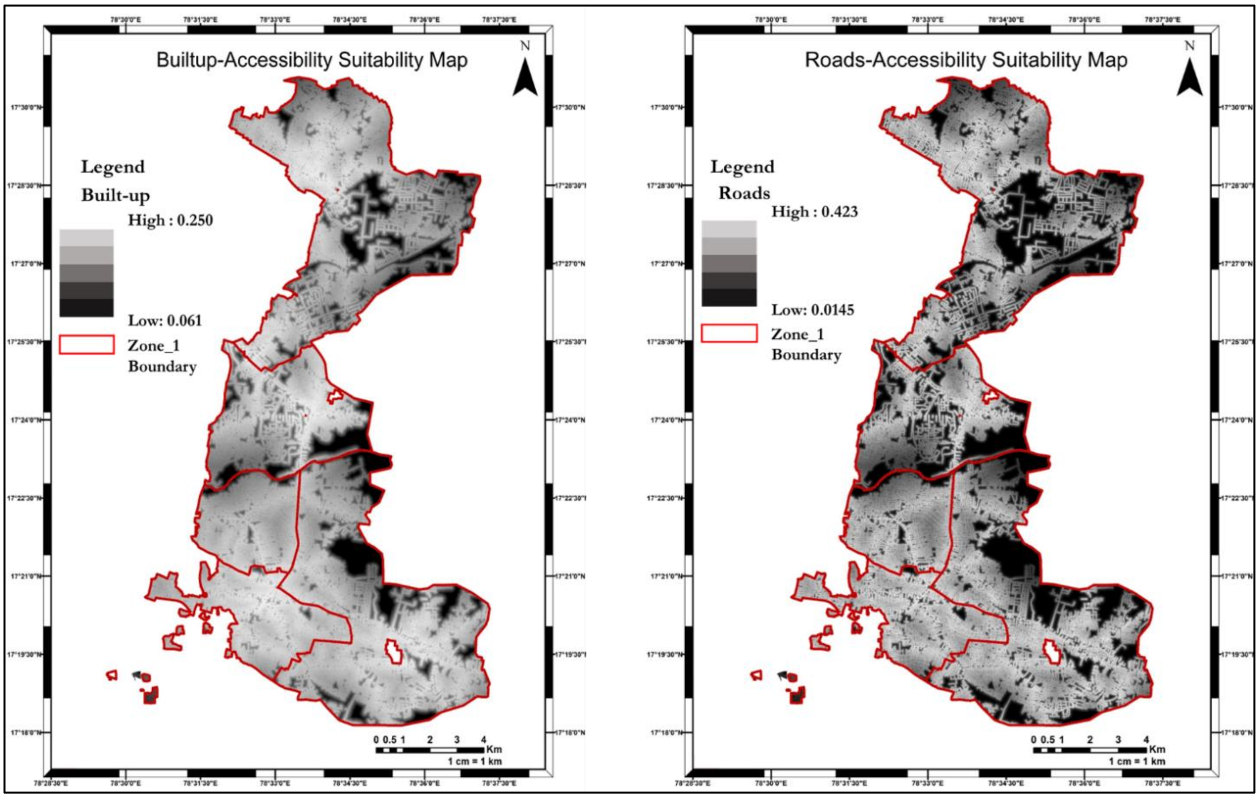
Table 12 Eight Actions of the Urban Growth Model

4 RESULTS AND DISCUSSION

The outcomes of several processes, such as suitability maps, maximum likelihood land use maps, and agent-based models, are covered in this chapter.

4.1 Land use Dynamic Model results

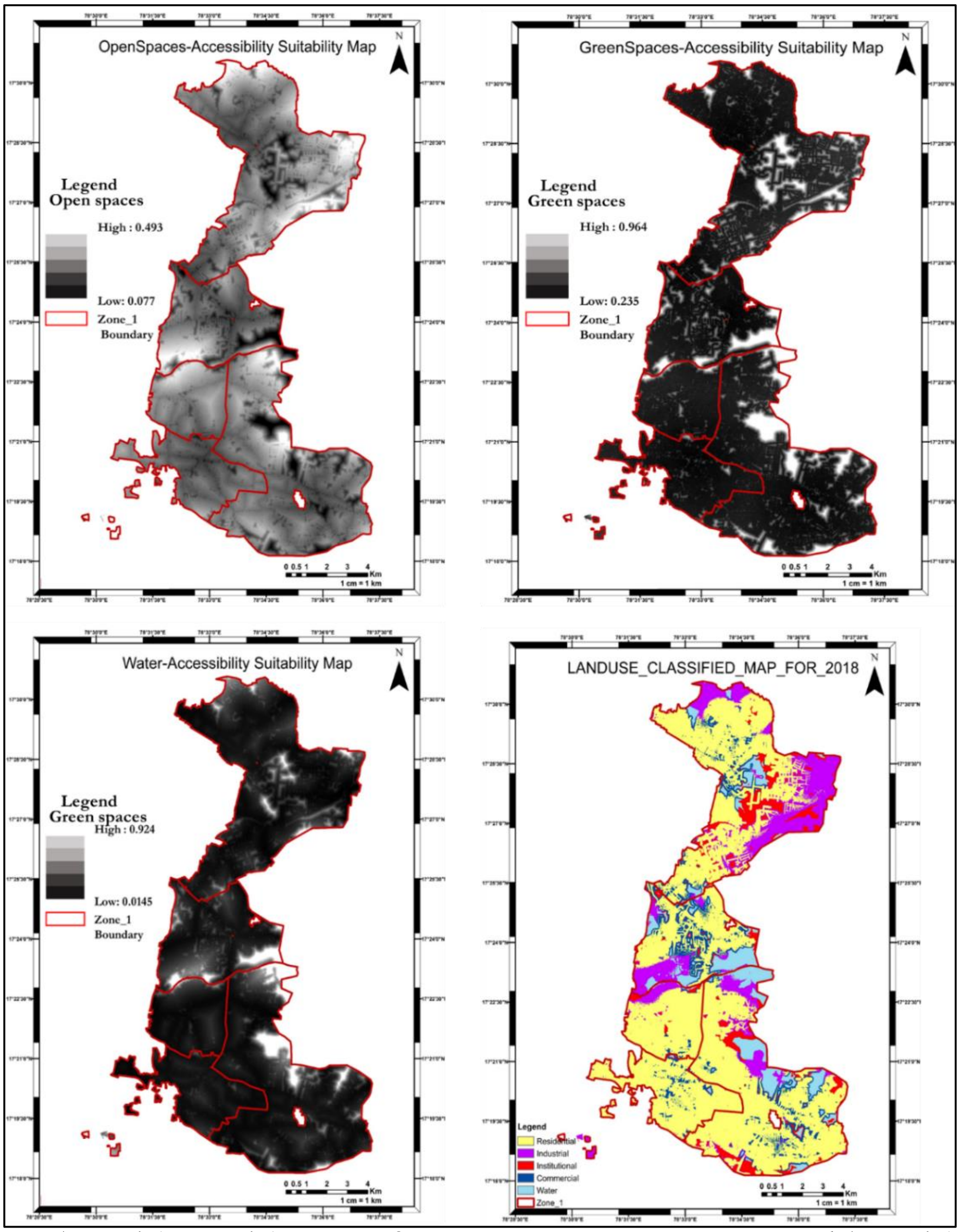
Accessibility Suitability maps for each landcover class.



Map 7 Road and Built-up Accessibility Suitability map

Suitability maps were generated using the LULC of 2016 and 2018 and distance drivers (distance to major roads, distance to local roads, distance to urban centers). These drivers were assumed to be same and constant for the predicted year(2018) because of lack of none availability of data for 2016. The suitability maps for all the five classiese were Water, Greenspaces, Built-up, Roads, and Open spaces were generated. The composite of these land cover suitability maps was used to create land use map maximum likelihood based dominant class using the maximum likelihood method. The result of it was the maximum likelihood based land use classes for year (2018). Around 250 samples for each land use class were used to determine the maximum likelihood. Previously, 2016 as time 1 and 2018 as time 2 LULC maps were also used along with drivers to prepare these suitability maps, so 2018 as time 2 year was determined as prediction year. In addition, based on information gathered from municipalities, that parcels data was only available for the 2018 year, the abm model was prepared and predicted for the 2018 year, and a classified map was prepared for the 2018 year to know the potentiality of model predicted parcels of 2018 for different land use classes.

The 2018 (prediction year) land use potential areas were finalized with the aid of maximum likelihood of the classified land use raster. Land use were assigned to the parcels by zonation method. As the classified map is accessibility-based Land use map, this helps decision makers understand growth potential of different land use as per accessibility parameter(major roads, local roads are considered as accessibility parameters).From,these maps the areas in need of utility development or extensions can be identified and used as base for preparing zonal development and mobility plans, for acquisition and development of future facility sites.These plans were not prepared in this research rather used to prepare accessibility-based Land use map of 2018.



Map 8 Accessibility suitability maps of Open spaces, Green spaces, Water and Accessibility Land use classified map for 2018.

Monitoring of land use change and conversion was identified for two years because these maps were created using two-year LULC maps and drivers that were driving towards the LULC change. Physical and socio-economic drivers was not added to prepare more realistic maps because of lack of information. The amount of effect of accessibility drivers on land use classes was drawn using co-efficient, as shown in the following coefficients table. With these co-efficients,inter relation impact of various drivers to the land use classes figures out the level of importance of each driver to each land use classes. Ongoing policies can also be included as drivers to increase, decrease, or restrict the growth of certain land use classes at a certain percentage and new policies can also be drawn according to the land use conversion rate, direction of growth and policy drivers but these policy drivers were not included because of lack of data and therefore policy based analysis was not carried out rather recommendations were given in conclusion chapter.

Co-efficient of the Drivers to the landcover classes

Drivers (Column wise)	**Distance to local roads**	**Distance to Major roads**	**Distance to Urban centers**
Land cover classes (Row wise)			
Water	4.67	2.43	-0.75
Green space	4.32	0.03	0.27
Built-up	-21.52	-1.97	-0.35
Road	-3.44	-0.51	-0.36
Open spaces	-2.02	0.81	0.64

Table 13 Logistic regression coefficients of drivers to land cover classes

These negative and positive co-efficient explains the relative influence of the driver to that respective class. Distance to local roads driver influence positively for the green space land use class and water class. Distance to major roads has positive influence on Green and open spaces land use classes and distance to urban has positive influence on green and open space land use classes.

4.2 ABM Results

This section discusses and shows the results of agent-based modelling

Year	*Newly Developed parcels	Undeveloped parcels	High density developed parcels
2016-base year	1,05,770	14,541	658
2018-SR<ST (main result)	1,08,288 (+2518)	12,019	4
2018- Reference	1619		

Table 14 Model Output Result and Comparison with Reference Data.

*Newly developed parcels are the parcels which are developed after the ABM model simulation and during the parcel generation process, undeveloped parcels were generated. During that step, 14,541 undeveloped parcels were prepared for the base year, and 2,518 of these parcels were developed during the model simulation for the 2018 year, so the remaining 12,019 parcels have a chance of development in future years. The parcels collected from municipalities in 2018 served as the reference parcels. Model output when suitability threshold was 0. 7286 and suitability low stop threshold was 0.25. For the first two years time step (2016-base year to 2018-prediction year), parcels with suitability ratings between these thresholds were developed. For next predicting year the suitability decrement determines the new threshold and new drivers for different land use, then the remaining undeveloped parcels have a chance of development.

As our research was based on agent-based urban growth modelling, the output was potential areas of various types of land use and development count and direction based on Hyderabad city planning guidelines of Residential, Commercial, Industrial, Open, and other land use classes, along with building rules of G.O 168.

Here ABM was able to simulate in both vector and rasters surfaces so, the parcel undergoes simulation on continuous surfaces such as accessibility-based rasters and Land use landcover rasters. Along with the manual input for expertise weightage, additional required fields, such as conditions, calculations and other supporting fields for these datasets that were used in the growth model during simulation creates a whole process for decision making. This process helps urban planning sector in making decision without wasting time on preparing fixed long-term statutory plans and policies, but by incorporating short-term objectives periodically based on ground truth and developing policies that take into account all perspectives' inputs and effects. ABM considers all types of rules (as per ground truth information, policies, and guidelines in the form of statistics, vector, and raster data) and this model was prepared as goal oriented.

Table 10 depicts agent-based growth model result and the newly developed parcels and undeveloped parcels from base year 2016 to predicted year 2018.The output was compared with the reference data of 2018. According to the reference data 1619 parcels were developed in total of zone and 2518 parcels were newly developed according to the Agent based modelling result. The outcome of the result was also on the basis of suitability threshold which were given according to the overall suitability rating. Around 60% of the result was accurate as per reference data. According to the ABM model output, four parcels are designated for high density development, and the remaining undeveloped parcels have a chance of developing in future years because the model simulation was conducted for two years from the base year, which was due to data availability being limited to 2018.

4.2.1 Accuracy Assessment

Accuracy was assessed on the basis of development count in each ward and through visualization. (Visualization of parcels over satellite imagery). Figure 32 shows the ward-wise comparison of newly developed parcels count over reference parcels for each ward. Based on all the calculations, conditions, and inputs for the growth model, agent-based model produced the result that 2,518 parcels out of 14,541 undeveloped parcels were developed over the course of two years. Land use classes were assigned to parcels from the classified map and the classes were Residential, Industrial, Commercial, institutional and water body.LU index values-1,2,3,4,5. These classes are assigned to newly developed parcels and now the parcels show the potential areas of the zone for various land use.

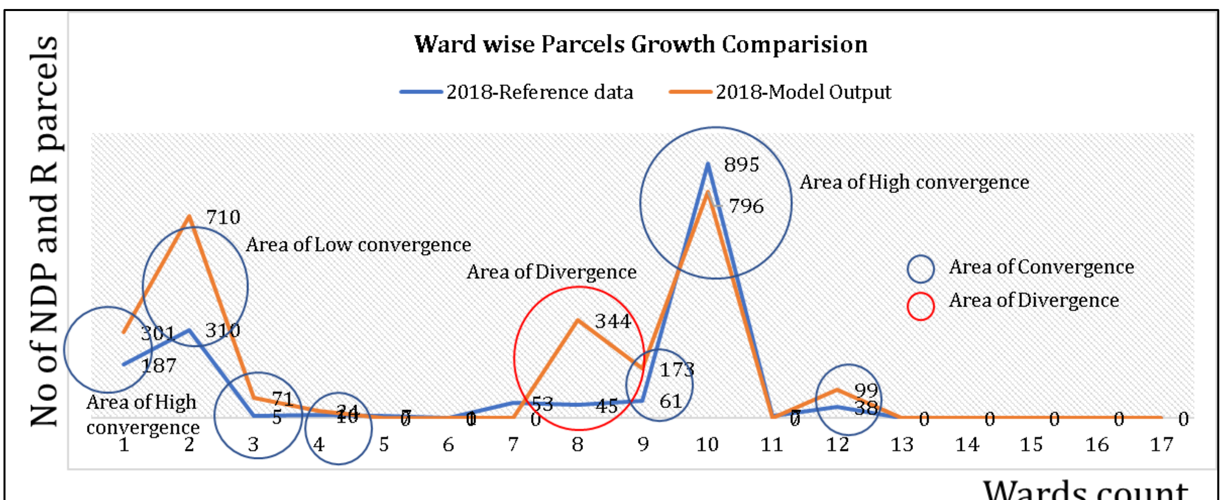


Figure 31 Ward wise Parcels Growth Comparison between reference data and Model output data

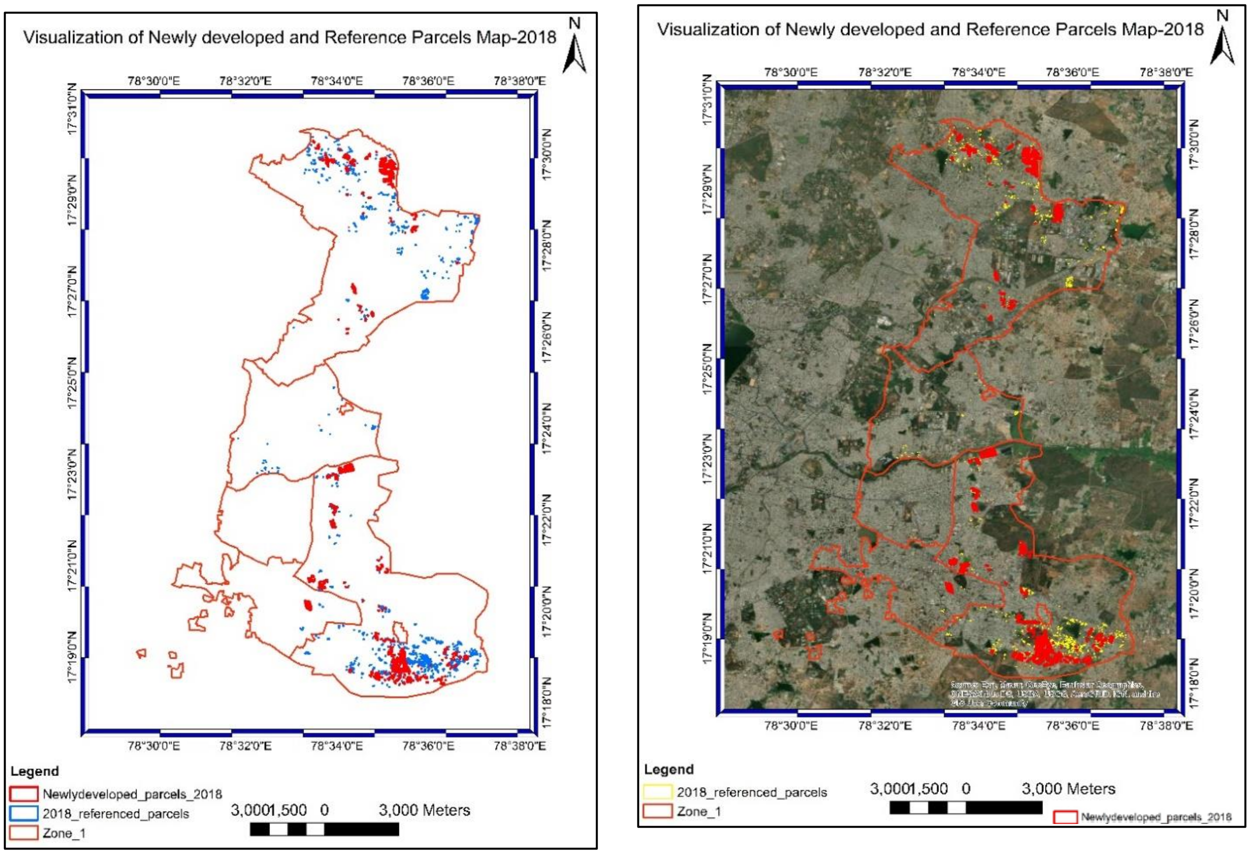
Figure 31 shows ward wise parcels growth comparison graph between reference data and model output data. NDP refers Newly developed parcels and R refers reference data parcels. X-axis has ward numbers and Y-axis has newly developed parcels (model output) and reference data parcels count. The parcels development was compared in accordance with the zone's division into 17 wards. The output accuracy of the model was measured in terms of count here. According to the graph, the model was almost correct in determining the growth rate over time. Only 12 of the 17 wards had undeveloped areas, and around 8 of these 12 wards converged with reference data count, while the remaining 4 wards diverged.

In fewer wards like 5, 6, 7 and 8 due to ward local characteristics, data management and other uncertainties divergence took place. A few parcels have grown in comparison to the reference parcels in these respective wards, and the reference indicated that there has been no growth in few wards and less growth in few wards.

This divergence obtained from the model was compared by crosschecking with population fitting in the parcels attribute category height (buildings height), Newly developed parcels according to model output were 2518 to this, population rise should be 11,331, but according to population data collected in 2018, the zone's population was greater than the reference parcels. So, it meant that the building height was more (fitting the population into the parcels was not enough as it requires more parcels to fit). To check the model accuracy in terms of population wise, was not carried out rather validated with count of parcels because of lack of building height data.

A few building parcels, such as those in Ward 8, were 45 according to the reference data, but 344 according to the model output data. Cross-checking model output data and reference data with high resolution satellite imagery revealed that around 120 parcels were more than reference data near water bodies (map 13 shows the comparison of parcels between reference data and satellite imagery). The model predicted parcels that were not present in the reference data but were present in satellite imagery. However, it was more important to stakeholders and decision-makers to limit growth near water bodies in order to avoid risks.

Wards 13,14,15,16,17 doesn't have any parcels growth as per model and reference data, with this result, model accuracy accounting of the neighbourhood effect, conditions, static, and dynamic drivers were determined. The parcels rapid growth in few wards of the zone was because of different reasons and uncertainties such as local-potential characteristics at respective areas. The uncertainty might be due to not adding of socio -economic drivers such as house income category, land values, Real estate market situations. The required analysis that was mentioned in the literature chapter such as socioeconomic survey analysis, market analysis, network analysis, and swot analysis need to be done for deciding of drivers and land use priorities. Economic base and employment, transportation (Industries-ware houses location), social infrastructure, physical infrastructure, and land use can be taken as major requirements to achieve good result and was not used for this study due to a lack of availability.



Map 9 Newly developed parcels map-2018

The above maps show newly developed parcels and reference data parcels, while the left map shows reference parcels and newly developed parcels. The red parcels are newly developed, whereas the blue parcels are reference parcels. These parcels were developed in the undeveloped areas of zone-1 in 2016 and the right-side map depicts the same but in different color code on satellite imagery.

Land use distribution over the wards of zone 1.Ward wise Parcels division and newly developed parcel's land use distribution and majority land use classes in their respective wards

1	2	3	4	5
S. NO (WARD NO)	REFERENCED PARCELS – 2018 (COUNT)	NEWLY DEVELOPED PARCELS – SR<ST- 2018 (COUNT)	NDP-LAND USE DISTRIBUTION (MAJORITY LAND USE CLASSES & WATER CLASS)	Color code
1	187	301	1>2	
2	310	710	1>2	
3	5	71	1	
4	10	24	1>2>3	
5	7	0	0	
6	1	0	0	
7	53	0	0	
8	45	344	2>1>4>5	
9	61	173	1>2>3	
10	895	796	1>2>4	
11	7	0	0	
12	38	99	1	
13	0	0	0	
14	0	0	0	
15	0	0	0	
16	0	0	0	
17	0	0	0	

Legend

1. Residential
2. Industrial
3. Institutional
4. Commercial
5. Water

Residential > Industrial

Residential > Industrial > Institutional

Residential > Industrial > Commercial > Waterbodies

- Residential
- Industrial
- Waterbody
- Greenspaces
- Open spaces
- Institutional
- Commercial

Figure 32 Ward Wise Parcels division and newly developed parcel's land use distribution and majority

Figure 32 depicts the dominance of land use classes and water land cover classes in their respective wards. The land was occupied by the residential, commercial, and industrial land use classes, as well as the water land cover class. Column 2 is reference parcels;3 is newly developed parcels. Among 12 wards, majority of the development was of residential class followed by industrial class and followed by institutional class and water bodies. In 8th ward industrial class had more percentage of growth followed by residential, institutional and water body, The reason for industrial land use class taking majority in this ward was because of water body (in detail please check potential Flood Risk locations for Proposed Land use (map 13)). With the help of this distribution table, potential locations got to knew for individual land use classes across the Zone-wide and the policies and plans can be framed accordingly to the zone.

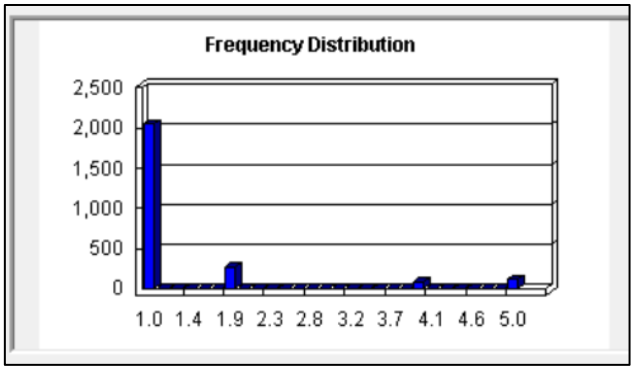


Figure 33 Newly developed parcels land use distribution

Figure 33 depicts the land use distribution across the entire zone. Residential land use accounts for the highest percentage of land use in the zone, followed by Industry, Commercial, and Water. This distribution was compared to the base year land use break-up (fig-2 in the Introduction chapter) as well as the standard (table-2) mentioned in the literature chapter in order to determine the land use percentage change of development and to determine whether or not the development met the standards. Residential class and Industrial class had potential to grow in the region as per base year (2016) land use and according to the model output, these two classes share a higher percentage of potential to grow in 2018.

The amount of land use growth had been compared between the base year (2016), the predicted year (2018), and with the standards land use percentages.

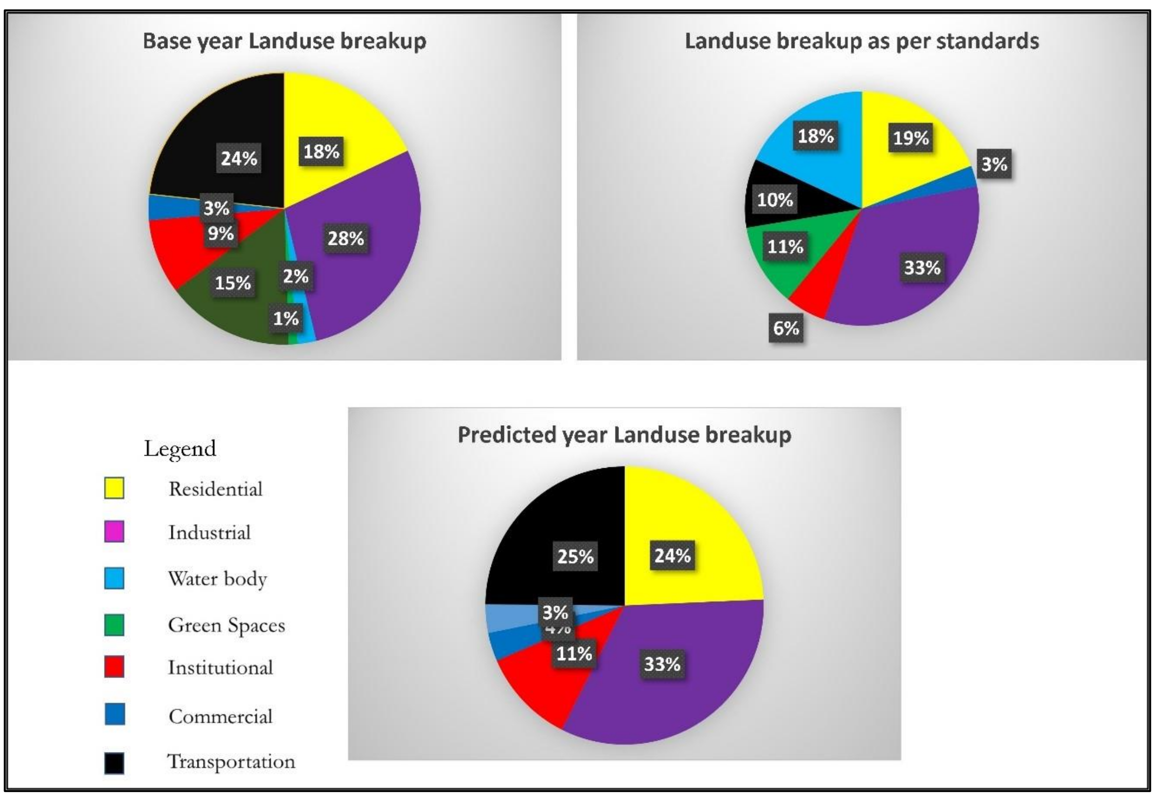


Figure 34 Land use growth comparison

Figure 34 shows the pie charts representing the land use percentage of predicted year compared with base year and standards of zone 1. When base year land use compared with standard, then found that residential land use class and Industrial land use class has higher potential to grow in the zone. As per the model output these two classes shared a higher percentage of potential grow in 2018 and followed by transportation and institutional classes. This model's output can be used to develop policies, adjust land use growth to meet future needs, and limit growth while keeping sustainability in mind.

4.2.2 Potential Locations for different land use across the zone

Potential locations for Residential Land use

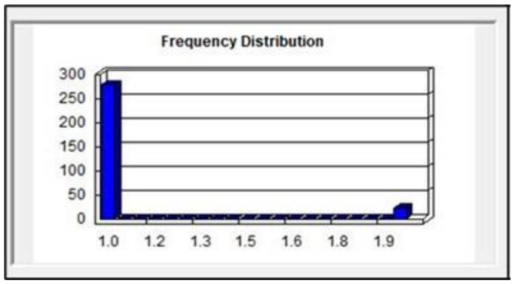
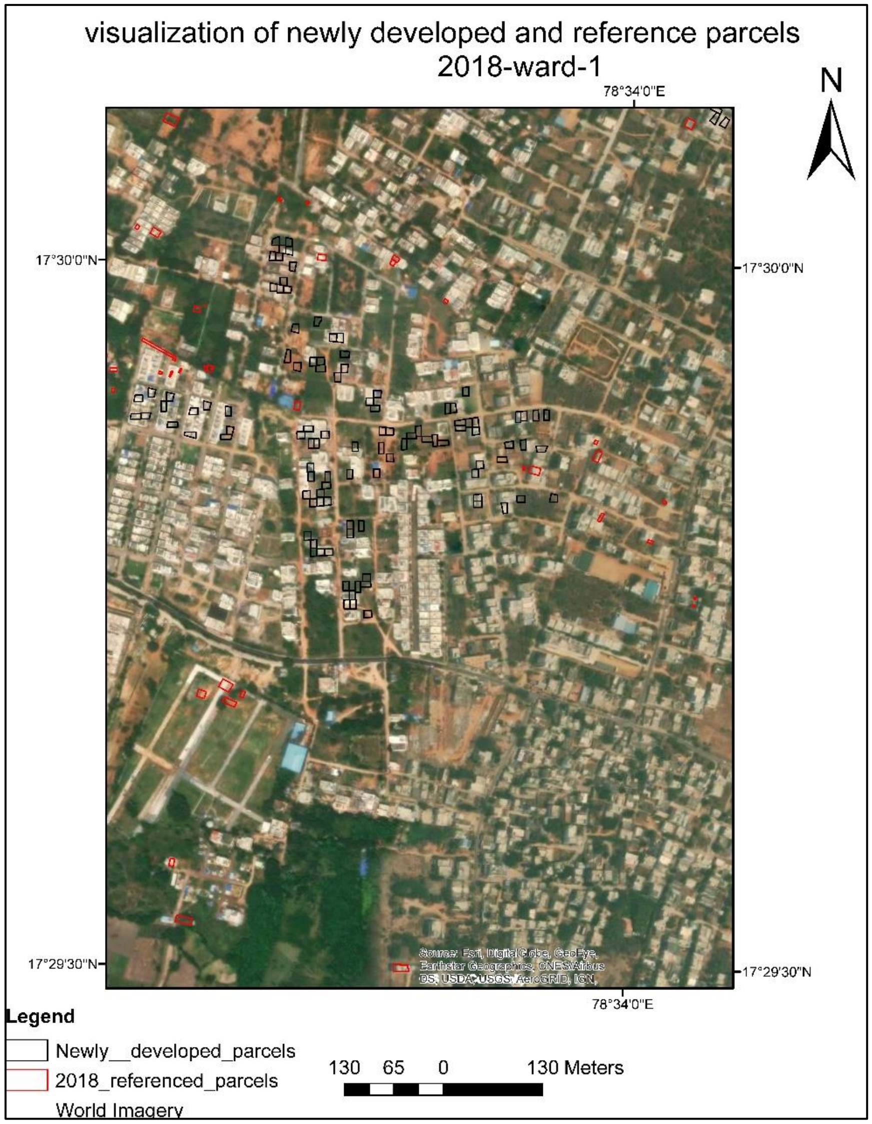


Figure 35 ward1-landuse class distribution

The potential expansion of land use in Ward 1 is depicted in Figure 35 The residential and industrial classes have grown in Ward 1.

Visualization Accuracy

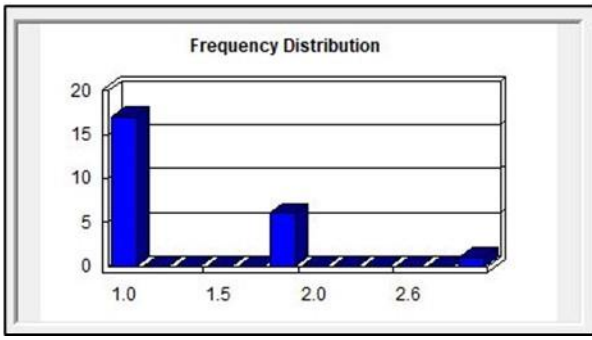


Map 10 Ward1 Newly Developed parcels overlaying on satellite imagery

To validate the model output parcels, an Arc map base map layer (imagery) was used. Overlaying newly developed parcels on satellite imagery demonstrates that the model output result was nearly correct, as the majority of the parcels were perfectly overlaying on the satellite imagery parcels (building), and those parcels were also developed.

When the newly developed parcels were superimposed on the reference parcels and satellite imagery, they fell on and around the reference parcels but almost overlapped on the satellite imagery buildings, indicating that the model decision was nearly correct in terms of the ward's 1 growth potential.70% of newly developed parcels perfectly overlayed on satellite imagery parcels in this ward. Due to parcel area or size differences, the remaining parcels were outside the building boundary of satellite imagery.

Ward-4



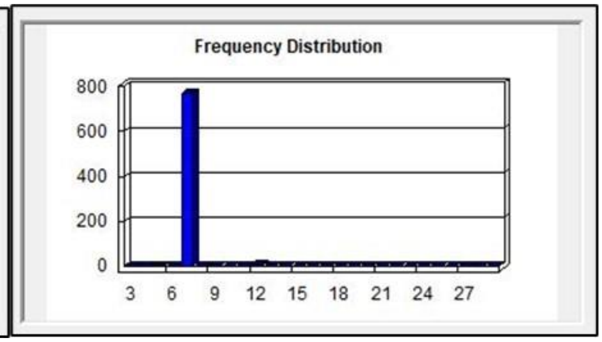


Figure 36 Newly developed parcel's Land use distribution chart and Road network relation chart

The Land use Distribution across ward-4 is explained in the left side histogram. The right-side histogram shows Road type distribution in ward 4 having a majority of 7m width road width and a small amount of 12m road width was observed, 7m road considered as residential street width according to the IRC (Indian road congress). Here from the model output, it can be concluded that growth percentage in ward 4 came as appropriate with road network standards. (It means residential land use class is growing along with 7m road network).The land use histogram and satellite imagery indicate that these are potential residential land use locations in this ward.

Ward-2

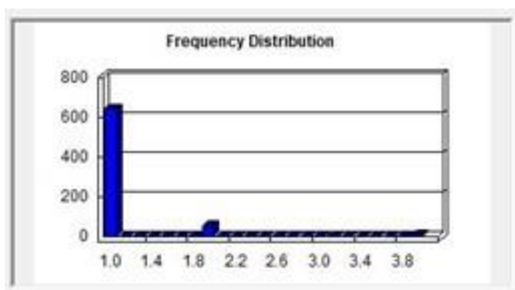
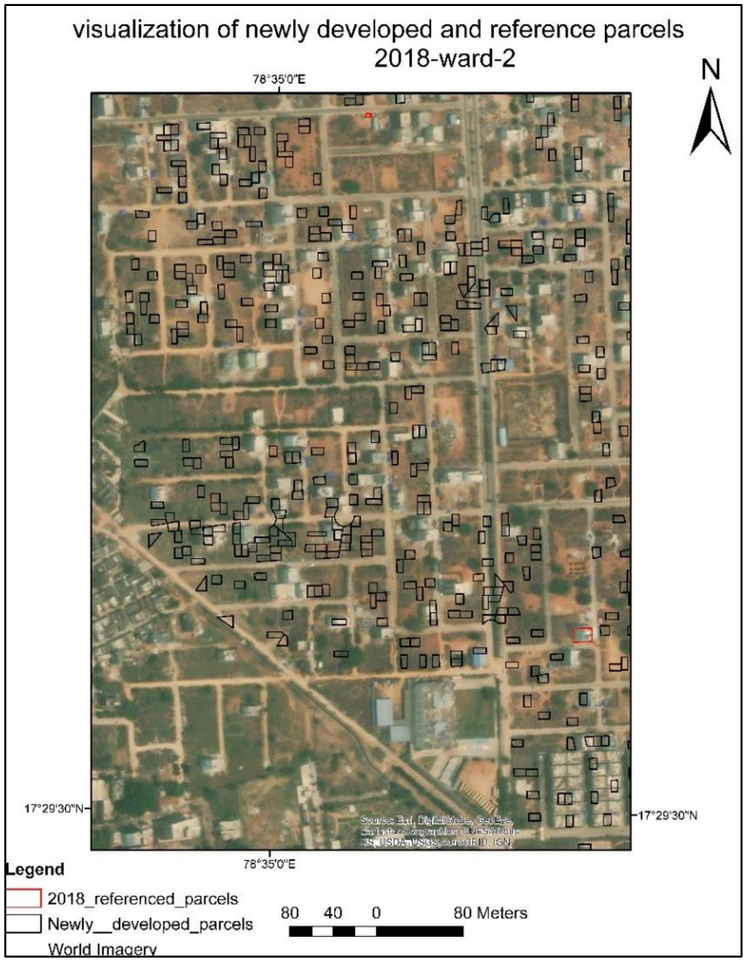


Figure 37 Land use growth distribution in ward -2

Figure 37 shows the land use distribution of ward 2. As per the histogram, Residential class had grown in this ward followed by industrial class. Below map shows the growth of parcels on satellite imagery of ward 2.



Map 11 Reference parcels and model output parcels of a part of ward 2.

Map 11 depicts the reference parcels and model output parcels, as per the model output 710 parcels were developed in ward 2. As per map 11 the model output, maximum number of parcels were properly falling(overlaying) on ground truth. Reference parcels were not many in this portion of the ward, this might be due to lack of updating the reference data sets as per real time, but model predicted almost correct as per the satellite imagery in terms of visualization. Decision makers will be able to predict future potential areas and parcel locations using this information for different land use classes. Building height restrictions and haphazard growth can be controlled in advance using these results.

Potential locations for Industrial Land use- Ward-10

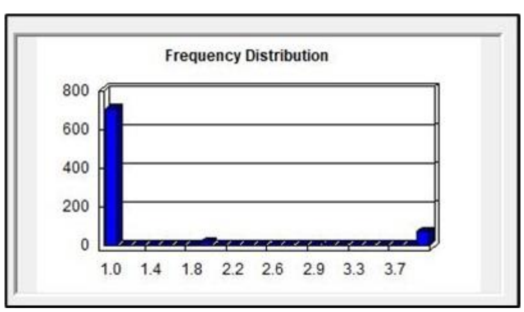
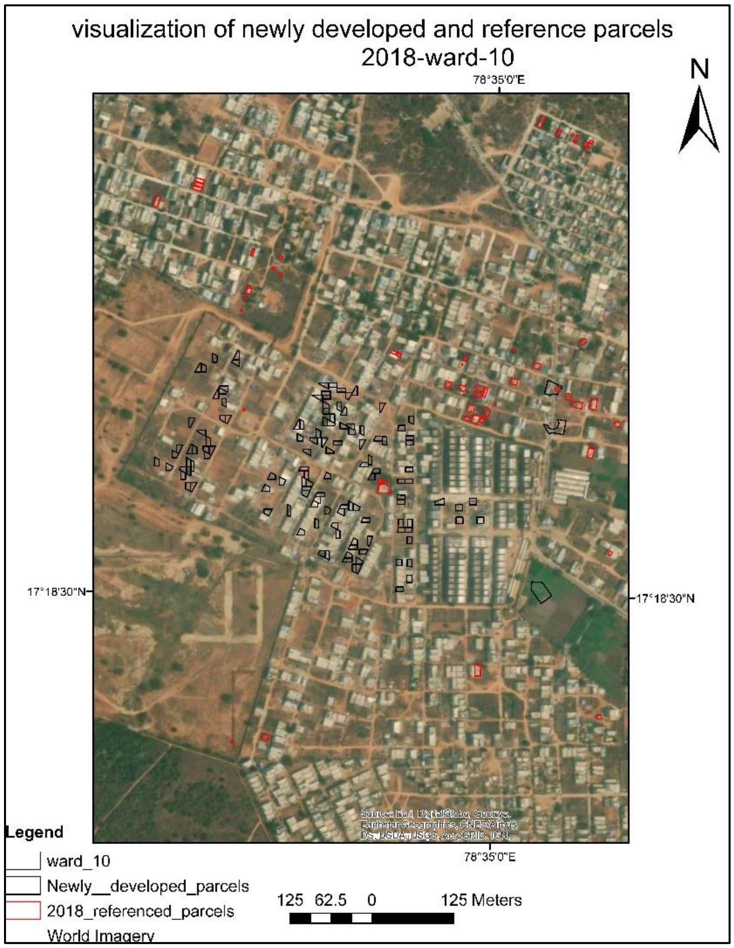


Figure 38 Land use distribution in ward 10

Total of 796 parcels are developed in ward 10, As per fig 38 residential land use had higher growth followed by institutional and industries.



Map 12 Newly developed Residential and Industrial parcels of ward-10

Map 12 depicts newly developed parcels, reference parcels overlayed on satellite imagery. The parcels that were developed are industrial as per model, here parcels with an area greater than 3000 square feet were developed as Industries, whereas parcels with the industrial Land use category but less than 3000 square feet are considered second-level industries or small-scale industries. This calculation was made using previously developed parcels of industrial land use in 2016. The average mean site area was 2239 square feet, with a maximum value of 196526 square feet and a minimum of 500 square feet.

These constraints, such as the suitability score threshold, large area development probability, and LU allocation, resulted in good output for industrial growth. Model output was almost correct in this ward according to satellite imagery observation (fig 40) ,the newly developed parcel count and these parcels around industries of base year. Using the constraints and parcel area rules listed above, the model identified industrial potential locations in the undeveloped areas around the industries.

The locations of newly developed parcels of industrial class from model output were depicted in map 12 and figure 40, newly developed industries were not fully overlayed and apart from the reference data, new industries were developed at various locations. This might be due to industries parcel's size difference from reference data or a sudden change in policies at the ground level in this area.

Uncertainty at this point can be resolved with proper primary surveying and real-estate market analysis. Including these analyses as drivers for predicting suitability and decision-making aids in obtaining accurate real-time results.

Future potential industrial land use locations

Figure 39 Potential locations of Industrial Land use in ward 10, Newly developed industrial parcels, which have potential to develop in future.

Figure 39 shows the potential location of industrial land use in ward 10, majority of the parcels were overlapped properly on satellite imagery building parcels, few were developed in open areas as the potential locations for future development or because of model uncertainty (the size of parcels for large industries were not properly given during the simulation).

Potential Flood Risk locations for Proposed Land use

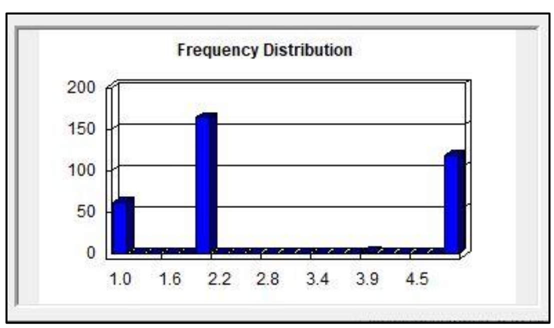
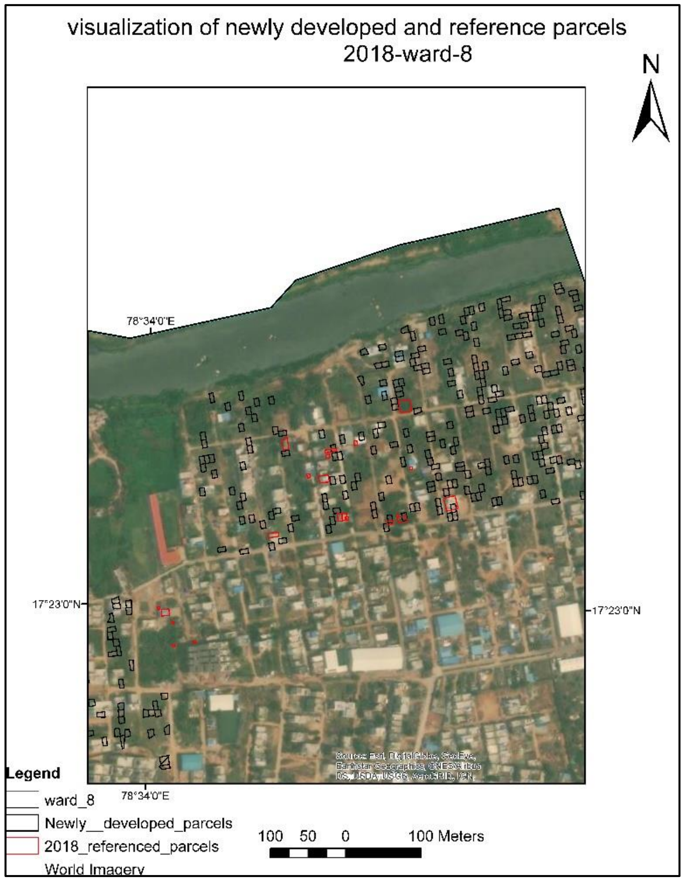


Figure 40 Land use Distribution of ward 8



Map 13 Newly developed parcels in ward 8 and
Potential risk locations of proposed land use of ward

According to the histogram (fig 40), the Industrial land use class is expanding relative to other land uses. Based on the size of the parcel that had grown, developed parcels were classified as second-level industrial land use, i.e small scale industries. The second major distribution category was water, so the parcels in this ward considered as small-scale industries that require more water for manufacturing or for other purposes. However, according to satellite imagery, these parcels were very close to the water body and thus fall within the danger buffer zone of 150-300m. These parcels were at risk of flooding as per the model. (Refer map 13)

The map 13 depicts the flood risk area and location of potential land uses. The parcels' risk location was predicted by the model. According to the reference data, only 45 parcels were developed in this area, but according to the model, 344 parcels were developed. This could be due to the reference data not being updated in real time, and also according to the figure41 industrial parcels were developed more in this area, and these were classified as small-scale industries that require water for production or to dump wastewater into the water body. Despite the fact that a body of water is nearby, the newly developed parcels were expanding. This falls under flood risk areas for proposed land uses.

Other than the risk zone, this area may be a focal point for water pollution. Environmental planners and decision makers can make environment impact assessment for the area and industries and segregating them as per pollution index categories and make the necessary changes.

5 CONCLUSION AND RECOMMENDATIONS.

Dynamic data, such as LULC(land use land cover) data, helps to prepare different scenario mapping of land cover and these LULC maps are more real and dynamic in nature as these are prepared with signature values of different LULC classes. LULCC is one of the major factor to find the growth momentum of a region and this can be determined by studying the temporal classification LULCC data of different years.

These LULC changes are the result of physical, economic, and other static and dynamic drivers. These drivers are derived from ground truth, distance calculations, policy involvement, political interference, and so on. This also gives the impression of a continuous growth direction.

On a city-wide scale, we can monitor the growth of Land Use. The first step is to consolidate all development sections into a single database. All data, both spatial and non-spatial, must be merged and linked to the database, from which permissions to access the required information in the other section can be granted. This procedure should be mandated wherever possible. This enables us to store, access, update, and fill data gaps, as well as serve as a single database platform. This enables development authorities to keep track of what is going on. Keeping and updating records of properties such as buildings, which include building structure, residing population, building usage in terms of categories such as Residential, Commercial, Industrial, Public Space, and also subcategories of these.

For this research, zonal characteristics, ground truth data, and time bound are considered to prepare and use in the model's parameters and functions. The agent based urban growth model ,which is decision-making model produced positive results for the study area as it operated on both static and dynamic agents. Realistic parameters, precise potential maps, and the ability to examine the type of development on a smaller scale allow models to be more sophisticated while remaining simple to use. According to model output, the predominant land use potential of maximum percentage of parcels is residential use and industrial use based on the norms considered.

By, this dynamic vector based cellular automata model, Planners and decision makers can investigate many situations for future potential development. Town officials can plan for possible expansion in their city more effectively if they have a better understanding of how the various suitability criteria interact.

For the model to produce more accurate results, additional conditions and constraints are required, such as, Water can be used for industries based on their industrial category, but it must not be contaminated. Open spaces are required for industries to deposit their trash and establish a collection and segregation system at that level. Policies which are given to implement in the municipality need to be consider in model, which can gve an idea of success and failure.

Since logistics, warehouses, and transportation are needed in the industrial zone, major roads are crucial. We need a large number of commercial sectors along major routes and for sales and marketing, so we must control growth and make appropriate plans because there aren't enough emergency facilities for fire safety and accidents, including medical infrastructure and health care.

Major roads are important in this zone, and an origin and destination survey of households is necessary to determine how many HH use these primary and secondary roads and to what extent. A traffic volume survey is also required to collect data on the vehicles (modes of transport (LMV,HMV) that pass and use these roads at what time and how many times. With this information, a matrix table with vehicle types to the number of industries and also type. Taking this as a transportation and network analysis, it helps to understand the generation of required roads and the formation of rules and regulations that require heavy motor vehicles

(HMV) to use only specific roads such as the Hyderabad's ORR(outer ring road) only at night. This reduces traffic congestion during day while also ensuring traffic safety.

The travel behaviour is created by connecting the road network with agents and land use patterns, as the agents (here agents are people) are dynamic in nature and use the network to reach their destinations (land use spaces). Here, the agents' generation and distribution patterns are studied using the aforementioned process and linked to the model, where rules and movement patterns assigned to the agents create a movement model, which helps decision makers understand the frequency of agents visiting these spaces and how the agents' behaviour changes when a minor change in the surrounding land use occurs. These moving pattern models generate scenarios for drivers based on distance, pattern movement, road type, floating population, and so on.

6 REFERENCES

Abdul Hussein Bedewy, B., Hassan Alwan, K., & Kamel Fleeh, M. (2021). Dynamic Urban Modelling for Urban Growth Varieties and Transport : Building A Complex Dynamic Model. *IOP Conference Series: Earth and Environmental Science*, *754*(1). https://doi.org/10.1088/1755-1315/754/1/012007

Analyst, A. (2013). *pdfcoffee.com*. Esri. pdfcoffee.com

Barros, G. (2010). Herbert A. Simon and the concept of rationality: Boundaries and procedures. *Revista de Economia Politica*, *30*(3), 455–472. https://doi.org/10.1590/S0101-31572010000300006

Batty, m. (2009). *Urban Simulation Models: Contributions as Analysis-Methodology in a Project of Urban Renewal.*

Becker, F. G., Cleary, M., Team, R. M., Holtermann, H., The, D., Agenda, N., Science, P., Sk, S. K., Hinnebusch, R., Hinnebusch A, R., Rabinovich, I., Olmert, Y., Uld, D. Q. G. L. Q., Ri, W. K. H. U., Lq, V., Frxqwu, W. K. H., Zklfk, E., Edvhg, L. V, Wkh, R. Q., …)2015. (ح, فاطمی. Agent-Based Modeling in ArcGIS. In *Syria Studies* (Vol. 7, Issue 1). https://www.researchgate.net/publication/269107473_What_is_governance/link/548173090cf22525dcb61443/download%0Ahttp://www.econ.upf.edu/~reynal/Civil wars_12December2010.pdf%0Ahttps://think-asia.org/handle/11540/8282%0Ahttps://www.jstor.org/stable/41857625

Bolman, L. (n.d.). *Reframing organizations: Artistry, choice, and leadership.*

Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences*, *99*(suppl_3), 7280–7287. https://doi.org/10.1073/pnas.082080899

Carra, G. (2018). *Evolution of urban systems : a physical approach To cite this version : Giulia Carra Evolution of urban systems : a physical approach.*

cdema.org. (2016). *Mapping buildings from satellite images*. https://www.cdema.org/virtuallibrary/index.php/charim-hbook/use-case-book/7-exposure-and-vulnerability/7-4-mapping-buildings-from-satellite-images

Douglas Samuelson and Charles Macal. (2006). *REPAST AGENT SIMULATION KIT*. Lionheart Publishing. http://repast.sourceforge.net/repast_3/

Government of Andhrapradesh. (2012). G.O 168 Building rules. *Government of Andhrapradesh*, *29*(17 2).

Grant, M., & Paterson, I. (2022). Urban Modelling. *Proceedings of the 12th International Conference on Education and Research in Computer Aided Architectural Design in Europe (ECAADe)*, 135–139. https://doi.org/10.52842/conf.ecaade.1994.135

Gross, M. (1982). The Lowry model of land use simulation and its derivatives. *Computers, Environment and Urban Systems*, *7*(3), 197–211. https://doi.org/10.1016/0198-9715(82)90007-2

Haynes, K. B. (2020). *The Urban Morphology of Hyderabad, India: A Historical Geographic Analysis*. *June*. https://scholarworks.wmich.edu/masters_theses

HMDA. (n.d.). https://www.hmda.gov.in/

ITC. (n.d.). *Living Textbook | Spatial-Temporal data model | By ITC, University of Twente*. https://ltb.itc.utwente.nl/page/483/concept/79214

Jha, A. K., Ghosh, S. K., Srivastav, S. K., & Saran, S. (2022). OpenLDM: Open-Source Land-Use and Land-

Cover Dynamics Modeling Platform. *Journal of the Indian Society of Remote Sensing*, *50*(6), 1071–1086. https://doi.org/10.1007/s12524-022-01516-9

Kelly, T. (2021). *CityEngine : An Introduction to Rule-Based Modeling*. Springer Singapore. https://doi.org/10.1007/978-981-15-8983-6

Kevin B. Haynes, M. S. (2020). *The Urban Morphology of Hyderabad, India: A Historical Geographic Analysis*. Western Michigan University.

Kim, D. (2012). *Modelling Urban Growth : Towards an Agent Based Microeconomic Approach to Urban Dynamics and Spatial Policy Simulation Centre for Advanced Spatial Analysis Bartlett School of Planning Bartlett Faculty of Built Environment University College London*.

Lahti, J. (2008). Modelling Urban Growth Using Cellular Automata: A case study of Sydney, Australia. *Transport*. http://www.itc.nl/library/papers_2008/msc/gem/lahti.pdf

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, *28*, 205–241. https://doi.org/10.1146/annurev.energy.28.050302.105459

Li, X., & Gong, P. (2016). Urban growth models: progress and perspective. *Science Bulletin*, *61*(21), 1637–1650. https://doi.org/10.1007/s11434-016-1111-1

Manzo, G. (2014). Potentialités et limites de la simulation multi-agents: Une introduction. In *Revue Francaise de Sociologie* (Vol. 55, Issue 4). https://doi.org/10.3917/rfs.554.0653

Matthews, R. B., Gilbert, N. G., Roach, A., Polhill, J. G., & Gotts, N. M. (2007). Agent-based land-use models: a review of applications. *Landscape Ecology*, *22*(10), 1447–1459. https://doi.org/10.1007/s10980-007-9135-1

Morgan, F. J., & Sullivan, D. O. (2009). Residential developers : Competition , behaviour and the resulting urban landscape. *Proceedings: 10th International Conference on GeoComputation*, *1990*.

MOUD, I. (2014). *URDPFI*. https://mohua.gov.in/upload/uploadfiles/files/URDPFI Guidelines Vol I(2).pdf

NBC. (2016). *National Building Code of India 2016 (NBC 2016)*. https://www.bis.gov.in/index.php/standards/technical-department/national-building-code/#:~:text=The National Building Code of,Code for adoption by all

Ozdilek, O., & Seker, D. Z. (2004). A web-based application for real-time GIS. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *35*.

Prabhudesai, A. V., & Viswanathan, C. V. (1978). Mathematical modelling of urban systems in Nigeria. *Chemistry and Physics of Lipides*, *22*(3), 71–77.

Shi, W., Goodchild, M. F., Batty, M., Kwan, M.-P., & Zhang, A. (2021). *The Urban Book Series*. http://www.springer.com/series/14773

Terra Economics and Analytics Lab. (2019). *MASTER PLAN*. https://www.tealindia.in/

Torrens, P. M., & O'Sullivan, D. (2001). Cellular Automata and Urban Simulation: Where Do We Go from Here? *Environment and Planning B: Planning and Design*, *28*(2), 163–168. https://doi.org/10.1068/b2802ed

Tran, Q., & Tian, Y. (2013). Organizational Structure: Influencing Factors and Impact on a Firm. *American Journal of Industrial and Business Management*, *03*(02), 229–236. https://doi.org/10.4236/ajibm.2013.32028

Vanegas, C. A., Kelly, T., Weber, B., Halatsch, J., Aliaga, D. G., & Müller, P. (2012). Procedural Generation of Parcels in Urban Modeling. *Computer Graphics Forum*, *31*(2pt3), 681–690. https://doi.org/10.1111/j.1467-8659.2012.03047.x

Wahyudi, A., & Liu, Y. (2015). Spatial Dynamic Models for Inclusive Cities: a Brief Concept of Cellular Automata (CA) and Agent-Based Model (ABM). *Jurnal Perencanaan Wilayah Dan Kota*, *26*(1), 54–70. https://doi.org/10.5614/jpwk.2015.26.1.6

Wang, S. W., Gebru, B. M., Lamchin, M., Kayastha, R. B., & Lee, W. K. (2020). Land use and land cover change detection and prediction in the kathmandu district of nepal using remote sensing and GIS. *Sustainability (Switzerland)*, *12*(9). https://doi.org/10.3390/su12093925

Wolfel, R. (2021). Urban Modelling | Encyclopedia. *E Scholarly Community Encyclopedia*, 9–10. https://encyclopedia.pub/179

Yeh, A. G. O., & Li, X. (2002). A cellular automata model to simulate development density for urban planning. *Environment and Planning B: Planning and Design*, *29*(3), 431–450. https://doi.org/10.1068/b1288

APPENDIX

Datasets

Datasets used at different phases of Research.

1. Data set of Hyderabad master plan and non-spatial attributes of the area.
2. Land use land cover classes (vector data) such as Residential, Commercial, Industrial, Institutional, water bodies, Open spaces, Greenspaces, Roads along with parcel (building) level footprints.
3. LULC maps of 2016, 2018, 2020 and Raster files of drivers such as Proximity drivers (Distance to Major roads, Distance to Local Roads, Distance to urban centers). Socio economic driver -Population, Population density, Physical drivers (Height of buildings, area and road width).
4. Planet imagery(3m), sentinel imagery (10m) of 2016, 2018, 2020.

Dataset	Consists of	Source
Land use map and GT attribute data and policies.	Local development plans, land use maps, land parcels vector data details and their attribute data.	Municipalities administration offices
Satellite data	Satellite imagery of required year (2016-2018-2020). Very High-resolution satellite images	Planet and Sentinel 2A

Table 15 Data set sources and status; Source: Author

Table 15 explains about the datasets and their source which were used in the research.

Software tools and modelling applications used are Arc-GIS Pro, QGis, Dbms, Erdas, Python, Cellular Automata Model, OpenLDM, Agent Analyst, City Engine, R Studio and other open source softwares.

Vector Datasets-Municipality (Ground Truth datasets)

Land parcels.

Roads-OSM

Urban centres locations-Municipality and Ground collected data.

The various attributes for the generation, segregation, and augmentation of newly generated parcels were prepared using these vector datasets.

Raster Datasets-Satellite datasets.

Sentinel-2A datasets from the years 2018, 2020, with a resolution of 10 m, were used. Sentinel-2A was launched on June 23, 2015, but for our study area imagery was not available for year 2016. Therefore, Planet imagery, with 3m resolution, was used for 2016. The 3m imagery was rescaled to 10 m resolution to match the sentinel-2A resolution. The Sentinel-2 carries the Multi Spectral Instrument (MSI). However, RGB bands were used for this research to have synergy between Sentinal and Planet Labs' derived data.

These satellite derived datasets were used to prepare LULC maps and along with other required drivers.

Drivers' used in the study

Physical drivers	Location and accessibility drivers	Institutional characteristics
	Distance to roads and transit-oriented development.	Governmentally imposed boundaries and content of regulations
Distance and buffer water bodies and Natural features	Distance to Urban centers	Size of individual parcels under separate ownership
-	Population density.	Infrastructure services

Table 16 Driver's selection for the research Source: Author

The above table explains about the selection of various drivers, which were utilized in the current study.

Classification of drivers as per different environments.

Classification	Driving Factors	Level-1
Natural Environment	Topography	Slope Distance to Water body
	Amenity	Distance to Green and Open spaces
Built Environment	Transportation	Distance to Local roads Distance to Major roads
	Land use	Distance to Urban center
Socio-Economy		Population Density. Land use plan Parcel status and attributes

Table 17 Classification of driver's

Source: (Wang et al., 2020)

Table 17 represents classification of drivers in three different levels such as Natural Environment, Built environment and socio economy, which consists of physical features, distance parametric drivers and administrative drivers, amongst which few drivers were utilized in the current study.