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AN EXPLORATION ON THE PREDICTION OF URBAN EXPANSION WITH CELLULAR AUTOMATA AND GEOSPATIAL DATA

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ABSTRACT

Using cellular automata and geospatial data, this project intends to forecast and analyse the growth of urban areas in India. The study covers a wide range of geographical locations in India, from rural areas to large cities like Bangalore, Kolkata, and Mumbai. Landsat and Sentinel satellite images, Digital Elevation Models (DEM), and information from government organizations like the Survey of India and the National Remote Sensing Centre (NRSC) are all part of the extensive geospatial data collection used in the research.Extensive data collecting and pre-processing are part of the methodology, which integrates multiple datasets to find areas with notable urbanization patterns. The modelling approaches used by cellular automata take into account a number of variables as inputs, including land use and land cover classifications, population density, economic indicators, and infrastructural development. Making better decisions on sustainable urban development and land management techniques is made possible by the study's insights into the drivers and patterns of urbanization, which include several geographical and climatic zones within India. The findings show a LULC map of Zhejiang Province from 1995 to 2020, with forest areas prominently displayed. There have been swings in arable land, a steady loss of forest acreage, and a meteoric rise in urban areas, according to the statistics. The study's overarching goal is to shed light on the processes of

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urbanization so that sustainable development approaches can be better implemented throughout India's varied topography.

Keywords: *Classic urban models, Cellular Automata (CA) models, Faults of conventional models, Principles of CA-based urban growth modeling, Problems associated with CA models*

1. INTRODUCTION

The rate of urbanization in India is accelerating at an alarming rate. Over the course of the past ten years, the urban population of India has expanded from 217.6 million to 285 million, and it now accounts for 27.8 percent of the country's overall population. It is anticipated that by the year 2021, thirty percent of the overall population of India would be comprised of this demographic. Cities, on the one hand, serve as engines of economic expansion, but on the other hand, they are accompanied by environmental degradation. This is because the surrounding agricultural areas, forests, and surface water bodies are turned into urban uses and are irretrievably lost. Urban growth has two conflicting aspects: on the one hand, cities act as engines of economic progress. Within the context of these significant adverse effects, there is an immediate requirement for urban planners to build models that can accurately estimate the rise of metropolitan areas. The purpose of these models is not only to provide an understanding of the process of urban expansion, but also to provide realizations of the different alternative growth scenarios that an urban region may take in the future. This kind of information may be very helpful in regulating the growth of urban areas, and it can also be used to properly prepare for the places that will be more suitable for urbanization in the future. Despite the fact that the traditional approaches to urban modelling are founded on strong theories, they suffer from key flaws such as insufficient handling of space-time dynamics, coarse encoding of data, and a top-down approach, which ultimately fails to generate accurate simulations of urban systems.

1.1 Traditional models of urban growth

A number of hypotheses and models have been advanced to account for the expansion of cities from the early nineteenth century. The central portion of a city would develop into a number of concentric zones of different land uses, according to Burgess's Concentric Zone Theory. But, several theories were developed in response to inconsistencies between the Concentric Zone Model and the distribution of urban land use patterns in reality; one of the most prominent of these was the Sector Theory put forth by Hoyt and Davie. Road networks extending outward

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from the city centre altered patterns of urban land use, according to this notion. The urban land use pattern was shaped by the sectoral pattern of land values that was established by the accessibility of highways. The real pattern of urban growth is typically significantly more complicated and varied than what either the Concentric Zone Theory or the Sector Theory predicted. Both theories, however, assumed that the city grew around a single centre. Hence, the Multiple-Nuclei Theory, put out by Harris and Ullman, postulated that, instead of a single nucleus, multiple nuclei were responsible for the urbanization of big cities. Therefore, in an effort to develop all-encompassing models of urbanization, these theories were utilized. All of these ideas attempted to graphically depict the spatial layout of urban socio-economic systems, but none of them were completely adequate because they were static and inflexible.

2. LITERATURE REVIEW

Xu, T., et.al., (2022) employed a high-temporal-resolution land use dataset to integrate ANN, CA, and MC in order to accurately model urban expansion in a zone that is quickly increasing. An essential part of managing scarce land resources and fixing ineffective land use policies is accurately modeling and forecasting the process of urban expansion, particularly in places experiencing rapid urbanization. An ANN-generated urban suitability index (USI) map was then input into CA-MC to locate cells that could undergo a change-to-urban transformation. For this comparison, two artificial neural networks (ANNs)—the long short-term memory network (LSTM) and the multiple-layer perceptron (MLP)—were used as simulation models. When it came to simulating the dynamics of urban expansion over a brief time span, LSTM fared better than MLP because it could capture more temporal information. Results showed that the combination of ANN and CA-MC can accurately model the locations of urban development, thanks to its strength in identifying the nonlinear link between the drivers of expansion and the simulated results were validated by (fuzzy) kappa simulation. Applying the same model to the southern part of Auckland yielded comparable results, revealing that land use rules enacted by various forms of government account for the bulk of the simulated variance.

Liu, Y., et.al., (2021) Cellular automata (CA) models have emerged and been used extensively in the field of land use change studies in urban and regional systems during the past forty years. Changes in urban land use are modeled by CA models as they develop from the ground up. Despite progress in this area, there is still a long way to go before CA models accurately reflect

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the dynamics of real-world urban systems in motion. Based on the information presented in this article, four interconnected theme areas need to be addressed by the broader CA urban modeling community. These areas are identified as contemporary difficulties in constructing CA models for cities. First, we need to construct models that can fully depict the many facets of urban change, such as redevelopment, gentrification, infill development, shrinkage, and vertical growth. Second, we need to build models that can analyze how human decision-making is incorporated into CA. Third, we need to use emerging "big data" sources to calibrate and validate urban CA models, and fourth, we need to strengthen theory-based CA models that can fully explain the mechanisms and dynamics of urban change. To wrap things up, we propose cellular automata with embedded agent-based models and large data input as the best analytical framework for improving our knowledge and preparation for the dynamics of modern urban transformation.

3.RESEARCH METHODOLOGY

3.1. Study Area

India, a large and varied South Asian nation, is the site of the research into the use of cellular automata and geographic data for the purpose of predicting future urban expansion. With more than 1.3 billion inhabitants and an area of about 3.287 million square kilometres, India is home to a broad variety of landscapes, climates, and socioeconomic situations. This research looks specifically at parts of India that are showing signs of rapid urbanization and have a lot of room to grow. Both thinly inhabited rural areas and densely populated urban hubs like Kolkata, Bangalore, Mumbai, and Delhi are included in these regions. In order to forecast and examine patterns of urbanization across various geographical and climatic zones, the study employs geospatial data in conjunction with cellular automata modeling approaches.

3.2. Data Source

The study uses a wide variety of geospatial data sources to thoroughly examine the mechanics of urban growth in order to forecast future urban expansion in India. Important data on land cover and land use patterns throughout the country's enormous expanse is provided by satellite images from platforms such as Landsat and Sentinel. In addition, DEMs help with terrain analysis, which in turn helps with comprehending how topography impacts urban development. Important geospatial datasets, including details about infrastructure and land use

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classifications, are made available by government organizations like the Survey of India and the National Remote Sensing Centre (NRSC). These databases form the basis of the research. Cellular automata modelling approaches are used to forecast and examine patterns of urban expansion using these datasets, in addition to population density maps, economic indicators, and other pertinent socio-economic data.

4 DATA ANALYSIS AND INTERPRETATION

4.1. Spatial and Quantitative Distribution of LULC in urban

Table 1 display the LULC mapping and statistical distributions from 1995 to 2020, correspondingly. According to the findings, forest areas were the most common type of land use in the research area.

Table 1: LULC categories' statistical data.

Sr No.	LULC	Area (km^2)					
		1995	2000	2005	2010	2015	2020
1	Agric. Land	27230.00	26,500.15	25,800.29	23,500.10	24,220.70	25,330.80
2	Forest area	70130.450	70,754.60	70.600.50	70.564.70	66,540.03	64,845.30
3	Grass land	25.450	16.70	25.13	28.90	16.45	10.45
4	Water Bodies	3001.10	3001.56	3516.80	3500.50	3387.60	3000.40
5	Build- Up Areas	2820.30	3547.70	5001.45	6594.50	7978.51	8875.16
6	Barren Land	0.26	0.25	0.40	1.15	1.20	1.90
		5847.11	103819.51	104944.57	104189.85	11367.31	102064.01

5 CONCLUSION

Cellular automata and geospatial data are used to forecast and analyse urban expansion in India's diverse and broad geography. The study's focus on rapidly urbanizing locations like Kolkata, Bangalore, Mumbai, and Delhi and sparsely inhabited rural areas helps explain urban growth dynamics. Satellite photos, DEMs, and government information provide a solid foundation for cellular automata modelling. Land Use/Land Cover (LULC) classifications reveal complex urbanization patterns and highlight the study region's forest dominance. From 1995 to 2020, agricultural land fluctuated, woodland areas declined, while built-up areas

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expanded. These findings emphasize the importance of population density, economic indicators, and infrastructure development in urban expansion analysis. The study's data collecting, pre-processing, and modelling methods provide a complete knowledge of India's urbanisation drivers and trends. This finding has major implications for sustainable urban development and land management decision-making. This study illuminate's urbanization's causes and patterns, helping policymakers create sustainable growth and development policies for India's diverse geographical and socio-economic terrain.

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