Final Report

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STATS 400: Introduction to Probability Models

Introduction

As cities grow in population, land degradation and rapid change in land use lead to "habitat destruction, acute loss of natural resources, pollution, unorganized urban growth, and exhaustion of groundwater level." Predicting the growth of these cities' built-up areas, however, can help governments plan for future demand and ensure sustainable urban development that prioritizes the well-being of both humans and the environment.

This study by Chumki Shikari and Somnath Rudra uses a Markov Chain Cellular Automata (MCCA) model to predict the future urban growth of Purulia, an unplanned city in the state of West Bengal, India, for 2030. This study was published in August 2022 in the Journal of the Indian Society of Remote Sensing.

Model/Method

The datasets used in this study were obtained from the US Geological Survey and the census. The datasets contained remote sensing data from the USGS Landsat missions from 1990, 2000, 2010, and 2020. The population data of the city was obtained from the census.

Utilizing this data, a Land Use Land Cover (LULC) map was made with maximum likelihood supervised classification (MLC) via Arc GIS to determine five classes of land: agricultural, bare, build-up, vegetation, and water bodies. The LULC classes were fixed to the five classes listed as the study was only concerned with predicting the growth of built-up area in the city. Kappa coefficients were used to assess the accuracy of these classifications and revealed strong accuracy for each land type.

A Markov Chain Cellular Automata (MCCA) model was used to predict the built-up expansion of the city in 2030. The MCCA model combines a Cellular Automata model, which handles spatial dynamism, and a Markov Chain model, which projects changes in space over time, to perform accurate long-term spatiotemporal analysis. This model is also generally known for its predictive accuracy in the field, which also contributed to why this model was chosen.

Results

The Land Use Land Cover (LULC) maps created by classifying satellite images revealed many notable insights. In the two decades from 1990-2010, agriculture was the most common use for land in the region but by the year 2020, the majority of the land was classified as built up due to urban expansion. The total amount of agricultural land in the mapped area decreased from 6.29 square kilometers in 1990 to 1.17 square kilometers in 2020. The amount of natural vegetation coverage and bare land also decreased, being replaced largely by urban development. In 1990, natural vegetation covered 15.03% of the total land area but by 2020 only occupied 3.98% of the total land area. In the case of bare land, it occupied 13.29% of the land in 1990 and accounted for 2.39% of the total land area in 2020. The amount of land covered by water bodies also decreased from 0.63 square kilometers in 1990 to 0.44 kilometers in 2020.

These changes observed in the LULC maps are due to the process of urbanization taking place in the area. From 1990-2010, the amount of built up land increased by 82.7% and from 2010-2020 the amount increased by 64.12%. In 2020, built up land accounted for over 80% of the total land area compared to 16.63% in 1990. The rapid expansion of urban areas has come at the expense of natural vegetation and open land prompting questions about this pattern of growth and sustainable urbanization.

Analyzing the transition probability matrix based on the LULC maps along with observations paint a similar picture with regards to the land use situation. The probability of agricultural land transforming into built-up area is 25% (1990-2000), 19% (2000-2010), and 49% (2010-2020) showing the increasing replacement of agricultural land by commercial and residential buildings. Similarly, the probability of change for bare land to built up land is 16% (1990-2000), 11% (2000-2010), and 27% (2010-2020). According to field visits done by the authors, much of the bare land has been replaced by housing to accommodate the increasing population. The probability of natural vegetation turning into built-up land is also growing: 14% (1990-2000), 33% (2000-2010), and 57% (2010-2020). Once again, the increasing probability of natural land being overtaken in the process of urbanization indicates the need for further study.

The authors note that “urban population size is the most important driving force for urban land expansion” and that this municipality is the only town with a population of more than 100,000 people in the region. In analyzing the population growth of the region, the authors discovered an interesting dynamic between the core and peripheral areas of the city. They found that the population grew faster in the peripheral areas of the city, i.e. away from the commercial center, due to the greater availability of land whereas the expansion of built-up lands was greater in the core.

From 2011-2021, the population in the peripheral wards increased at a rate of 2.78% compared to 1.91% in the core areas. Conversely, from 2010-2020, urban expansion took place at a rate of 0.95% in the peripheral areas versus 3.65% in the core areas. The authors observed that the transition to built-up land in peripheral areas consisted mainly of residential buildings while expansion that took in the core of the municipality was primarily commercial.

The CA-Markov model was used to predict the land use changes for the year 2030. The model indicates that “the municipality’s built-up area has been covered by 10.11 sq. km area which will be spread over 21.07 sq. km area by 2030 replacing other land use.” According to the analysis, the expansion of the urban area would soon overtake the remaining suburban areas indicating further degradation of the natural environment. The model’s validity was tested by comparing the built-up map projected by the model for and the actual map for the year 2020. In this test, the Kappa value of 91.5% indicates that the values predicted by the model largely aligned with the actual built-up map of the area.

Takeaways

The unplanned nature of urban expansion in the area has led to many issues such as the degradation of natural resources, illegal dumping, inadequate housing, and poverty, etc. The model’s prediction of further expansion to the built-up area indicates the need for a deep and critical examination of the urban development policy for the municipality. The authors recommend the following strategies as possible solutions:

- Local planners should implement adaptive plans to provide basic amenities such as proper housing to the residents in the peripheral areas
- Place a greater focus on the conservation of natural spaces to maintain a proper land use level
- There needs to be more economic balance between the core of the municipality and the periphery
- Proper sewage and garbage collection systems must be constructed in the core which

is more prone to pollution and slum conditions

- The government must support the creation of small towns close to the Purulia Municipality in order to reduce the pressures caused by increasing population

References

Shikary, C., Rudra, S. Urban growth Prediction for Sustainable Urban Management Using Markov Chain Model: A Study on Purulia Municipality, West Bengal, India. *J Indian Soc Remote Sens* **50**, 2229–2244 (2022). https://doi.org/10.1007/s12524-022-01596-7

Urban growth Prediction for Sustainable Urban Management Using Markov Chain Model

A Study on Purulia Municipality, West Bengal, India

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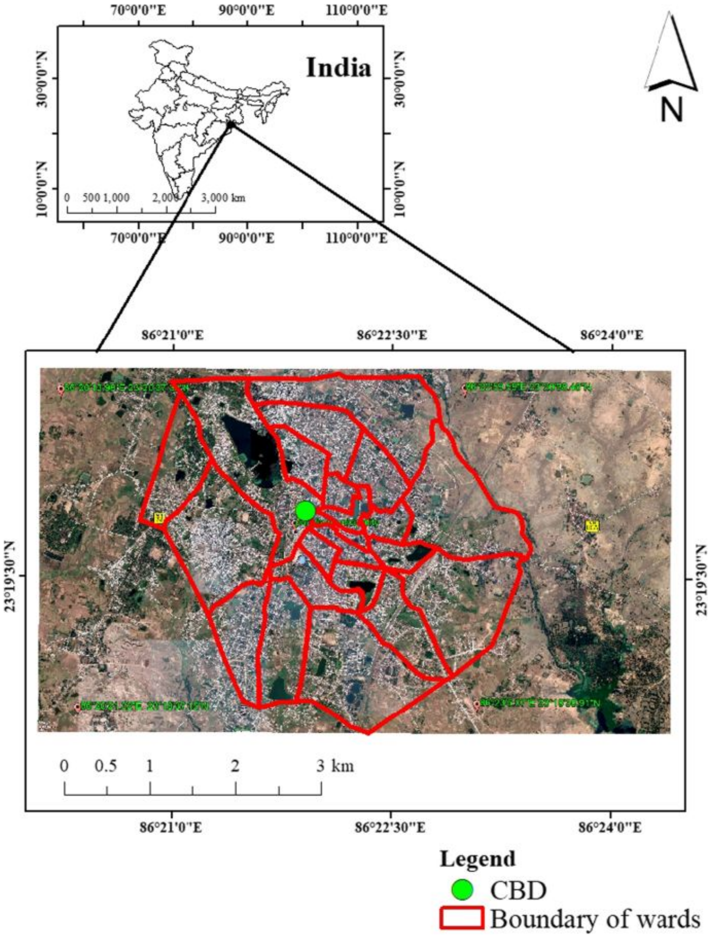
Research Question

How can Markov Chains be used to predict the urban sprawl of a rapidly emerging municipality?



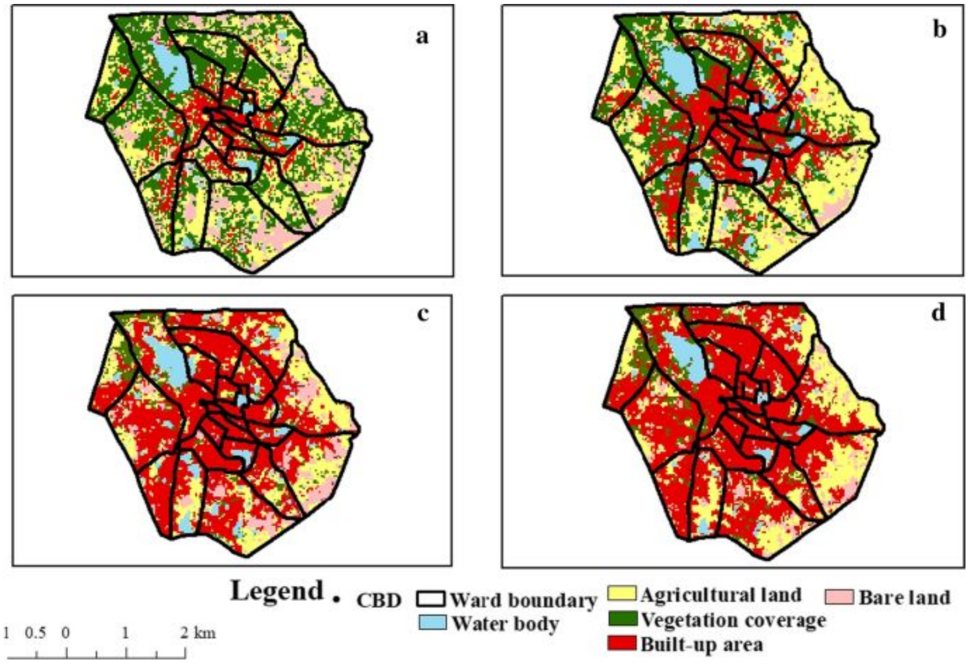
Model and Method

Markov Chain Cellular Automata model was used to predict the built-up expansion of the city in 2030

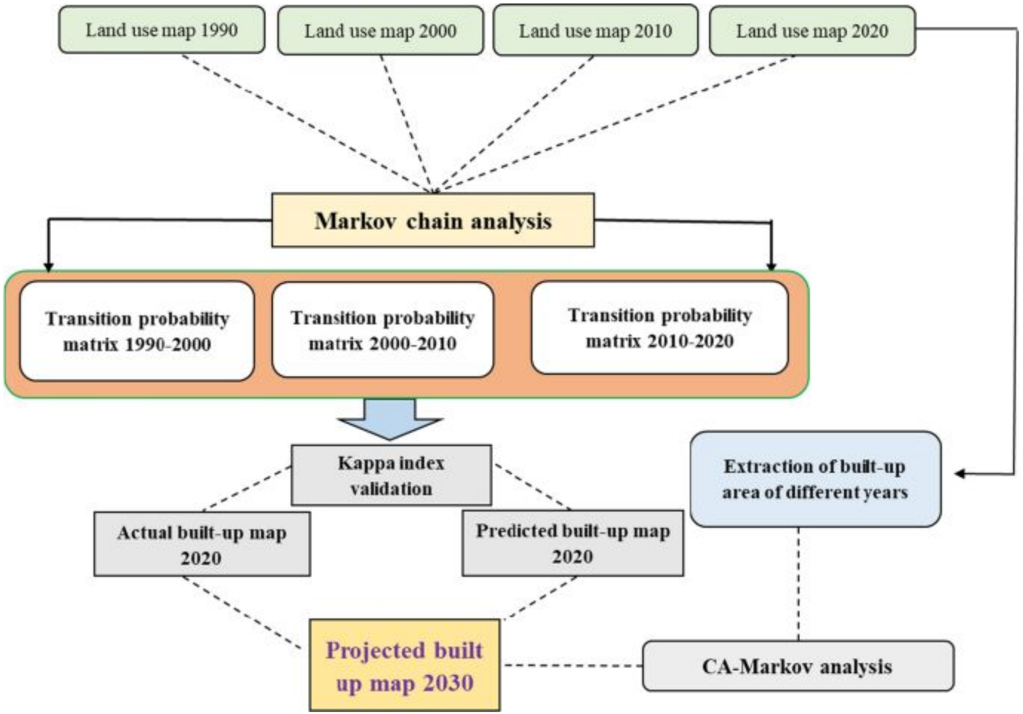
Combines a **Cellular Automata (CA) model** and **Markov Chain (MC)** model

- CA - handels spatial dynamism
- MC - projects changes over time

Performs accurate long-term spatiotemporal analysis, known for its predictive accuracy



Model and Method



Model and Method

Land Area Transitions

LULC classes	Area (in sq. KM)				Changes in LULC (in %)		
	1990	2000	2010	2020	1990–2000	2000–2010	2010–2020
Agricultural land	6.29	5.85	5.01	1.17	- 7.00	- 14.36	- 76.65
Bare land	1.67	0.50	0.35	0.30	- 70.06	- 40.00	- 14.28
Built-up area	2.09	3.82	6.13	10.11	82.70	60.47	64.12
Vegetation coverage	1.89	1.8	0.51	0.50	- 4.76	- 71.67	- 1.96
Water body	0.63	0.60	0.59	0.44	- 4.76	- 1.67	- 25.42

Model and Method

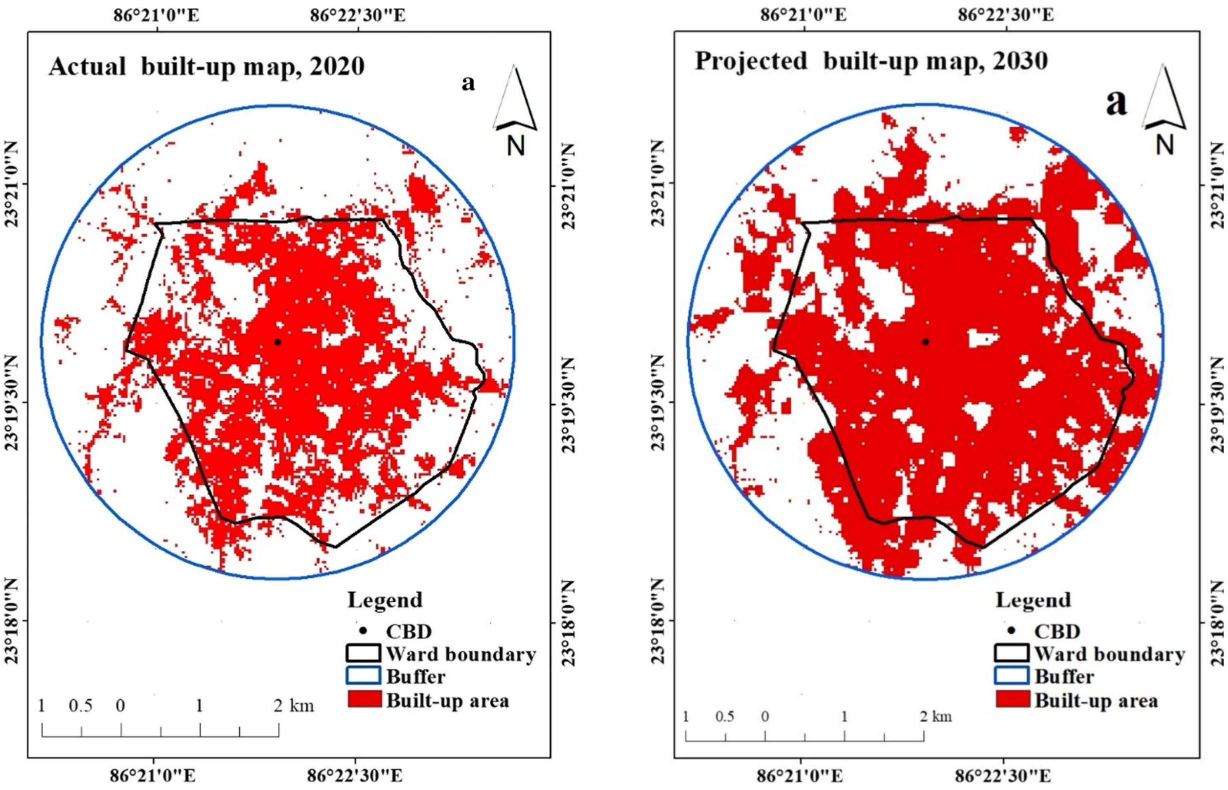
Transition Probability Matrix

LULC class	1990–2000				
	Agricultural land	Bare land	Built-up area	Vegetation coverage	Waterbody
Agricultural land	0.49	0.02	0.25	0.8	0.06
Bare land	0.64	0.06	0.16	0.7	0.03
Built-up area	0.013	0.005	0.69	0.09	0.09
Vegetation coverage	0.18	0.01	0.14	0.54	0.13
Water body	0.05	0.001	0.03	0.06	0.85
LULC class	**2000–2010**				
	Agricultural land	**Bare land**	**Built-up area**	**Vegetation coverage**	**Waterbody**
Agricultural land	0.74	0.06	0.19	0.01	0.01
Bare land	0.64	0.24	0.11	0.003	0.004
Built-up area	0.0012	0.004	0.84	0.003	0.04
Vegetation coverage	0.55	0.03	0.33	0.02	0.07
Water body	0.28	0.01	0.29	0.02	0.39
LULC class	**2010–2020**				
	Agricultural land	**Bare land**	**Built-up area**	**Vegetation coverage**	**Waterbody**
Agricultural land	0.21	0.18	0.49	0.12	0.001
Bare land	0.25	0.44	0.27	0.04	0.0002
Built-up area	0.002	0.01	0.94	0.003	0.002
Vegetation coverage	0.04	0.02	0.57	0.36	0.004
Water body	0.03	0.01	0.76	0.09	0.09

Results

Built-up area has been covered by 10.11 sq. km will spread to over 21.07 sq. km by 2030, replacing other land use.

The expansion of the urban area would soon overtake the remaining suburban areas indicating further degradation of the natural environment.



Conclusion

- Local planners should implement adaptive plans to provide basic amenities such as proper housing to the residents in the peripheral areas
- Place a greater focus on the conservation of natural spaces to maintain a proper land use level
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