URBAN GROWTH MODELING USING CELLULAR AUTOMATA BASED MACHINE LEARNING TECHNIQUES

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by

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ABSTRACT

Rapid urbanization across the world is changing the landscape with significant deterioration to the environment affecting the quality of living of humans. It is estimated that currently, almost 55% of the world's population reside in urban areas, whereas in 1950 it was only 30%. It is expected that by 2050 about 68% of global population will be urbanized. Urbanization is one of the reasons for global warming throughout the world and has become very common in developing as well as developed countries. Urbanization is a gradual process, which is influenced by various economic, political and geographical factors. Urbanization refers to the growth of towns and cities as people move from rural areas to urban centres in search of better education, good health care, proper sanitation, comfortable housing, better business opportunities, transportation facilities and so on. In India, population, industrial and economic growth has resulted in rapid migration and urbanization in the country and thus the number of urban towns and cities has drastically increased and urban agglomeration is expected to continue in the years to come. Cities are rapidly expanding horizontally as well as vertically by utilizing all of the surrounding land to build residential areas and thus urban growth is happening in a haphazard and unplanned way. Urban growth has both positive and negative effects on the development of a city. Positive effects of urbanization includes better standards of livings as urbanization provides lots of employment opportunities, advancements in technology and infrastructure, improvements in transportation and communication, quality of educational and medical facilities and improved standards of living. On the other, the negative impacts of unplanned urbanization are numerous including overcrowding, housing problems, unemployment, under-employment, development of slums, water scarcity, sanitation problems leading to poor health issues, traffic congestion, air and water pollution, poor waste management, increase in crime and so on. Despite many challenges, governments are working hard to find out the solutions to minimize and resolve various problems pertaining to these consequences of unplanned urbanization. Sustainable development of a city depends mainly on successful management of environmental resources thereby leading to a better quality of living of mankind. Hence, efficient and appropriate urban development policies are needed to improve the lives of both urban and rural dwellers so as to avoid the adverse effects of urbanization.

Recently, urban growth models are developed and extensively used to study the urban sprawl of a city and its impact on the environment. These models can be employed in urban policy-making for the development of different urbanization scenarios to predict the future urban trends of the city. For the sustainable management of the natural resources and for the improvement of quality of living of humans, an efficient and appropriate urban growth models are indispensable, which is dependent on the simultaneous monitoring and modeling of urban land use. Remote sensing provides a useful tool for monitoring the land cover/land uses from local to global scale. Spatial models are increasingly employed as decision support tools in urban planning in order to inform planners

and decision makers. In the past two decades, several types of simulation and prediction models have been used within a GIS environment to determine a realistic future for urban growth patterns. These models include quantitative and spatio-temporal techniques that are implemented to monitor urban growth. The results derived through these techniques are used to create future policies that take into account sustainable development and the demands of future generations. Cellular automata based urban model has gained great attention from urban researchers in recent years. They have the potential to simulate the complex systems like cities. Cellular automata models are effective in simulating the urban growth dynamics and in projecting the future scenarios. In this research, the urbanization of Sriperumbudur Taluk, Kancheepuram district and Chennai Metropolitan Area, Tamil Nadu, India were modeled using Cellular Automata based machine learning techniques. Also the uncertainties arising from the model and input parameters were assessed through sensitivity analysis. The type and distribution of the urban sprawl of these study regions were analyzed through Shannon's entropy which would provide detailed information to the urban planners regarding the rapid urbanization occurring in these regions.

A pilot study on Sriperumbudur Taluk to assess the efficiencies of three Cellular Automata based urban models including Traditional Cellular Automata (TCA), Agents-based Cellular Automata (ACA) and Neural Network coupled Agents-based Cellular Automata (NNACA) models in capturing the urbanization of the taluk in 2016 was performed. The urban maps of the study region for the years 2009, 2013 and 2016 prepared from the satellite imageries, along with the agents of urbanization namely transportation, industries, elevation and also hotspot locations (future urban expansion based on the Government policy) were used in the modeling. Analytical Hierarchical Process technique was adopted to estimate the weights of the agents for suitability map preparation in ACA model. On validating the 2016 predicted outputs, NNACA model proved to be a better urban model (kappa coefficient - 0.72) when compared to the other models (kappa coefficient - 0.6 each). Further, the influence of agents of urbanization on the prediction output was assessed through 'sensitivity analysis' which revealed that all the 12 agents of urbanization selected based on the experts' opinions were equally important in determining the urban development of the taluk in 2016. To study the type and distribution of the urban sprawl, the study area was divided into 8 directional zones with the Sriperumbudur Head Quarters as centre and based on the urbanization in 2009, 2013 and 2016, Shannon's entropy for the study periods was measured. The results suggested that urban growth is dispersive in the taluk and higher urbanization is found towards the north-east direction of the taluk which is towards Chennai city. Further, the urban sprawl of the taluk was predicted using NNACA model for 2020 with an expansion of 157 km^2 from 113 km^2 of urban cover in 2016.

Based on the results from the pilot study, NNACA model proved to be efficient in capturing the urban growth of Sriperumbudur Taluk and thus the model was used to predict the urban growth of Chennai Metropolitan Area for the year 2017 based on 2010 and 2013 urban cover maps and hotspots region identified from the Chennai city master plan as. As per the experience from pilot study, 18 different agents of urbanization including transportation, hotspots, and industries were used in the prediction modeling. The prediction model was performed under two scenarios. One scenario included the hotspots based on the city's master plan into the urban map of 2013 and the other without the hotspots in the 2013 urban map. On validating the 2017 predicted outputs, the neural network model with hotspots proved to be better (urban hits: 498.52 km^2) than that of without hotspots (urban hits: 488.31 km^2). Out of the total 18 agents of urbanization, the most influencing agent of urbanization of 2017 was identified to be the 'Existing built-up of 2013' itself using 'sensitivity analysis' showing that the influence of agents unique for each study area. Further, the urban sprawl of the study region for 2010, 2013 and 2017 was measured through Shannon's entropy. The study area was divided into five directional and distance-based zones with the State Secretariat as the center. Entropy values suggest the need for more careful planning for further development in the southern region of CMA which has undergone congested urban growth while urbanization is dispersed in the northern part of the study region which can be thought for future urban developments. Though, NNACA models have proved to predict the urban growth more close to reality, recently, deep learning based techniques are being used for the prediction of urban growth to overcome the dimensionality issues arising from the neural network architecture. Hence, for Chennai Metropolitan Area, the urban growth of 2017 was performed using Deep-belief based Cellular Automata (DB-CA) model and the accuracies of the prediction outputs of these two models were compared. Upon validating, DB-CA model proved to be the better model, as it predicted 524.14 km^2 of the study area as urban with higher accuracy (kappa co-efficient: 0.73) when compared to NNACA model which predicted only 502.42 km^2 as urban (kappa co-efficient: 0.71), while the observed urban cover of Chennai Metropolitan Area in 2017 was 572.11 km^2. Analyzing the effects of different types of neighbourhood configurations (Rectangular: 3×3, 5×5, 7×7 and Circular: 3×3) on the prediction output based on DB-CA model was also performed and it was found that 3x3 rectangular neighbourhood configuration is the most appropriate one in predicting the urbanization of CMA in 2017. Further, Chennai Corporation (earlier Chennai city limit) was excluded from current limit of Chennai Metropolitan Area and neural network based prediction was implemented for the region beyond the Corporation limits, to check the influence of agents of Corporation beyond its boundary. Result suggested that the agents of urbanization of Chennai Corporation have lesser impact in the region beyond its boundary. Sensitivity analysis of the region beyond the corporation boundary suggested that all the 18 agents were appropriate to model the urbanization in 2017. Hence, urban prediction for 2020 for the region beyond the Corporation limits was done through neural network based Cellular Automata model with a future urban extent of 343.51 km^2 which would serve as a tool for urban planners and policy makers to take appropriate development plans to have sustained development of the study region.