LAND USE ANALYSIS AND MODELLING BASED ON AGENTS USING CELLULAR AUTOMATA

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ABSTRACT: Over the last two decades urbanization and increase in paved surface has been unprecedented and has led to uneven sprawling of the cities and weaking the basic necessary utilities for citizens. Cities have now attained saturation in terms of resource consumption and are growing beyond administrative boundaries in an unplanned and dispersed fashion, leading to urban sprawl. This study provides a case report of a peri-urban growth in a city of western India to understand this phenomenon. Results of study reveals growth of paved surface increased five folds in last three decades. An Integrated agent based Cellular Automata (CA) model provided valuable insights in understanding the growth poles of the region. This provided socio economic understanding of the growth poles and also visualized the future scenario of the growth. The model explains the next urban growth would be concentrated in the regions that have necessary basic infrastructure.

1. INTRODUCTION

Urban area is characterized by high population density and inhabitants employed in less land intensive sectors. Urban growth is a significant social and economic phenomenon occurring rapidly around the globe. Increase in population as well as the overall economic development have led to fast growth of urban agglomerations. It has changed significant amount of earth's land use / land cover over time. According to studies published such as Ramachandra et al., 2012, refers to urbanization as an irreversible physical process that has effects on both landscape and the behavior of the processes that are connected to earth and environment. Urban paved surface has grown many times in last few decades and covers closer to 55% of the total population is either dependent or lives in these regions. It was 30% of the population in 1950 and 68% of population is projected to be urban dwellers by 2050. Asia has almost half of its population residing in urbanized regions (United Nations, 2019). The pace of urban growth is quite alarming with the advent of industrialization, automation and globalization (Bharath et al., 2016). Rapid urbanization, fueled by population explosion and urban migration, is causing unplanned and un-sustainable development leading to problems that can effect humans such as Air contamination, heat island and cold spots, loss of green cover etc. (Aguilar, 2008; Bharath et al., 2018; Nimish et al., 2020).

Urban Growth in India it is at an unprecedented rate with urban population in India is said to be growing at a rate of 3.1% per year. India has more than 60 urban regions that have more than 1 million population. Kerala is one of the most urbanized state in India. In 2011 census of India, new 2532 census towns have been identified without urban statutory status and hence without building byelaws. This evidently points out the lack of planning and monitoring of the urban growth phenomenon. In this scenario, several policy measures have been initiated by governments. National Urban Housing and Habitat Policy, 2007 stressed on avoiding unplanned development to tackle urban sprawl. National Land Utilization Policy, released in 2013 by Government of India, tried to incorporate sustainability in the process of land use conversion happening as a part of development. Policy addresses the impacts of unplanned growth of urban areas in high quality fertile land in the peri- urban region. It pointed out the lack of proper district level land use plans, leading to improper conversions of land use and unplanned development. National Manufacturing Policy-2011 setting a target of 12-14 % industrial growth rate. Under this policy the closed cluster growth if industry and township that supports the industry would be developed called as National manufacturing and investment zones (NMIZ) with large areas of land. These regions have special privileges and are called as special economic zones.

Several programmes have been launched in last decade by different governments to improve the pace of urbanisation, to attain transparency and decentralization, to ensure effective and optimal use of resources and thereby attain sustainability. JnNURM was one of the earliest programs that envisioned the planned development along with sectoral growth (Mehta et al., 2010). A step ahead with Smart city mission launched in 2015 aims at providing the basic core necessities for cities In India. Researchers such as Datta. A, 2019 has critiqued the idea of smart cities as an instant urbanization programme with very few planning insights leading to widen the social inequality. Atal Mission for Rejuvenation and Urban Transformation (AMRUT) was also flouted to help cities that are Tier II in nature and certain special landscape features in it. These programmes initiated the sustainable, planned development of urban agglomerations in the country (Ministry of Housing and Urban Affairs, 2019). Kerala has been a forefront leader in developing urban cities and implementing strategies necessary for city infrastructure development but yet falls short due to rate of urban growth and visualized growth. Kerala is one of the rapidly urbanizing states within the country with 47.7 % of the population living in urban settlements (Bhagat & Mohanty, 2009; Ramachandra et al., 2014). There has been a proposed industrial corridor between Kochi and Bengaluru, which will simulate a considerable development along the Kochi-Palakkad stretch in Kerala. Along with that, Kerala Industrial Infrastructure Development Corporation (KINFRA) has taken up projects of erecting several small scale as well as large scale industrial parks such as Petrochemical Park, Defence Park, KINFRA Mega Food Park, Electronic Manufacturing Cluster, Life Sciences Park in different parts of the state which will lead to industrialization and further change in the pattern of land use. Other infrastructure projects such as Kochi metro rail, light metro rails in Thiruvananthapuram and Kozhikode, Port in Vizhinjam, high-speed coastal highway etc. are also expected to contribute their part to the process of urbanisation. Thus, Kerala is about to witness a meteoric urban growth, that is required to be carefully monitored and planned to ensure the sustainability factor in development (Jayalakshmy & Mereena, 2016; KINFRA, 2019; KSIDC, 2019).

Economic reforms in 1991 was turning point in the history of India in many aspects. It too had impacts in the process of urbanization. Rapid urbanization, as a consequence of economic reforms is described to be with underlying effects that has occurred due to increase in land use change, population and population densities, transport and transport cost etc., urban land consumption, motor vehicle growth, fuel demand, and urban housing shortage scenario in metropolitan India. Thus, made it is necessary to identify the factors effecting urban growth for the efficient management of urban resources. Urbanization evolved in various forms. Transit oriented and compact development with mixed land use is essential to ensure sustainability of Indian cities (Chadchan & Shankar, 2012). This could only be addressed using remote sensing analysis of the land use and using geoinformatics as platform to extract the knowledge through land use maps and scenario-based modelling. Land use and land cover are closely related terms which are used interchangeably quite often (Chandan et al., 2019).

The purposes of land use is mostly associated with its type of cover. E.g.: forest, water, agriculture, industrial, urban etc. Image processing and data analyzing techniques make use of the patterns, texture, shapes and site associations, to determine the type of land use. Land use class are defined subjectively and hence the number of classes as well as class definitions depends on the purpose of study (Anderson et al., 1976). One we understand it is essential to visualize this dynamic nature of urban growth. Batty (1976) described the urban models as functions that represent the spatial structure of urban areas through the analysis of land change patterns, population and other relevant indicators. Land use pattern evolves with the interaction of human and natural systems. Understanding the process has been a topic of scientific study in various disciplines, locations and scale. But the land use dynamics cannot be comprehended by direct measurement alone. Linking the observations at spatial and temporal scale with empirical models are required to understand the causes and consequences of the process (Parker et al., 2003; X. Li & Gong, 2016; Bharath et al., 2018; Bharath et al., 2020; Aishwarya et al., 2020). Glaeser et al. (2004) studied the economic aspects of urban growth and sprawl using Alonso-Muth-Mills monocentric economic model, a simple framework to understand the sprawling phenomenon by considering land price as a determining factor for spatial distribution of growth. This model was also suitable for further modifications to accommodate poly-centric nature and decentralization. Complex urban simulations form and excellent way of understanding the interaction and large-scale transformations (Candau, 2000). Cellular Automata (CA) has evolved as a discrete model widely used in various branches of science. CA is found to be a useful and efficient model for land use changes simulation and modelling. The entire landscape is divided into cells (Clarke et al., 1997; Rienow & Goetzke, 2015; Yakubu et al., 2018; Bharath et al., 2018; Ramachandra et al., 2019). CA can be made more realistic by improving the transition rules. The transition rules can be grouped into six categories: (Bhatta et al., 2009). Type I rules: Simple and orthodox rule in which the state of a cell is a function of its initial state and state of neighborhood. Type II: Probability of each cell changing to a land use is the key driver for urban evolution. This probability is known as transition potential. Type III: These rules are based on urban shape and form. Type IV: Artificial Intelligence methods such as neural networks or kernel-based learning methods are used for defining the rules. Type V: these rules are based on fuzzy logic which incorporates the uncertainty in human behavior. Type VI: These consists of the rules that cannot be grouped into a general method. Therefore, the study couples CA along with markov through agent based solution coupled with AHP and fuzzification of the agents to understand the influence. This model is based on Bharath et al., 2014 model using CA.

2. STUDY AREA & DATA

Kochi is one among the most important port-cities in the western coast of India. Study considers Greater Cochin and a 5 km buffer around it to understand the urban pattern dynamics as shown in figure 1. Temporal remote sensing data from Landsat Series were obtained for the years 1992, 2002, 2008, 2019. Aster DEM were also obtained for the slope analysis. Google earth and open street maps were used in collecting various points, lines and polygons which served as an input for modelling in terms of agents and constraints. Field visit data was collected using GPS. These points were used in geo-correction and validation of datasets.

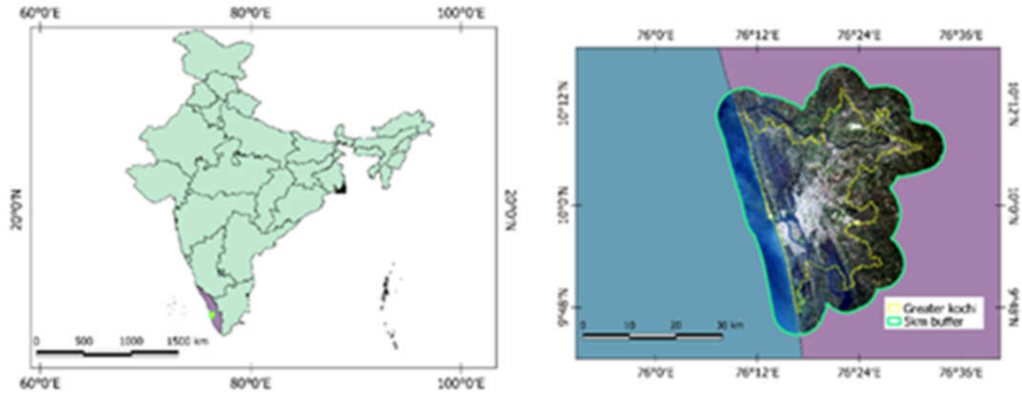


Figure 1: Study area of Kochi and buffer considered

3. METHOD OF LAND USE ANALYSIS AND VISUALISATION

Land use is classified by supervised machine learning technique. Gaussian Maximum Likelihood Classifier (GMLC) is used for the classification. Training polygons for 4 different land use classes as Urban, Water, Vegetation and others. Error matrices was used to compare the relationship between different classes on the actual ground and in the classified image. Kappa value was also determined for the land use classification. Kappa helps in determining the statistical significance of a matrix or the differences among matrices (Lillesand et al., 2015). This land use analysis data is then used for visualization of future scenarios as described in figure 2.

3.1 Land growth Modelling

CA Markov model integrates the stochastic Markov process with cellular automation for incorporating the temporal changes in land use along with the spatial transformation. Transition probability of each land use class to another is calculated from historical land use images. Distance to agents of growth such as industries, schools, social amenities, roads, transit stops etc. and population density were considered. Fuzzification of agents driving changes, incorporates the closer-to real scenario of the complex system. It defines a set of values between 0 and 255 for the agents indicating least and highest probability for change respectively. Weighted linear combination of the agents yields the transition probability of each spatial coordinate. Analytical Hierarchy Process was employed to obtain the weight by pair-wise comparison of factors. Two scenarios were considered for predicting the land use for the year 2031. Scenario 1 was considering the constraints of City Development Plan (CDP) and Costal Regulatory Zones (CRZ). This scenario predicts the land use of 2031 if the strict actions are ensured to restrict the development activities in accordance with the CDP and CRZ regulations. Scenario 2 based on Business as usual scenario. Here we assume that development happen in the city without any major interventions or regulations by the government authorities. Slope greater than 25% is also considered as a constraint for urban growth in both scenarios. Validation was performed by predicting the land use of 2019 and comparing the predicted LU 2019 with classified LU 2019. Confusion matrix and accuracy statistics were calculated.

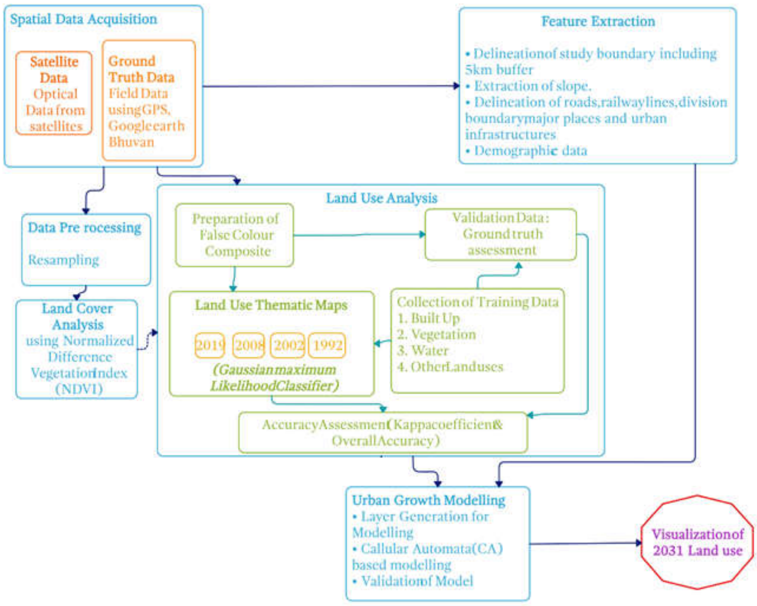


Figure 2: Method used for the analysis

Different factors/ agents responsible for the urban land use transformations are identified from the literatures. Such as (1) Industries: Kochi has grown as a hotspot for IT/ITES. They are considered along with conventional heavy engineering industries like refineries, fertilizer manufacturers, food processing etc. as an agent driving urban growth/ transformation. (2) Services: Locations of hospitals, police stations, fire stations are extracted (3) Major roads were extracted from the open street maps using query. (4) Transit stops of buses, metros, ferry services and trains (5) Social amenities such as Burial grounds, Religious places, Educational Institutions (6) Population/ Population Density (7) other physical - Social Amenities such as Parks, Grounds, Recreation areas. The complete visualization is described in figure 3. Example of collected data used as agents have been described in figure 4. Constraints include slope >25%, waterbody, urban area, costal regulatory zones (CRZ), open spaces and wetlands in City development plan 2031 (CDP). Land use was visualized based on two scenarios to obtain the transition change for 2031.

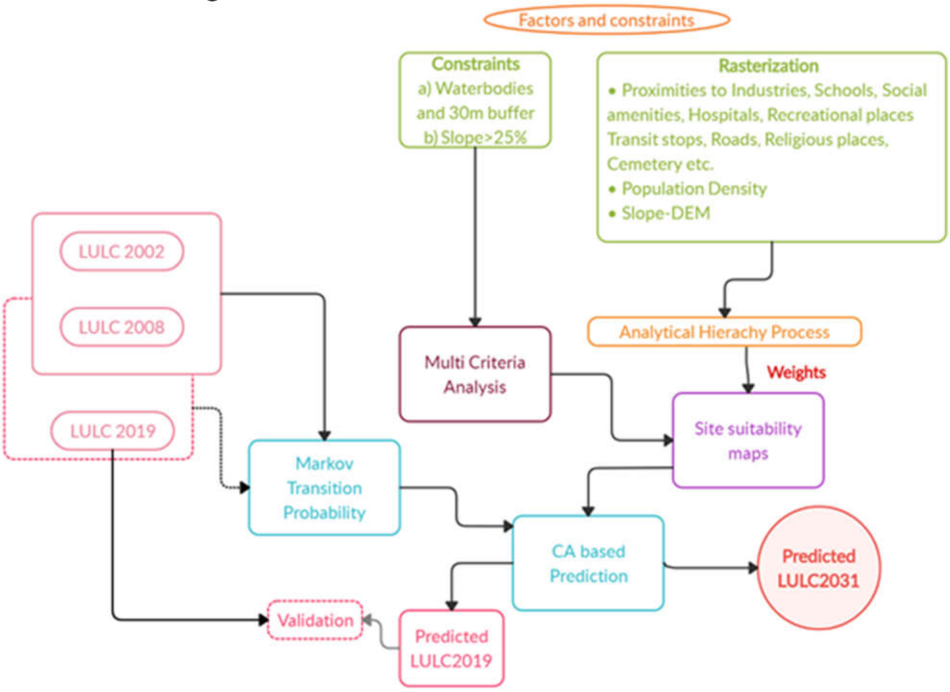


Figure 3: Method used for the analysis

4. RESULTS

4.1 Land use pattern change analysis

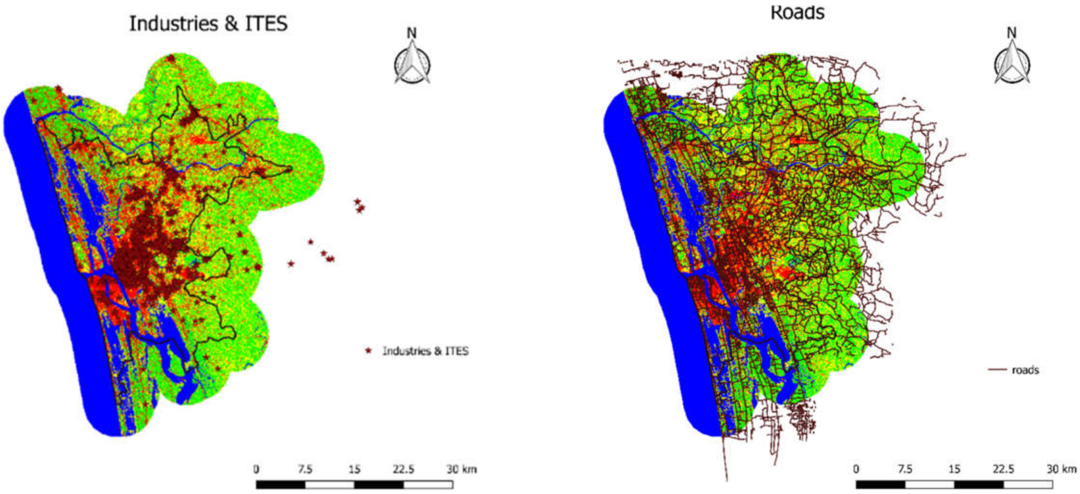
Land use pattern has changed drastically in 27 years' time. Urban Built-up area which was just 2.82% in 1992 has become 16.01% in 2019. Urban Land use has increased at 1.7, 1.85 and 1.89 times in 1992-2002, 2002-2008 and 2008-2019 periods respectively. Maximum growth was witnessed in 2002-08 time. The results of land use analysis are shown in figure 5. The overall accuracy and kappa statistics is as shown in Table 1.

4.2 Model Validation

The model was developed and agents were used for the analysis as described earlier. The model is first validated by using 2002 and 2008 as base years and visualizing the urban growth for the year 2019 using agents as growth poles, as illustrated in figure 3. Comparing the projected map with classified LULC 2019, kappa value is observed to be 0.82 and hence the model was validated and used for further prediction.

4.3 Land use Modelling using CA

Land use was modelled based on two scenarios to obtain the transition change for 2031. Urban Area is growing exponentially throughout the years. Kochi municipal region, Kalamassery, Vazhakkala and Varappuzha are the local bodies expected to undergo maximum growth in the near future. Thrikkakkara is the part of city which is predicted to have the maximum rate of urban expansion. Urban area of Thrikkakkara is observed to expand 3-4 times to that of 2019. Koratty, Kodungallur, Athani, Kizhakkambalam, Pattimattom, Kumbalam, Aroor, Mulanthuruthy and Kolenchery is observed to develop as a new urban patch. These towns on the periphery of the core city area, has the potential to transform as new urban sub-centres. Relaxing the implementation of CRZ and CDP guidelines can lead to over expansion of built-ups in Kumbalam, Elamkunnapuzha, Thiruvankulam, Vazhakkala, Maradu, Cheranallur, Puthuvype, Kochi and Thrippunithura regions. Rapid growth is also observed in the reclaimed islands of Puthuvype, with projects like LNG terminal and Ship Repair Complex. The modelling outcome also suggests eco-sensitive area with mangrove cover is extremely vulnerable, if the regulations are not strictly implemented. Results of the land use prediction modelling is as shown in figure 6a and 6b based on scenarios. Urban Area is growing exponentially throughout the years. Kochi municipal region, Kalamassery, Vazhakkala and Varappuzha are the local bodies expected to show maximum growth during this span. Thrikkakkara is the part of city which is predicted to have the maximum rate of urban expansion. Urban area of Thrikkakkara is observed to expand 3-4times to that in 2019. Smart city, IT parks and townships and Cochin SEZ has driven a growth in the region in past years. Large Urban growth is expected with the completion of projects such as Infopark Phase-2, extension of metro line etc. Koratty, Kodungallur, Athani, Kizhakkambalam, Pattimattom, Kumbalam, Aroor, Mulanthuruthy and Kolenchery is observed to develop as a new urban patch. These towns on the periphery of the core city area, has the potential to develop as a new urban sub-centres. There are spatial differences in the growth for both scenarios. Relaxing the implementation of CRZ and CDP guidelines can lead to over expansion of built-ups in Kumbalam, Elamkunnapuzha, Thiruvankulam, Vazhakkala, Maradu, Cheranallur, Puthuvype, Kochi and Thrippunithura regions. Rapid growth is also observed in the reclaimed islands of Puthuvype, with projects like LNG terminal and Ship Repair Complex. Eco sensitive area with mangrove cover is in danger if the regulations are not strictly implemented.



(a) **(b)**

Figure 4: Example of agent's data that was collected for analysis

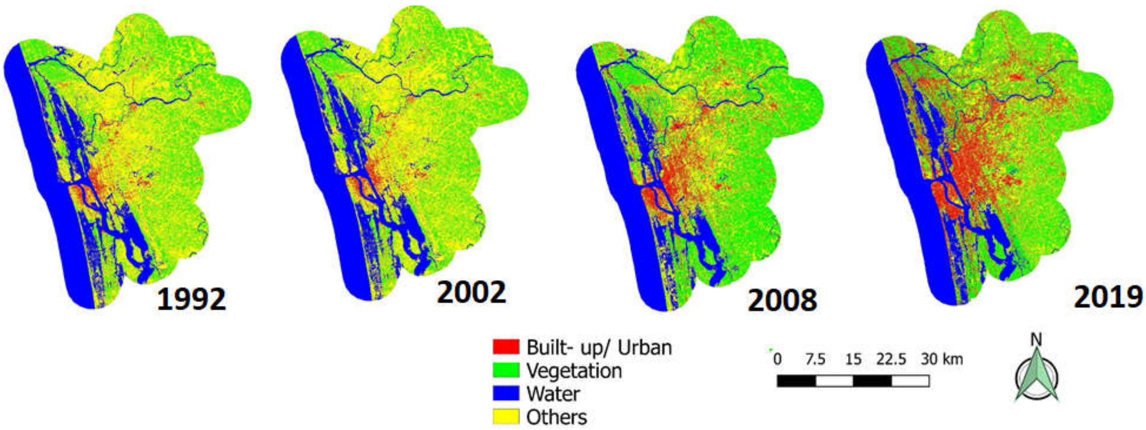


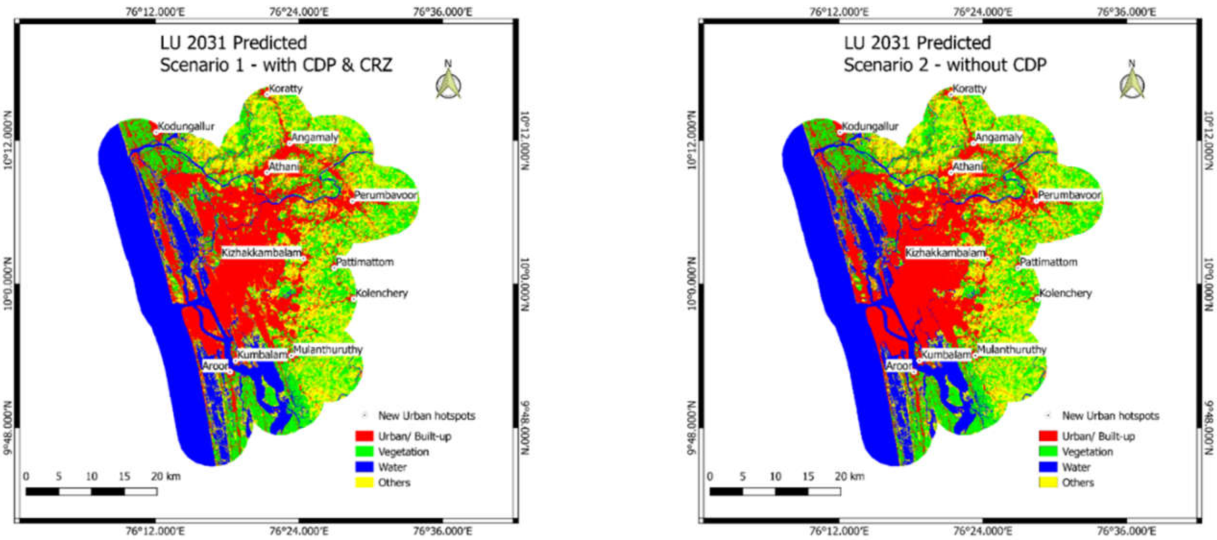
Figure 5: Land use pattern change analysis

Table 1: Land use change statistics

Year	**1992**	**2002**	**2008**	**2019**
Land use class	**%**			
Urban	2.82	4.80	8.92	16.01
Vegetation	21.79	25.35	34.52	29.92
Water	27.65	27.32	25.70	25.85
Others	47.74	42.53	30.86	28.22
Overall Accuracy (in %)	86.3	84.2	89.21	93.4
Kappa	0.94	0.81	0.84	0.88

5. CONCLUSION

Kochi, as a fast-growing city in the western coast of India, has geographical constraints restricting its urban expansion. The city is also part of a sensitive eco system comprising of low-lying lands, estuaries, backwaters, mangroves, reclamation lands and wetlands. Hence, monitoring of the urban growth is necessary for ensuring its sustainability. Growth of the city has been centered on the port and recently, it grew up as a hub for IT related industries. Visualization of spatial growth of the city over time, is an important input for effective regional planning. The study has demonstrated the effectiveness of remote sensing and GIS in monitoring the urban dynamics. Supervised classification of historical satellite images, multi-criteria decision-making techniques and cellular automata and Markov process-based modelling were successfully combined to predict the land use pattern of the city for a future period. Sprawling characteristics of the city is also analysed using suitable indicators.



(a) (b)

Figure 6: Predicted land use of Kochi region for the year 2031(a) Scenario-1 and (b) Scenario-2

This study put forth a methodology and technique for predicting the future Land Use pattern, considering different agents governing the urban expansion, such as roads, transit services, topography/slope, industries, educational institutions, social amenities, services etc. along with the Census population data. Influence of the agents were quantified as fuzzy values. Land use pattern was predicted for two different scenarios: 1) with strict implementation of CDP Land Use and Coastal Regulatory Zone regulations 2) business as usual scenario without any restriction for expansion. AHP was used as a decision technique for attributing weights to each influencing factor. GIS was used as tool for integrin various layers of influence together. The results obtained from the Land Use classification showed the exponential growth of built-up area from 1992 to 2019. It increased from 2.82% of the study area to 16.01% in this period. 2002- 2008 witnessed 1.85 times growth in built-up area. . Historical part or the core area of the city is observed to reach saturation for further growth. Low density growth or sprawling is observed to happen towards the NE direction, with the emergence of satellite towns in Perumbavoor and Angamaly. Unplanned growth of the city can hamper its sustainability in different ways. Transit Oriented Development (TOD) has been a significant development model proposed in the recent times. Assessing the accessibility to transit services in the city showed its poor spatial coverage, with 10 local bodies having a mean distance to transit stops greater than 700m.

Cities were considered as a complex system which evolves with the multitude of interactions between different agents. Cellular automata incorporate the complexity characteristics in modelling the land use pattern.CA is combined with Markov process, to contain the temporal effects of changes. Predicted LU 2031 pattern for both scenarios established the significance of CDP and CRZ regulations in protecting the sensitive land forms from further urban penetration. Thrikkakkara is predicted to have a rapid growth with to its proximity to the IT industries. Koratty, Kodungallur, Athani, Kizhakkambalam, Pattimattom, Kumbalam, Aroor, Mulanthuruthy and Kolenchery is observed to develop as a new urban patch. These towns on the periphery of the core city area, has the potential to develop as a new urban sub-centres. Unplanned rapid growth of cities has led to non-judicial exploitation of natural resources and extra pressure on primary infrastructures like roads, water distribution etc. In this context, this study analyses the existing growth patterns and predicts the future pattern of Land Use with the available data. This can be used as a framework to evaluate the situations of other cities as well. Fine spatial resolution satellite imageries could improve the classification accuracy. Sub-classification of urban to residential, commercial, industry etc. adds more dimension to the analysis. This requires primary surveys along with the satellite data. Incorporating suitable agents with other socio-economic factors can generate closer to reality model. Complexity of the urban growth phenomenon can be represented with Artificial Intelligence with the help of neural networks.

6. ACKNOWLEDGMENT

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