Modeling Colombo's land uses with Metronamica: a demonstrative approach

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Abstract

The enormous complexity built into cities makes them difficult to understand for any purpose. The ever changing land uses in any city is not an exemption, despite its importance for planners to know at some level of certainty. In order to overcome this difficulty Cellular Automata (CA) models are widely used in the field of urban planning as means of simulating land use changes with adequate bearing on the complexities associated with urban systems. This paper is a demonstrative attempt to model the land use changes in Colombo Metropolitan area in Sri Lanka between 1987 and 2010, within a modeling framework developed with CA based simulation application: Metronamica. Simulation results are assessed and validated using visual comparison and statistical methods. This study is placed in a context where the current planning practices in Sri Lanka are in need of robust methods and versatile techniques to comprehend land uses in rapidly growing urban areas.

Keywords: *land use changes, urban complexity, simulation, cellular automata (CA)*

Introduction

'...Our traditional image of the city no longer holds. Cities appear much more complex than we generally assume...'(Michael Batty, 2005)

Urban systems are becoming ever larger and increasingly complex as urban economies, social and political structures and norms, and transportation and other infrastructure systems and technologies evolve(Waddell & Ulfarsson, 2004). The situations generated with the growth of urban areas raise vital issues that need to be considered in the planning process(Pinto & Antunes, 2010). Therefore, one of the important subjects of concern in the field of urban planningis to predict and simulate the said trend of land use transition. However, projections without a sufficient understanding of the system under study embody a greater degree of uncertainty due to the numerous unknown factors involved(Cheng, Masser, & Ottens, 2014).

To overcome this situation, urban simulation models have been developed in many approaches. Initially developed urban land use models were based on the assumption that urban patterns are the changes in the equilibrium within the city system(Lahti, 2008), but these were having many limitations such as the centralized structure, lack of detail, little usability, flexibility and realism(Torrens & O'Sullivan, 2001).Theycouldnot successfully capture the complex nature of cities. These traditional modelswere followed by complexity models or geosimulation models that were developed considering the bottom up approach of modeling. Among a wide range of modelling techniques that are used for urban simulation, Cellular Automaton (CA) has been considered asone that could successfully capture the complex nature of cities. CA is defined as 'an automaton of a processing mechanism with characteristics that change over time based on its internal characteristics, rules and external input"(Benenson & Torrens, 2004).

The importance and the need of employing such tools in the planning process are widely recognized in Sri Lanka in a context wherethe conventional urban planning practiceslacked sound methods to predict the growth scenarios under different circumstancesenvisaged by development decisions.

This paper is a demonstrativeattempt towards modeling the future land uses of Colombo, based on current trends of development using the Metronamica model, which is a cellular automata based RIKS (Research Institute for Knowledge Systems)' Spatial Decision Support System (SDSS) for urban and regional planning applications (RISK, n.d.). The first section of the paper briefly discusses the concepts associated with the CA, its applications and the principles at the base formulation of Metronamica model. The second section elaborates the methodology of the study, data preparation, model calibration process and applications.

Urban Simulation Modelling, Cellular Automata & Metronamica

Cellular automata (CA) getsits name from the fact that it consists of cells – like the cells on a checkerboard – and that the cell states may evolve according to a simple transition rule, the automaton (RISK, n.d.). A conventional cellular automaton consists of: A Euclidean space divided into an array of identical cells,for geographical applications a 2 or 3-dimensional array is most practical; A cell neighborhood,for flow and diffusion processes the 4 (Von Neumann neighborhood) or 8 (Moore neighborhood) adjacent cells are sufficient, but for most socio-economic processes larger neighborhoods are required; A set of discrete cell states; A set of transition rules, which determine the state of a cell as a function of the states of cells in the neighborhood; Discrete time steps, with all cell states updated simultaneously (RISK, n.d.). A cell's new state is a function of all the states in the cell's neighborhood at the previous moment of time (or during the previous generation). We calculate a new state value by looking at all the previous neighborhood states.The fundamental formula for calculating a cell's state at any given time *t* is:

CELL state at time t = f (CELL neighborhood at time t - 1)

The CA model managed to capture the complexity in urban systems by capturing their characteristics of emergence, self-similarity, self-organization and non-linear behavior of land use changes with time (Micheal Batty & Longley, 1994). The use of tools that can help in the understanding of the above–mentioned characteristics is important to gain knowledge about the patterns and mechanisms behind urban dynamics (Sanchez, Z.Vojinovic, Price, & Waly, 2011).If predominantly based upon local interactions, complex systems can be modeled as cellular automata (Blecic, Cecchini, Prastacos, & Trunfio, 2004). Inherently bottom-up, friendly to use and interactive CAs can be an effective way to test and evaluate planning actions(Blecic et al., 2004). What makes CA-based models particularly attractive is their ability to "spontaneously" give rise to global dynamics out of local interaction rules(Michael Batty, 2005). Furthermore, these tools do not tend to simplify reality, but rather employ its complex nature, which makes them an effective instrument for the exploration of spatial dynamics(Blecic et al., 2004). CA were first introduced in the 1940s by John von Neumann, the founder of game theory, and Stanislaw Ulam, who worked in the Manhattan Project and did intensive research in the field of Monte Carlo simulation (Pinto & Antunes, 2007).

When considering the use of CA in urban studies,several CA based applications are proposed and applied to various geographic - spatial phenomena and to understand the growth of different urban regions(Pinto & Antunes, 2007). During the next two decades, a great effort was made to develop CA-based models: Couclelis (1997), White and Engelen (1997)and Michael Batty (2005)had intensively worked on different theoretical underpinning issues regarding CA application to urban studies. M Batty and Xie (1997)and Clarke, Hoppen, and Gaydos (1997) studied the application of important evolutions of CA to real world problems, Semboloni (2000)studied urban infrastructure development, O'Sullivan (2001)used an integrated approach based on CA and on graph theory to study gentrification and Silva and Clarke (2002) had calibrated a CA model- SLEUTH (slope, landuse, exclusion, urban extent, transportation and hillshade)- to simulate the urban growth model for Lisbon and Porto, Portugal, while Barredo, Kasanko, McCormick, and Lavalle (2003)made applications of previously developed CA models to large metropolitan areas.

As stated above, several cellular automata modelshave been developed during the past years to simulate the land use changes and tounderstand their complex nature. 'Metronamica' is one of the modeling applications which have successfully captured this complex nature. Factors affecting land use changes in a particular context aredependent on the characteristics of the particular area. Therefore there is no set method to simulate land use changes in cities. Metronamicaconsists of a dynamic, spatial land use change model and can optionally include a regional migration model and a transport model for modeling congestion and traffic pressure on the transport network (RISK, n.d.).

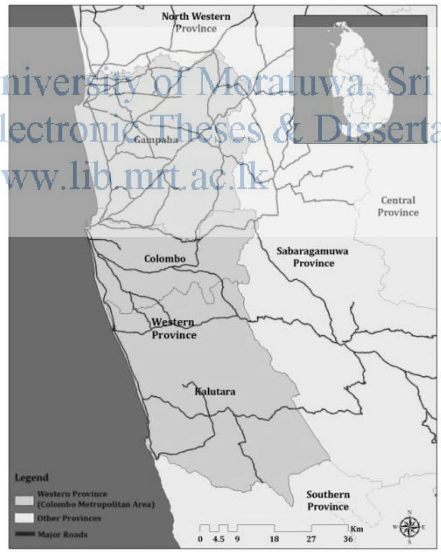
Metronamica simulates land use changes based on a number of different drivers. First, there are external factors such as population growth or the decrease of natural area that determine the demand for different land uses. Populations and jobs are divided over the regions, based on how attractive these regions are to people and businesses. This attractiveness depends again on a number of factors such as the existing activities and local characteristics such as the accessibility. Finally, within each region, the land uses for every location are determined based on socio-economic factors (e.g., will a business flourish in this location?), policy options (e.g., are there policy rules in effect that restrict new housing development in this location?) and biophysical factors (e.g., is the soil suited for agriculture here?) (RISK, n.d.).

The Studyand the Methodology

The Colombo Metropolitan Region (Western Province), Sri Lankais selected as thecase study area of the study. The Colombo Metropolitan Region consists of three districts; Colombo, Gampaha and Kalutara. The total land area of Colombo Metropolitan region is about 3,745 square kilometers.

As per the Department of Census and Statistics (2012) the total population is 5,835,852. Over the years, Colombo had become the main economic and administrative hub in the country and the western province is the main contributor to the GDP of the country. Relatively, a large portion of the employments and other infrastructure facilities are concentrated within this region thatmakes the region with the highest population concentration.Availability of data was another crucial factor that justifies the selection of case study area. A conceptual framework was developed considering the factors identified through literature review to simulate the land use pattern in the Colombo Metropolitan region (Western Province) with the effect of transportation, zoning regulations, interactions between land uses and physical suitability for different land.

Figure 012: Colombo metropolitan region (Western province)



Cell structure

Cell structure is considered as the first component of a CA model. The inbuilt regular cell structure of the Metronamica model is taken for this study. The cell size for the model was considered as 100mx100m (2.47acres).

Cell states

Eleven cell states were assigned for the model by taking eleven land use categories. Namely: highly urbanized, moderately urbanized, less urbanized, very less urbanized, waterbodies, paddy, marsh, forest, other crops/ cultivation, sand/beach and rocks. In this, highly urbanized, moderately urbanized, less urbanized, very less urbanized, paddy and marsh were considered functional cell states, while Forests, rocks, sand/ beach and water bodies were taken as feature states- fixed cell states - which will not change over time and other crops was considered as a vacant land use. Accordingly the functional cell states can change its states with the model simulation. This means that land use dynamics are allowed in six land uses classes. The potential probability for change and the strict legislation framework existing in the country on preserving forests, beach and water resources had been taken to consideration in assigning fixed cell states.

As the main consideration is on simulating urban growth pattern, the data sets were prepared accordingly. In the original map layer there was no land use category named urban. Instead there were categories named built up and homestead. So these two land uses were categorized into four urban categories named highly, moderately, less and very less urban based on the population density, intersecting the land use with population data using the Arc GIS application.

Neighborhood

The extent to which land use interactions occur is incorporated to the CA model through the neighborhood component. For each location, each cell that is, the model assesses the quality and the character of its neighborhood.As Pinto and Antunes (2010) argued, neighborhood component plays a key role on the overall CA modelling framework since it's representing the spatial extent of interactions, embodying Tobler's theory on geography; " everything is related to everything else, but near things are more related than distant things"(Tobler, 1970). The neighborhood for the standard Metronamica model is defined to be a circular area with a radius of 8 cells containing 196 nearest cells (Delden, Escudero, Uljee, & Engelen, 2005). The same is adopted in this study. In spatial terms the neighborhood in CA represents a distance of 800mfrom the considered cell.

Transition rules / Neighborhood rules

The dynamism of the CA models relies on the transition rules of a CA model. Cellular Automata models consider various factors in transition of land uses. The pre-defined rules of the original model are used in the study. In the Metronamica cellular automata land use model, there are pre-defined rules. It considers four factors; *neighborhood effect, suitability, accessibility* and *zoning*. Transition potential of a cell is determined by the result of all these four factors. Accordingly, the transition potential for land use function *f* in cell *c* ($^tPf,c$) is calculated using the following equations:

$$^tV_{f,c} = \begin{cases} {}^tR_{f,c}\,.\,(1+e) & \text{if } \alpha > 0 \\ {}^tR_{f,c} & \text{else} \end{cases}$$

$$^tP_{f,c} = \begin{cases} {}^tV_{f,c}\,.\,{}^tS_{f,c}{}^tZ_{f,c}{}^tA_{f,c} & \text{if } {}^tV_{f,c} \geq 0 \\ {}^tV_{f,c}\,.(2 - {}^tS_{f,c}\,.\,{}^tZ_{f,c}\,.\,{}^tA_{f,c}) & \text{else} \end{cases}$$

Here transition potential is a multiplication of neighborhood potential ($^tR_{f,c}$), suitability ($S_{f,c}$), zoning ($^tZ_{f,c}$) and accessibility ($^tA_{f,c}$). If a stochastic perturbation is included, two extra factors are taken into account: a random value drawn from a Weibull (1/α ,1) distribution (*e*) and a parameter that controls the extent of the random effect in the potential (*a*). The value of this last parameter must be in the range [0,1]. For vacant states the transition potential is: $^tP_{f,c} = {}^tS_{f,c}$(RISK, n.d.). These four factors have been calculated using several algorithms separately.The findings of this paper are based on the simulations carried out with the neighborhood effect, suitability, and accessibility factors.

Neighborhood Effect

Neighborhood effect is dependent on the interaction of different land uses with each other. In the model, the neighborhood distance is 8 cells. It will create a sophisticated model if all the cells were assigned a value. So the influence functions are transformed to splines defined by only four points rather than calibrated to all 30 points.

The points which give the influence functions are (0, inertia), (1,a), (d,0) and a point between the second and last point (RISK, n.d.).

$$^{t}R_{f,c} = \sum_{c' \in D(c)} w_{f,{}^{t}f(c')}(d\,(c,c'))$$

$^{t}R_{f,c}$ = The neighborhood effect in cell *c* for land use *f* at time *t*.
^{t}f (c) = The land use occupied by cell *c* at time *t*.
d(a,b) = The Euclidian distance between cell *a* and cell *b*
$w_{f,f'}$ (d) = The influence function, expressing the strength of the influence of a cell with land use *f'* on land use *f* for each distance *d* in the CA neighborhood.

Suitability

Suitability maps are based on physical characteristics of a location. These remain constant during simulation, but affect the transition rules. There is no algorithm which is applicable. The value applied during the map preparation will be taken into consideration.

Accessibility

Accessibility is an expression of the ease with which an activity can fulfill its needs for transportation and other infrastructure in a particular cell based on the infrastructure network. The accessibility is calculated per land use function. In the model, four types of accessibility are considered; local accessibility, zonal accessibility, implicit accessibility and explicit accessibility. The total accessibility is calculated per land use function and only changes if the user changes the zonal accessibility parameters in the transport model or the infrastructure network or the accessibility coefficients. In other words, the importance of different land use functions of different elements of the network is incorporated in the land use model. Total Accessibility of a cell is defined as:

$$^{t}A_{f,c} = \begin{cases} ^{t}EA_{f,c} & \text{if } ^{t}f(c) \in LU_{I} \\ ^{t}ZA_{f,z_c} \cdot {}^{t}LA_{f,c} \cdot {}^{t}IA_{f,c} \cdot & \end{cases}$$

$^{t}EA_{f,c}$ = the explicit accessibility of cell *c* for land use *f*
^{t}f (c) = the land use occupied by cell *c*
LU_I = The set of impassable land uses
$^{t}ZA_{f,z}$ = the zonal accessibility for land use function *f* in transport zone *z*, z_c the transport zone, in which cell *c* is located
$^{t}LA_{f,c}$ = Local accessibility of cell *c* for land use *f*
$^{t}IA_{f,c}$ = The implicit accessibility of cell *c* for land use *f*(RISK, n.d.)

Since,only the land use model has been used in this study, the zonal accessibility has not been considered as it is based on the generalized cost from a transport zone to origins and destinations**.** In the Metronamica application, this was calculated through the transport model of the application.

Local Accessibility

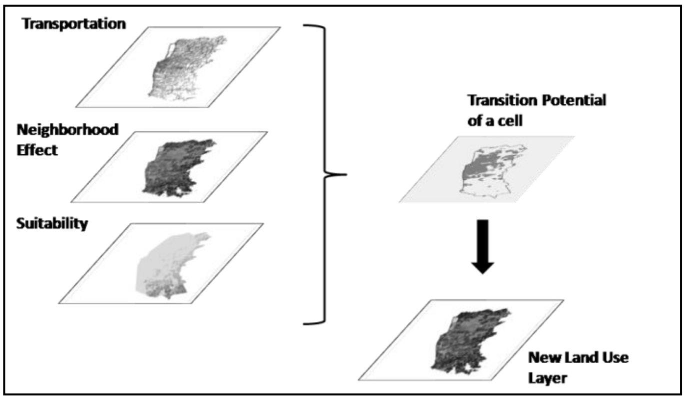
Local accessibility represents the extent to which the need for the presence or absence of the transportation network of a land use can be fulfilled.Local accessibility of cell c to link type 's' for land use 'f' is calculated by;

$$^{t}LA_{s\,f,c} = \begin{cases} \dfrac{a_{s,f}}{D_{s,c} + a_{s,f}} & \text{if } a_{s,f} > 0 \\ 0 & \text{if } a_{s,f} = 0 \\ 1 - \dfrac{|a_{s,f}|}{D_{s,c} + |a_{s,f}|} & \text{otherwise} \end{cases}$$

$^{t}LA_{s,f,c}$ = Local accessibility of cell *c* to link type *s* for land use *f*
$^{t}D_{s,c}$ = Distance (in cells) between cell *c* and the nearest cell that is covered by link type *s* at time *t*
$a_{s,f}$ = Accessibility distance decay parameter, expressing the importance of good access to an infrastructure element of type *s* for land use *f*(RISK, n.d.)

Implicit accessibility takes one of two possible values for each land use class; one for urbanized areas and one for non-urbanized areas(RISK, n.d.). The explicit accessibility is defined as the areas occupied by some specific land uses – such as lakes – which cannot be crossed and which should be taken into account when considering the distance from a certain location to the nearest link of a certain type(RISK, n.d.).

Figure 02: Conceptual illustration on the modeling framework



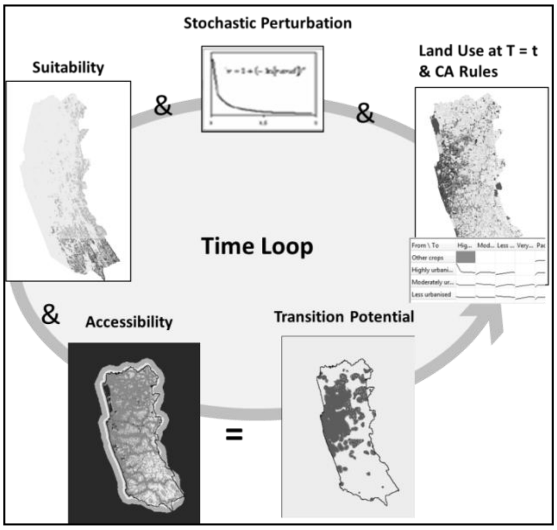
Calibration framework

CA models need to be calibrated in order to ensure the best possible application between the simulated outcomes and the reality that is being modeled. The time step of this model is taken as one year. During each time loop, the model is dynamically evolved with the mentioned algorithms of each factor. Figure 03 represents the overall modeling process.

Within the scope of this study, the tools available for the model validation in the Metronamica are used to test the calibration results. Further, it is required more time for validation for every new rule introduced. Visual inspection of the simulated maps is, of course, an important method used to validate the result, but the modelling tools and the Map Comparison Kit offer a wide range of methods to qualify and quantify the results (Fertner, Jørgensen, & Nielsen, 2012). TheMap Comparison Kit was developed by the Research Institute for Knowledge Systems in the Netherlands and was obtained with the application.

Global measures were used to compare the global performance of the model, focal measures to compare the compare the similarities in a certain radius of a cell and local measures to analyze the analogy of single cells. In this paper, the validation is done using global measures by analyzing the total number of cells in a certain category that have changed in simulation and reality. The local measure used to assess the local performance of the model and evaluated using the contingency table and Kappa simulations. (Fertner et al., 2012).

Figure 03: Modelling process



Neighborhood influence parameter

Neighborhood effect was defined based on the attraction and repulsion between different land uses. Among the land use categories, a set of land use pairs having high levels of interaction were selected. The rules were defined to match the observed interactions of land uses and with the knowledge available on these. Then the model was run until the end of the calibration period, and the final land use map generated by the model was compared with the actual land use map of 2010. Then the similarity between two maps was checked. When the maps did not approximate enough, the rules were changed, and the model was run again. This process was continued until having a high degree of similarity between the model output and the real map. The values of the influence were based on the knowledge taken by literature review. Not the value of influence, but the relative influence is taken to decide the transitional potential.

Accessibility parameters

Accessibility parameters were set considering the influence on functional land uses by different types of roads. Accessibility for urbanized land uses were considered more important than the other land uses. So the accessibility parameters were defined accordingly. Marsh, water bodies, sand/ beaches and rock/ quarry land uses were considered impassable land uses for networks.

Table 01: Accessibility parameters for the model

Road Category	Highly Urbanized		Moderately Urbanized	
	Distance Decay	Weight	Distance Decay	Weight
Main Roads	1 km	1	2km	0.7
Minor Roads	500m	0.75	1km	0.7
Jeep/ Cart Tracks	250m	0.5	500m	0.6
Footpath	50m	0.2	100m	0.3
Railway Stations	500m	0.1	500m	0.1

Preparation of dataset

Data and data sources

Datasets required for the model were basically collected from the Survey Department and the department of Census and Statistics. Land use maps were prepared using the shape files gained from the Survey Department. Data was only available for two years. The Slope map was prepared using the DEM (Digital Elevation Map) layer in Arc GIS application. Road networks and railway stations were considered for the accessibility. Road layers were considered for two years. Initial layer in 1987 and the road network changes of main roads in 1996.

Table 02: Data and data sources

Data	Type of Data	Source
Land use maps (1987 & 2010)	Shape files	Survey Department of Sri Lanka
Population data	Shape files	Department of Census and Statistics
Road and Railway Network	Shape files	Survey Department of Sri Lanka Road Development Authority of Sri Lanka
Elevation data	Shape files	Survey Department of Sri Lanka

Macro Model Data

Overall demand for functional land uses in 1987 and 2010 were defined in the model at the beginning as to indicate whether those land uses increase or decrease. Cell counts for each land use for both 1987 and 2010 were obtained from respective land use maps. The growth was considered as a linear growth and cell count for all the functional land use categorieswere increased during the above period.

Table 03: Macro model data set preparation

Land Use Category	Cell Count (1987)	Cell Count (2010)	1980- 2010 (+/-) %
Highly urbanized	14675	15000	2.21
Moderately urbanized	11093	16497	48.72
Less urbanized	25962	31705	22.12
Very less urbanized	48825	50471	3.37
Paddy	61495	63644	3.49
Marsh	3456	3543	2.52

Results and Discussion

The model was calibrated by taking 1987 as the base year and for the period of 1987-2010. Themodel was calibrated by 20 occasions to achieve the satisfied level.

Contingency table

Contingency table details the cross distribution of categories on the two maps selected. The table 4 is expressed in number of cells.

Table 04: Contingency table for land use map of 1987(Vertical) and 2010 (Horizontal)

	Other Crops	Highly Urbanized	Moderately Urbanized	Less Urbanized	Very Less Urbanized	Paddy	Marsh	Total
Other Crops	110888	1739	1834	4651	11017	22989	126	153244
Highly Urbanize	2414	8871	2018	509	148	640	75	14675
Moderately Urbanized	2253	615	5777	1392	322	734	0	11093
Less Urbanized	6005	776	2270	12631	1871	2400	9	25962
Very Less Urbanized	13300	537	707	4741	26753	2787	0	48825
Paddy	2832	2358	3840	7769	10315	34086	295	61495
Marsh	198	104	51	12	45	8	3038	3456
Total	137890	15000	16497	31705	50471	63644	3543	

According to the results, it clearly shows that highly urbanized lands have been converted into other land uses although the rule was given to prevent that. But most of the highly urbanized lands have remained the same. Other land use categories also show this same pattern. Marsh has been correctly simulated to a considerable degree converting in fewer amounts into any other land use.

Kappa Statistics

Kappa is the measure of agreement between the two categorical maps. It is less than or equal to 1. A value of 1 indicates perfect agreement and values less than 1 indicate less than perfect agreement. This can be interpreted as follows (table 05):

Table 05: Defining kappa measure -agreement and values

Agreement	Value range
Poor agreement	Less than 0.20
Fair agreement	0.20 to 0.40
Moderate agreement	0.40 to 0.60
Good agreement	0.60 to 0.80
Very good agreement	0.80 to 1.00

Kappa for this model map is 0.467 which is a moderate agreement. It should be more than 0.8 to be a very good agreement. But these results indicate that the modeled map has a moderate level of agreement to the original map (table 06).

Table 06: Kappa values for simulated maps

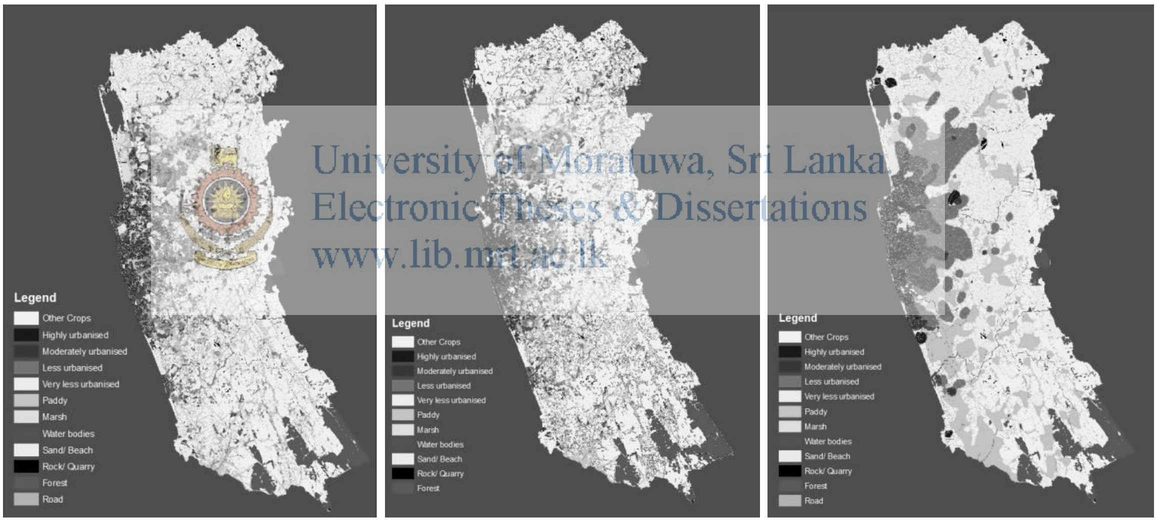
Land Use / cell states	Highly Urbanized	Moderately Urbanized	Less Urbanized	Very Less Urbanized	Paddy	Marsh
Kappa values	0.427	0.255	0.297	0.393	0.403	0.815

Kappa of individual land use categories indicates a very good agreement of marsh which is 0.815. Paddy and Highly urbanized land use are under a moderate agreement and moderate and less urbanized land uses are within fair agreement.

Visual Interpretation

Visual comparison is recognized as one of the suitable methods used in thecalibration process. Changes which have been occurred during the years can be observed visually which gives a clear idea of how different land uses have been changed or distributed over the years. For the visual comparison, three maps were used; Initial land use map of 1987, 2010 Land use map, and Modeled 2010 land use map.

Figure 04: Visual representation of actual maps (1987 and 2010) and simulated map 2010



Initial Land Use Map 1987 | Actual Land Use Map 2010 | Modeled Land Use Map 2010

In considering the differences between the actual land use map of 2010 and the modeled map of 2010, it displays the number of overlapping cells in both maps.

Table 07: Analysis of the simulation results with global measure

Land Use Category	Cell count in 2010 Actual Map	No of cells in Both 2010 modeled map and 2010 Actual map	No of cells in modeled 2010 map which not overlapping with 2010 Actual map	Level of Accuracy (Percentage)
Highly Urbanized	15000	6745	8255	44.97
Moderately Urbanized	16497	4752	11745	28.81
Less Urbanized	31705	11313	20392	35.68
Very Less Urbanized	50471	23980	26491	47.51
Paddy	63644	32081	31563	50.41
Marsh	3543	2892	651	81.63

According to the comparison, it clearly shows that the model has been capable to generate the patterns of marsh land to a higher extent which is 81.63 percent. Among urban categories, very less urbanized (47.51%) land use is the most correctly simulated land use and secondly the highly urbanized land (44.97%). Paddy also has been simulated with more than 50 percent of accuracy. But the model has not been capable of generating patterns in urbanized land uses with a higher level of accuracy.

Table 08: Map comparison (1987 with actual 2010 Map)

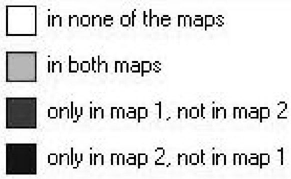
Land Use Category	In both Maps	Only in map 1 (1987)	Only in Map 2 (actual 2010)
Highly Urbanized	10254	4421	4746
Moderately Urbanized	6471	4622	10026
Less Urbanized	18356	7606	13349
Very Less Urbanized	40216	8609	10255
Paddy	56412	5083	7232
Marsh	3239	217	304

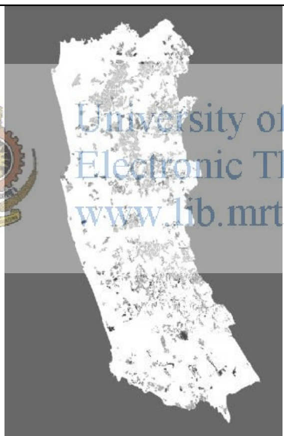
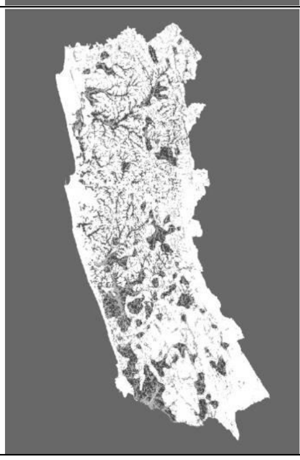
Table 09: Map comparison (1987 with modeled 2010 Map)

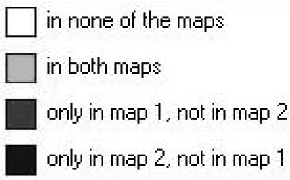
Land Use Category	In both Maps	Only in map 1 (1987)	Only in Map 2 (Modeled 2010)
Highly Urbanized	8871	5804	6129
Moderately Urbanized	5777	5316	10720
Less Urbanized	12631	13331	19074
Very Less Urbanized	26753	22072	23718
Paddy	34086	27409	29558
Marsh	3038	418	505

The comparison between the 1987 land use map with the actual land use map of 2010 and the modeled map of 2010 shows how the land uses appeared and disappeared within the region and how land uses have been changed. It also shows to what level the modeled map has been capable to simulate the change between two years.

Figure 05: Comparing the actual change and model change from 1987- 2010 for selected land use categories

Land Use Category	Actual Change Map 1 - Land Use 1987 Map 2 – Land Use 2010	Modeled Change Map 1 – Land Use 1987 Map 2- Modeled Land Use 2010	
Highly Urbanized			

Moderately Urbanized			in none of the maps in both maps only in map 1, not in map 2 only in map 2, not in map 1
Less Urbanized			in none of the maps in both maps only in map 1, not in map 2 only in map 2, not in map 1
Very Less Urbanized			in none of the maps in both maps only in map 1, not in map 2 only in map 2, not in map 1
Paddy			in none of the maps in both maps only in map 1, not in map 2 only in map 2, not in map 1

Marsh			

These calibration results show that the model has been capable of modeling marsh lands with a great level of accuracy. In the modeled map, land uses have been concentrated in many places and the small patches have been disappeared.

According to the analysis, the model has been successful in capturing the dynamics of marsh lands up to 81.63. Although the main focus of the model was to capture the dynamics of urban land uses, the model didn't show a considerable result. This may be mainly due to the neighborhood rules which were not implemented correctly. For this study, urban land uses were categorized according to the population density. This may be caused for this result as these neighborhood rules were not capable of capturing the dynamics of population density distribution.

Conclusions

The findings of the study hasindicated the possibilities of employing this model as a potential tool in simulating urban land uses in Sri Lanka. It is found that model had simulated the changing pattern of marshy lands with a high level of accuracy. Simulations of highly urbanized and less urbanized land uses also showed relatively higher levels of accuracy of nearly 50%. More importantly, this modeling exercise opened up further avenues to explore further on land use dynamics and to investigate the validity of the results obtained from a simulation of this nature and the contingencies involved in it.

Despite the promising results of the application of the model, there is significant space for further improvements and customization of the tool in the decision making process. It is understood that the number of calibrations needs to be increased by changing the basic parameter values of the neighborhood rules.

As Byrne (1997) stated, the simulation is clearly a tool which helps us not to know what will happen, but what can be made to happen. In this manner, this will be a very useful tool forplanning decision makers as it can handle dynamic factors and visualize those changes, which will be instrumental towardsmaking better informed decisions.However, the constraints related to technicalities and the information sourcing need to be addressed infutureapplications of the model.

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