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INTEGRATION OF REMOTE SENSING AND GIS WITH SLEUTH TO CHARACTERIZE THE URBAN GROWTH OF MATARA, SRI LANKA

S.P.INOKA SANDAMALI [1], LAKSHMI N. KANTAKUMAR[2] & S. SIVANANTHARAJAH[3]

[1]Mahaweli Authority of Sri Lanka, 3rd floor, No.500, T.B. Jayah Mawatha, Colombo10

in.sandamali@gmail.com,

[2]Institute of Environment Education and Research, Bharati Vidyapeeth University, Dhankawadi, Pune, Maharashtra 411043, *Lakshmikanth@bvieer.edu.in,*

[3]Senior Supdt. of Surveys (GIS), District Survey Office, Park Road, Jaffna. *siva271.survey@gmail.com*

Abstract

Urbanization causes population growth and physical expansion of built-up area in cities and its suburb. It puts immense pressure on natural resources, conversation of agricultural land and degradation of water, air qualities and have profound impact on human lifestyle and health. Since last two decades, Sri Lanka is experiencing speedy urbanization. The urban population of Sri Lanka is expected to reach 60% by 2030 from 14% in 2010. This rapid increase in urban population may cause serious socio-economic disparities. In-order to plan for a sustainable urban future in Sri Lanka, planners are in need of new tools that can be capable to monitor and predict the urban growth under various scenarios. In this paper, we attempted to characterize the urban growth characteristics of Matara city using Geoinformatics and SLEUTH model. SLEUTH is a well-known urban growth model based on cellular automata. Multi-temporal remote sensing datasets from 1980-2010 have been used quantify the urban growth of Matara. SLEUTH model is calibrated using the data sets prepared from aerial photographs, Landsat sensor data and topographical data from Survey department. The derived calibration coefficient are used to project the growth of Matara by 2030 to understand and analyze the areas that are likely to be urbanized by 2030. The model results showing that out of 66 Grama Niladari Divisions 29 (in Matara Divisional Secretariat Division) will be urbanized with a probability ranging from 80% to 90%.

Keywords. *Geoinformatics, Remote sensing, Cellular Automata, SLEUTH , Matara*

1. Introduction

Urbanization is a spatiotemporal process of conversion of rural land into urban. Since, unplanned urbanization involves in breakdown of natural and social cohesion, it often regarded as destructive process as per *Anti Urban* view. On the contrary, a well-planned urbanization empowers the nation's economic development and provides better access to employment, education and health care to citizens. Sri Lanka experiencing a speedy urbanization since few decades. United Nations Habitat report (2009) has illustrated, the urban population of Sri Lanka will reach to 60% by 2030 from 14% in 2010. This massive growth in urban population unless handle properly, it may create serious socio-economic disparity which is hard to fix. In-order to plan for a sustainable Sri Lanka, planners are in need of new tools that can be capable to monitor historic urban growth and project their city growth into near future under various scenarios. Recent advancement in Geoinformatics and complexity science given birth to new age urban models based on Cellular Automata (CA) and Agent Based Models (ABM). These models are capable to project the city growth into near future both on spatial and temporal scale. KantaKumar et al. (2011) has illustrated, the CA and ABM model are based bottom up approach Geoinformatics used extensively to map and manage the rapidly growing urban areas. Chaudhuri & Keith (2013) are presented, CA based SLEUTH model is widely used to simulate the urban growth of cities all over the world. In this study, SLEUTH model is used first time to simulate the urban growth of a Sri Lankan city Matara. The city of Matara is witnessing rapid urban and socio-economic growth since last two decades. The main objective of the study is to understand the urban growth characteristics of Matara city and projecting its urban growth under business as usual scenario.

2. Study Area & Methodology

2.1. STUDY AREA

The Matara city is located on the southern coast in Sri Lanka. It is situated 160 km south of Colombo. The Matara city is one of the main commercial center in Sri Lanka and administrative capital of Matara District. It was known as "Mahathota" means "The great ferry". L.H. Indrasiri (2002) has presented it is one of the largest city and in currently the city is second order regional urban center in Sri Lanka. Fig. 1 shows the study area called Matara Divisional Secretariat Division (DSD). The study area bounded between 5°59'9.41"N to 6°00'05.60"N latitudes and 80°30'2.32"E to 80°37'57.62"E longitudes. It falls in the toposheet number 91 on 1:50000 issued by Survey Department. The Matara city historically belongs to the area called Ruhuna, one of the three kingdoms in Sri Lanka (Thun Sinhalaya).The town contains many remnants of Sri Lanka's colonial period and was dividing by the island's third longest river the Nilwala Ganga (Blue River).

Figure 1: Study area

Urban Development Authority (UDA) was declared a municipality in 2002 including 18 Grama Niladari Divisions (lowest administrative unit) and recorded immense growth with the higher infrastructure development projects. Information related to population in census 2001 (only Matara DSD) disseminated by urban population as a 40% (Department of Census and Statistics, 2001). As a result of that UDA was decided to expand the municipality in 2010 incorporated with 46 of GNDs (Figure 2). Predicted that by 2030, urban population is gradually increasing from 40% to 68% in the study are.

2.2. METHODOLOGY & SLEUTH IMPLEMENTATION

The research methodology adopted here was actually based on requirement of SLEUTH model (fig. 3). The aerial photographs were used to calculate urban extent in the year of 1980. A time series of Landsat imageries specific to Thematic Mapper, Enhance Thematic Mapper + sensors were downloaded from Global Land Cover Facility website. All the datasets were re-projected to Kandawala Sri Lanka Grid and clipped to the study area. The Landsat dataset was used to prepare urban extent and land use maps of 1990, 2000 and 2010. Maximum likely hood supervised classification method was used to classify the Landsat dataset into five land-use and land-cover classes, i.e. Built-up land (urban), homestead and garden, forest, marsh or paddy and water. Accuracy of the land-use maps were carried out with the help of existing 1: 100000 land use data, 1: 1000 (Survey dpt., 1986 and 2008 respectively) and Google imageries 2011 (Spot image). Digital Elevation Model (DEM) with resolution of 5m prepared by 1:10,000 spot heights data obtained from Survey Department. Hill shade layer was prepared by using

DEM of 5 m resolution. The model required at least two road network. Therefore one road layer was extracted from 1980 aerial photographs and other was extracted from road layers (1:10000) which prepared by the Survey Department in 2008. Fig. 3 shows the methodology of study.

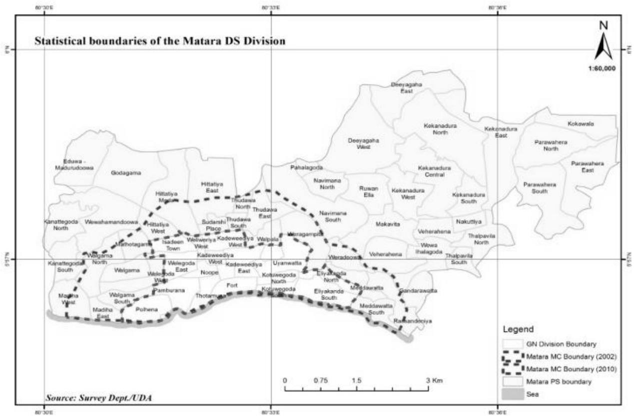

Figure 2. Expansion of City boundary

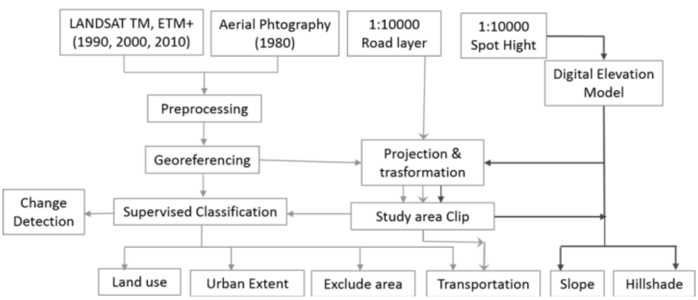

Figure 3. Research Methodology

Format standards for all data layers should be

- Grayscale Graphics Interchange Format (GIF)images
- Images are derived from grids in the same projection (Kandawala Sri Lanka Grid)
- Images are derived from grids of the same map extent
- Images the same resolution [row(471) x column(236) count is consistent]
- Images follow the required naming format <location>.urban.<date>.[<user info>].gif

The model was used here as a tool to project future urbanization pattern in the study area via the calibration under business as usual scenario (continuation existing development condition). To run model required inputs are historic urban extent at least 4 time of period, at least two historic Land use layers, historic transportation network at least two time periods, slope and excluded layers (Water layer). The figures 4 shows the inputs maps use to run the model.

The implementation of the SLEUTH involves three steps called as test, calibration and prediction. Before the Calibration phase test mode is important to verify the input data requirements and their response. The calibration stages are helping to assign best fit values for prediction stage of the study area. By the weighted sum of statistical measures, the best combination is identified. Table. 1 shows the results of each steps of modelling simulation.

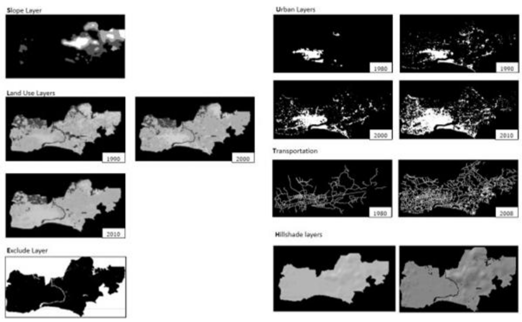

Figure 4. Input maps

Table 1. Model input data test and calibration parameters

Calibration Phase Input						
Items		Test	Coarse Calibration	Fine Calibration	Final Calibration	Derived parameters
Model Input Data	Image Resolution	30	30	30	30	
	Slope	mat30.slope.gif	mat30.slope.gif	mat30.slope.gif	mat30.slope.gif	
	Land use	mat30.landuse.1990.gif	mat30.landuse.1990.gif	mat30.landuse.1990.gif	mat30.landuse.1990.gif	
		mat30.landuse.2000.gif	mat30.landuse.2000.gif	mat30.landuse.2000.gif	mat30.landuse.2000.gif	
		mat30.landuse.2010.gif	mat30.landuse.2010.gif	mat30.landuse.2010.gif	mat30.landuse.2010.gif	
	Excluded	mat30.excluded.gif	mat30.excluded.gif	mat30.excluded.gif	mat30.excluded.gif	
	Urban	mat30.urban.1980.gif	mat30.urban.1980.gif	mat30.urban.1980.gif	mat30.urban.1980.gif	
		mat30.urban.1990.gif	mat30.urban.1990.gif	mat30.urban.1990.gif	mat30.urban.1990.gif	
		mat30.urban.2000.gif	mat30.urban.2000.gif	mat30.urban.2000.gif	mat30.urban.2000.gif	
		mat30.urban.2010.gif	mat30.urban.2010.gif	mat30.urban.2010.gif	mat30.urban.2010.gif	
	Transportation	mat30.roads.1980.gif	mat30.roads.1980.gif	mat30.roads.1980.gif	mat30.roads.1980.gif	
		mat30.roads.2008.gif	mat30.roads.2008.gif	mat30.roads.2008.gif	mat30.roads.2008.gif	
	Hillshade	mat30.hillshade.gif	mat30.hillshade.gif	mat30.hillshade.gif	mat30.hillshade.gif	
		mat30.hillshade.water.gif	mat30.hillshade.water.gif	mat30.hillshade.water.gif	mat30.hillshade.water.gif	
Calibration Parameters	Calibration Mode	Test	Calibrate	Calibrate	Calibrate	
	Monte Carlo Iteration	1	4	7	8	100
	CALIBRATION_DIFFUSION_START	5	0	0	1	1
	CALIBRATION_DIFFUSION_STEP	1	25	5	1	1
	CALIBRATION_DIFFUSION_STOP	5	100	25	1	1
	CALIBRATION_BREED_START	5	0	25	30	40
	CALIBRATION_BREED_STEP	1	25	5	1	1
	CALIBRATION_BREED_STOP	5	100	50	30	40
	CALIBRATION_SPREAD_START	10	0	75	90	100
	CALIBRATION_SPREAD_STEP	1	25	5	1	1
	CALIBRATION_SPREAD_STOP	10	100	100	90	100
	CALIBRATION_SLOPE_START	95	0	75	75	1
	CALIBRATION_SLOPE_STEP	1	25	5	5	1
	CALIBRATION_SLOPE_STOP	95	100	100	75	1
	CALIBRATION_ROAD_START	5	0	0	1	9
	CALIBRATION_ROAD_STEP	1	25	5	1	1
	CALIBRATION_ROAD_STOP	5	100	25	1	9
Best FIT values	PREDICTION_DIFFUSION_BEST_FIT	20	20	12.5	1	1
	PREDICTION_BREED_BEST_FIT	20	20	37.5	30	40
	PREDICTION_SPREAD_BEST_FIT	20	20	87.5	90	100
	PREDICTION_SLOPE_BEST_FIT	20	20	87.5	75	1
	PREDICTION_ROAD_BEST_FIT	20	20	12.5	1	9

3. Results & Discussions

3.1. DEMOGRAPHIC CONDITION

The impact of rapid urbanization of Matara city is change in the urban environment. Especially increasing population in the study area causes rapid change in land and loss of natural vegetation. Over the last 14 years urban population of the Matara have experienced dramatic growth. Statistics are mentioned in Table 2 that the population is gradually increasing from 40% in 2001 to 68% in 2030 in the study area.

Table 2: Population of the Matara Four Gravets 2001-2030

Year	2001	2009	2020*	2030*
Urban Population	43,442	47,418	89,333	97,707
Rural population	64,796	70,415	40,705	44,520
Total Population	108,238	117,833	130,038	142,227

Source: Department of Census & Statistics report 2001 Resource profile Matara DSD, 2009. *Estimated population

3.2. CHANGE DETECTION

As a result of rapid urbanization process most of the homestead garden and forest lands are converting to the built-up area. Multi-temporal satellite imageries (1990, 2000 and 2010) are showed the changes in land-use in last 20 years (Fig. 5). Supervised classification using maximum likelihood classification was performing with TM and ETM+ Landsat images for the summarized land use change. Training samples were selected with the assistance of land use map (1:10,000), Topographical sheets (1:50,000) data as well as aerial photographs of the study area. Training samples were selected to be detailed as possible in the study area, for example urban, homestead/garden, marsh or paddy, forest and water.

The change detection of land was summarized by using the intersect tool in ArcGIS 10. The nature of change was to analyze land conversions using matrix analysis. This method was use to characterize the land conversions for the periods from 1990-2000 and from 2000-2010 (Table 3 and Table 4)

There are 25 possible combinations for each time period. This study focused on the urban characterization, because only 5 combinations were selected for further analysis related to urban land conversion, such as urban (no change), homestead/garden into urban, forest into urban and water into urban. The other combinations were merged into single (Table

5). The loss of homestead/garden category has contributed to irresistible share of urban growth among other land use categories. During 1990-2000 urban use had a net addition of 556 ha (10%) and 2000-2010 it was increasing to 1046 ha (19%). The urban extents were selected for model calibration phase with slope, land use, exclude, transportation and hill shade.

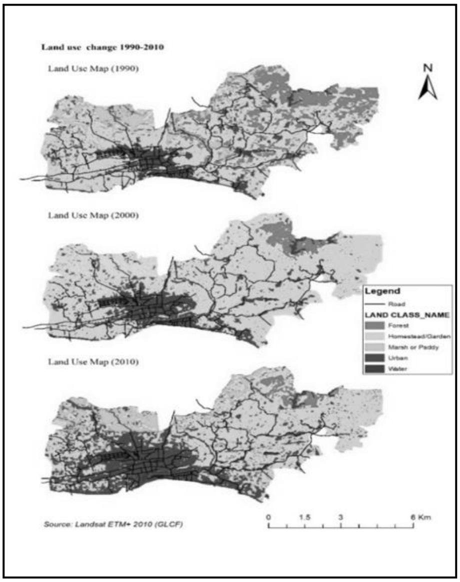

Figure 5. Land use change 1990-2010

Table 3: Transition matrix of land-use change from 1990-2000

Land use category/ Extent (ha)	Urban	Homestead/Garden	Marsh Or Paddy	Forest	Water	2000
Urban	411	416	45	17	33	922
Homestead/Garden	140	2433	248	775	64	3660
Marsh Or Paddy	25	154	341	21	50	591
Forest	1	34	11	202	5	253
Water	16	7	26	8	72	130
1990	593	3044	670	1023	224	5555

Table 4: Transition matrix of land-use change from 2000-2010

Land use category/ Extent (ha)	Urban	Homestead/Garden	Marsh Or Paddy	Forest	Water	2010
Urban	698	863	113	2	20	1697
Homestead/Garden	183	2626	143	111	17	3079
Marsh Or Paddy	31	98	319	6	21	474
Forest	1	54	5	126	14	200
Water	9	19	11	7	57	104
2000	922	3660	590	253	129	5555

Table 5: Urban land conversion in different time period

Nature of change	Urban Land Conversion (ha)			
	1990-2000	%	2000-2010	%
Urban (No change)	411	7	698	13
Homestead/Garden into Urban	556	10	1046	19
Marsh Or Paddy into Urban	70	1	144	3
Forest into Urban	18	0	3	0
Water into Urban	49	1	29	1
Other combinations	4451	80	3634	65

3.3. URBAN GROWTH PROBABILITIES IN 2030

SLEUTH model was used here as a planning tool to visualize and project the urban growth of the Matara city. KantaKumar et al (2011) has illustrated models are often judged by their predictive power. The urban growth was simulation by using the best fit values (fig. 3) which derived from final calibration. Urban extent layer of 2010, slope layer and hill shade layer and road layer in 2008 are used as a seed layers and simulation urban growth during period of 2011 to 2030. The growth parameters are showed that the urban growth of the study area was mainly contributed from the spread coefficient (old or new urban centers spawn additional growth) and Breed coefficient (growing urban centers from spontaneous growth) than the other control coefficients (Table 6).

Table 5: Urban land conversion in different time period

Urban Growth	
Predict Year	Urban Area(km^2)
2011	19
2015	29
2020	38
2025	44
2030	46

Under the business as a usual scenario, the total urban area for 2030 would be 46 sq.km. Furthermore, out of total extent 82% of lands become an urban area in 2030. In order to model results the 3rd order polynomial graph (Fig. 6) is show up required area need by population in 2030.UDA was proposed to extend the urban area towards west part of the study area; from Matara Municipal Council (MC) area to part of Weligama DSD (Fig. 7).That is the key component of this task since the model output similarly displays the trend of urbanization in future.

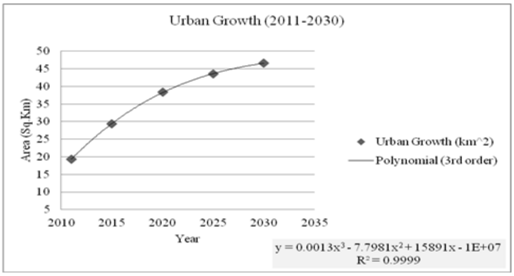

Figure 6: Urban growth (2011-2030)

Table 7: Probabilities of Urban growth in 2030

Condition	Probability	Extent of land (km^2)
Modeled (2010)		16.49
Modeled (2030)	50%-69%	0.25
	70%-94%	2.29
	95%-100%	26.95
Extent of urban area (2030)		45.98
Not modeled Area (Exclude water layer and hilly area)		10.17
Extent of study area		56.15

The spatial distribution of simulated urbanization can be distinguished in fig. 8. It shows that the chances of urbanization of the study are in 2030 and expansion of probable urban pixel of the study area. Except Kekanadura forest reserve and Kiralakele wildlife reserve, rest of the area will be urbanized by 2030. The model results were indicated out of 66 GNDs 29 will be fully urbanized and 26 with in the category of 80%-99%. Kokawila, Parawahera East, Parawahera North Kakenadura East, Kakenadura North and Deeyagaha East were recorded less than 50% of built up area in 2030, because aforesaid area are belong to Kekanadura forest reserve.

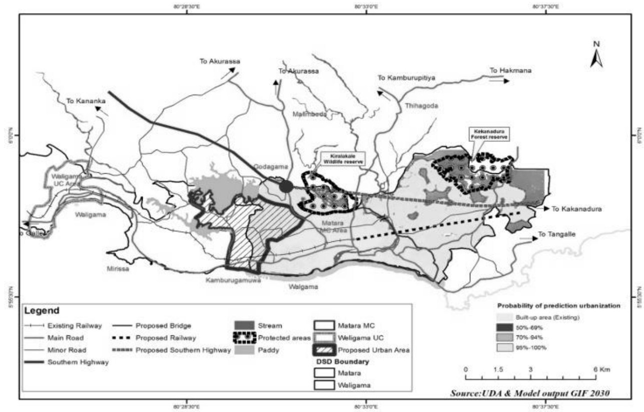

Figure 7: Development proposal of UDA and urbanization trend in Matara

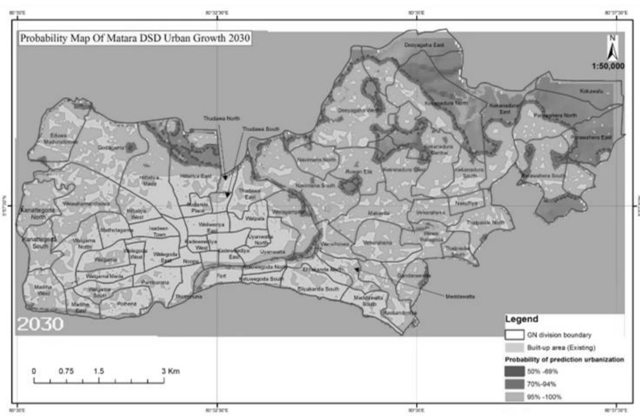

Figure 8: Probability map of Matara DSD urban growth 2030 (by GNDs)

3.4. VALIDATION OF THE MODEL AND SIMULATION SPATIAL ACCURACY

SLEUTH simulation accuracy was analyzed using derive forecasting coefficients avg.log file or last stage of the model calibration process. Urban extent layers which are prepared from Land sat TM, ETM+ by using the maximum likelihood classification method. The urban patterns predicted during the past to future simulation were quantitatively accurate up to 84%

to 100% (Table 8). Furthermore the simulated urban growth is developed from the satellite imageries, and it shows in Fig. 9.

Table 8: Model input data test and calibration parameters (1990-2010)

	Existing Condition	Calibration results		
Based Year	Urban Extent (Sq.Km)	Urban Pix	Modeled Area (Sq.Km)	Accuracy (%)
1990	6.04	6417	5.77	96
2000	9.22	10230	9.21	100
2010	16.97	15763	14.19	84

There are several possible reasons to concern the model precision. SLEUTH model considers a range of various factors controlling new development by most physical factors. But there are some other aspects such as economic and social influence human life. The input images of SLEUTH model during the research were generalized 30m pixel size. The model input images resolution display to cell size because a computational approaches were limiting aspect.

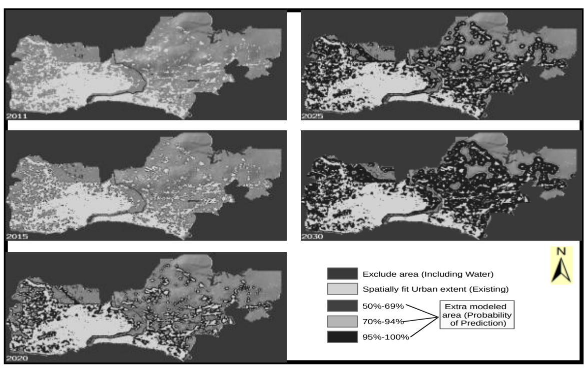

Figure 9: Spatial accuracy (Simulation urban growth, 2011-2030)

4. Conclusion

This paper presents the successful integration of remote sensing data, GIS and an urban model. It also present an approach how urban growth models can be used in planning process. The SLEUTH model is a prediction tool which is useful for decision makers related to urban environment. Basically model output was consisting historical urban extent forecast in pixel based on physical factors like slope resistance and road gravity. The drawback of SLEUTH model is, it doesn't consider socio economic factors. The whole process of this study has gone to predict urban land change in study area

2011 to 2030. The simulations of SLEUTH are found accurate up to 84% to 100% in this study. Therefore the SLEUTH is accurate and future oriented urban growth model and it consider significant factors which are effect to land use change; urban extent, transportation and slope can be used to model the urban growth and also as an effective tool for the formulate urbanization policies of Sri Lankan cities.

5. An acknowledgement

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