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APPLICATION AND ASSESSMENT OF USABILITY OF THE LAND USE MODEL METRONAMICA

A case study in the Southern Sri Lanka

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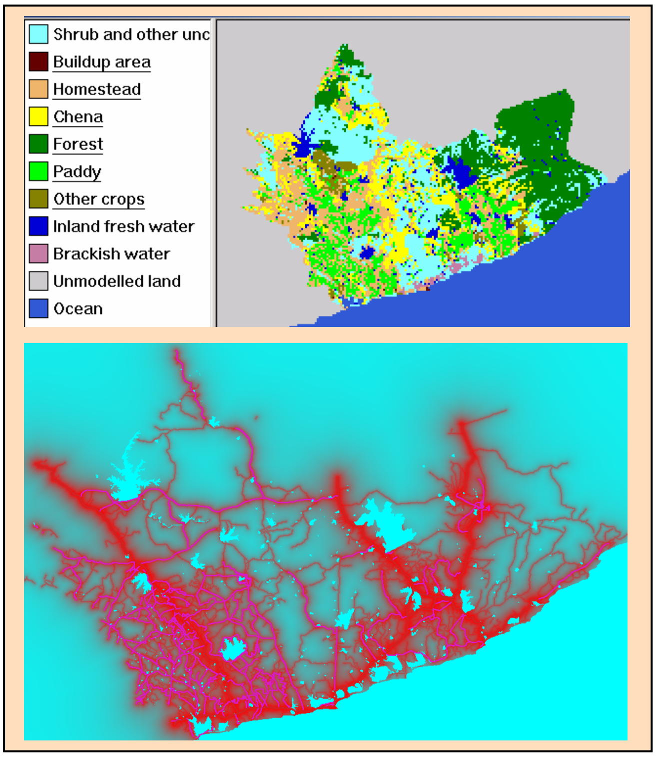

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Application and assessment of usability of the land use model METRONAMICA

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Dedicated to my beloved wife Sanji

Abstract

The spatial policy decision making in Sri Lanka is still paper based, and not supported by any scientific means. However, land use models have been successful elsewhere in the world as Spatial Decision Support Systems (SDSS). METRONAMICA is the modeling framework behind some well-known land use models which serve as SDSS. The backbone of the METRONAMICA framework is a Cellular Automata (CA) model. The objective of this study was to find out how a land use model developed using METRONAMICA could enhance the spatial decision making in Sri Lanka. In order to achieve the objective, a land use model was set up (the RUHUNUPURA model) using the METRONAMICA framework, for the Ruhunupura area of Sri Lanka. The land use classification adopted includes eleven land use classes altogether, out of which only seven are dynamic. Four classes are static over the simulation period. There were three predefined algorithms available in METRONAMICA to calculate the transition potential of cells. All three predefined algorithms were unable to simulate the dynamics of the land use class *chena* properly. *Chena* is a characteristic cultivation method followed by the local farmers and is also known as the shifting cultivation. Therefore, a new algorithm was developed by incorporating a time component, especially to capture the dynamics of *chena*. The RUHUNUPURA model was then manually calibrated for the period 1985 to 2001. The Fuzzy Kappa statistic, visual interpretation, and wavelet verification were used to assess the results of calibration. The calibration results reveal that the model can be safely used to study the behaviour of the land use classes *shrub and other uncultivated area, homesteads, chena, forest,* and *paddy*. However, the model could not handle very well the dynamics of the land use class *other crops*. The calibrated model was then used to run four scenario. The first scenario was a validation test for the model. The model could predict lengthening cultivation periods and shortening fallow cycles of *chena*, which is a well observed, distinct character of *chena* dynamics. The second and the third scenario were formulated to try out two alternative zoning policies for the modelled region. The aim of the fourth scenario was to foresee what might happen if another tsunami hits the coasts of Sri Lanka. The final task of the study was to assess the usability of the RUHUNUPURA model for the user organization, the Urban Development Authority (UDA) of Sri Lanka. The usability assessment was conducted for a period of 3 weeks at the user organization with 10 participants. An extended workshop was the protocol for the usability assessment, which consisted of an introductory session, one week of guided training, non-guided practical exercise, group discussion, and an interview with the Director of the UDA's GIS centre. During the assessment, two questionnaires were used; the first questionnaire checked participants' knowledge in land use modelling concepts, while the second questionnaire estimated the user satisfaction and users' attitude towards the model. The second questionnaire was evaluated twice; once in the beginning and then at the end of the assessment to study the change in attitude of the participants. The average time spent by the participants to complete the practical exercise was 24 minutes. The participants were very effective in handling the model where the average number of tasks completed by a participant was 7 (total number of tasks were 8). The user organization feels that the freedom the model offers to analyze alternative policies through simulations as the most important function of the model. The larger cell size (500 m) of the model was considered as the biggest disadvantage by the user. Overall, the UDA was satisfied about the RUHUNUPURA model.

Keywords: Spatial Decision Support System, Land use model, Cellular Automata, Chena, Calibration, Scenario, Usability

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1 Introduction

1.1 Context and background

Models are, by definition, a simplification of some reality which involves distilling the essence of that reality to some lesser representation (Batty and Torrens, 2001). Dynamic spatial models are one of the interesting branches of the whole modelling arena, because these are a group of smart tools that enable us to understand the dynamic behaviour of spatial objects and processes.

In the last decade, dynamic spatial models have gained popularity as a modelling tool for the simulation of spatially distributed processes (Barredo and Demicheli, 2003). Among different categories of spatial models, land use models possess a great degree of importance for decision makers. There exist various modelling approaches for the simulation and exploration of land use changes, and if done in a spatially explicit, integrated and multi-scale manner, land use modelling is an important technique for the projection of alternative pathways into the future, for conducting experiments that test our understanding of key processes, and for describing the latter in quantitative terms (Lambin *et al.*, 2000; Overmars *et al.*, 2003).

Land use models have been developed all over the world for different spatial extents and for different purposes: A *regional level* dynamic simulation model of land use changes in Sudano-Sahelian countries of Africa (Stéphenne and Lambin, 2001), the Environment Explorer model for the Netherlands (Engelen *et al.*, 2003) at *country level*, SLUETH model for the Portuguese *cities* of Lisbon and Porto (Silva and Clarke, 2002) are examples of such models at different scales.

There are several categories of land use models; Empirical-statistical models, stochastic models, optimisation models, and dynamic simulation models (Lambin *et al.*, 2000). Agent based modelling and Cellular Automata (CA) based modelling are two common approaches used in dynamic simulation models (Batty, 2003). An increasing trend of using CA approach for modelling the land use changes has been observed during the last few years (Barredo and Demicheli, 2003; Batty, 2003). The land use change model METRONAMICA researched in this study as well is primarily a CA model.

Although a number of land use change models have been developed in recent years, only few of them are useful to support policy decision making (Van Delden and Engelen, 2005). METRONAMICA is one of those few, and it has been developed with the aim of exploring the effects of (alternative) policy options on the quality of the socio-economic and physical environment and, with this information at hand, to stimulate and facilitate awareness building, learning, and discussion prior to the decision making proper (RIKS BV, 2005).

METRONAMICA comprises of an explicitly dynamic land use model applied to the full territory of the area modelled. The key characteristic of the model is that it does not seek to optimise the separate economic, ecological and social dimensions, rather to maximise the whole. The benefit of this approach is the strong integrative and interactive nature of the resulting system, in which highly dynamic, autonomous processes play a key role (RIKS BV, 2005).

1.2 Problem statement

Although many different types of models such as hydrological models (De Silva and Rushton, 1996; Hall *et al.*, 1996), yield predictive models (Amarasinghe *et al.*, 2002), etc. have been applied successfully in Sri Lanka, there are hardly any developments or applications of land use change models.

There are some examples of models that have been used in Sri Lanka to support decision making in practical fields such as farming (Illukpitiya and Gopalakrishnan, 2004). However, there is no literature available on the use of land use models in planning and decision making in Sri Lanka.

Even though there are no reported applications of land use modelling in Sri Lanka, many researches have shown the importance of land use models for different purposes elsewhere in the world. Lau and Kam (2005), who applied cellular automata based land use change model to the metropolitan Melbourne area, have shown an increased accuracy and reliability of land use forecasting with the use of the attribute and gravity effects. Silva and Clarke (2002) too have shown the capability of another land use model 'SLEUTH' in investigating the impact of planning and transportation construction in the Portuguese metropolitan areas of Lisbon and Porto. According to Yuzer (2004), the Land Use Cellular Automata Model (LUCAM) which he applied to the settlement of Bursa in Turkey proved drastic reduction of the calculation time in growth estimation processes.

Applications of METRONAMICA model have also proven the ability of the system to support the analysis of a wide range of social, economic and environmental policies and their associated temporal and spatial dynamics. Environment Explorer, an application of METRONAMICA in The Netherlands, is widely accepted as an analytical instrument for the design and evaluation of spatial plans as well as a tool for communication about such plans by most users at the provincial and the national levels (Engelen *et al.*, 2003).

Two exercises carried out by Van Delden and Engelen (2005) also show the potential of METRONAMICA as a Decision Support System (DSS). The aim of the first exercise was to find suitable locations for the expansion of residential and business activities in Utrecht Province, The Netherlands. The second exercise aimed at exploring the impact of different scenario on land use developments and the state of the environment in Europe, and was carried out as part of the EEA-PRELUDE project. The authors conclude that METRONAMICA contributed to both exercises significantly thanks to its high level of completeness, flexibility and interactivity.

After initial discussions with some local experts and the key stakeholder in Sri Lanka, it was understood that spatial policy decision making is not supported scientifically. Mostly, personal judgments of experts and suggestions of politicians are used in deciding spatial activities. Therefore, a land use change model like METRONAMICA would be very helpful for policy decision makers to try out different spatial policies before implementing them directly.

The first task of this study was to set up a new application (model) for Sri Lanka within the METRONAMICA modelling environment, since there is no up-and-running model available at the moment. According to RIKS BV (2005), no programming is required to set up and run a new METRONAMICA application, but experience with GIS and spatial modelling are desired. Furthermore, GIS data and some statistical data are required for successful setting up of a new model. By considering the time available for this study, the choice has been made to set-up a new model only for a small area of the Southern Sri Lanka. The proposed new land use change model would have the highest importance if developed for this area, because the area is expected to undergo massive land use changes in the coming years due to policies of the current government.

After setting up or developing a model, it has to be calibrated and validated before actual applications can be carried out. Calibration and validation are seen as major challenges for application of a model (Straatman *et al.*, 2004). Calibration of a model must aim at obtaining a best fit of model simulations with historical data, as well as the general landscape structure or morphology that unrolls from the model dynamics when it is applied for a period that long surpasses available data (Hagen-Zanker *et al.*, 2005). The new METRONAMICA application developed for Sri Lanka would also need to be calibrated. It is important to note that the historical data validation of the new model has to be omitted mainly due to time limitations of this study and lack of additional data. Since the major aspect of the study is the exploration of the usability of the new model and most time should be spent on that, classical validation can not be employed during the time period of this study. However, the usability assessment can be considered as a kind of *face validation* (Sargent, 1998).

Land use models can support the exploration of future land use changes under different scenario conditions. Hence, scenario analysis with land use models can support land use planning and policy (Verburg *et al.*, 2004). The calibrated new METRONAMICA application for Sri Lanka was also used for scenario analysis. However, not every form of scenario development commonly proposed by modellers is useful to planners (Couclelis, 2005). Therefore, the interests of the key stakeholder of this study, local experts' ideas, and knowledge of the researcher about the area are used intensively for generating scenario.

After development of any computer system, in this case the new METRONAMICA application, it is vital to discover the usability of the new system. Hence, the usability of the new METRONAMICA application developed for Sri Lanka should also be evaluated.

Usability refers to the effectiveness of the interaction between humans and computer systems and it can be specified in terms of how well potential users can perform and master tasks on the system (Butler, 1996). The abstract concept of usability can be measured in terms of the usability elements (Wachowicz *et al.*, accepted). Although there are over 40 usability elements proposed in the literature, there is a lack of specified measures for most of them (Hunter *et al.*, 2003). Therefore, the usability assessment of the new METRONAMICA application is focused on measuring a few, very important, usability elements namely, effectiveness, efficiency, and user satisfaction. Apart from measuring these usability elements over an extended workshop at the user organization, the possibility of adopting the new model within the user organization for real practice is also examined. The details of the usability assessment are described in Chapters 3 and 4.

1.3 Research objectives and research questions

1.3.1 Research objectives

The overall objective of this research is to find out how the land use change model METRONAMICA can enhance the spatial policy decision making in Sri Lanka. This overall objective is achieved by carrying out four tasks:

1. setting up a land use change model for the Ruhunupura area of Sri Lanka within the METRONAMICA modelling environment (Hereafter, the new land use change model is referred to as the RUHUNUPURA Model):
2. calibrating the RUHUNUPURA model:
3. applying the RUHUNUPURA model to assess the impact of different policy decision scenario with the aim of exploring the spatial and temporal dynamics of the land use developments: and
4. assessing the usability of the RUHUNUPURA model for the user organization, the *Urban Development Authority* in Sri Lanka.

1.3.2 Research questions

The research questions to be answered while accomplishing the four tasks are listed below.

1. Setting up the RUHUNUPURA model within the METRONAMICA modelling environment

   i. What are the required data to set up the model, and which data are available for the study area?
   ii. What are the important land use classes in the study area?

2. Calibrating the RUHUNUPURA model

   i. What is the appropriate method to calibrate the RUHUNUPURA model (manual or semi-automated)?
   ii. What is the level of required accuracy in calibration?

3. Applying the RUHUNUPURA model to assess the impact of different policy decision scenario with the aim of exploring the spatial and temporal dynamics of the land use developments

   i. What are the key policy decisions made by the user organization?
   ii. How can a set of policy relevant indicators be developed so as to link the policy questions to model inputs, and model output to policy relevant information?

4. Assessing the usability of the RUHUNUPURA model for the user organization, the *Urban Development Authority* in Sri Lanka

   i. What does the user see as the main function(s), advantages, and disadvantages of the model?
   ii. How efficient, effective, and satisfied are the users in handling the model?

1.4 Structure of the thesis report

The text of the report so far has introduced mainly the problem, the objective, and the research questions of this study.

Chapter 2 provides an overview of the METRONAMICA framework that has been used to set up the new land use model, the RUHUNUPURA model. It basically describes the factors incorporated in METRONAMICA to calculate the transition potential of cells at the micro level.

Chapter 3 is a summary of the concepts of usability and the methods employed to assess the usability. Usability assessment of the RUHUNUPURA model is an important aspect of this study. The idea of the literature review on usability was to identify a suitable framework to carry out the usability assessment in this study.

Chapter 4 illustrates the methodology used in this study in detail. The main aspects covered in Chapter 4 are the user organization, study area, setting up the RUHUNUPURA model, calibration of the model, scenario running, and usability assessment.

Chapter 5 analytically describes the results of the calibration, scenario running, and usability assessment.

Chapter 6 reflects on the research questions with the aid of results obtained in the study. The conclusions drawn from the results are also stated. At the end of the chapter 6, few recommendations to further improve the model have also been discussed.

2 METRONAMICA: A land use modelling framework

METRONAMICA is a CA based framework used to develop land use change models, without needing to write a single line of code. In a number of past and ongoing projects, METRONAMICA has proven to be a generic and very flexible modelling framework which can be applied at a variety of spatial and temporal resolutions (RIKS BV, 2005).

The modelled area is represented as a mosaic of grid cells typically representing a parcel of land cover depending on the type of application and the desired spatial detail, anything from ¼ ha to 4 km^2. Each cell is modelled dynamically and together the cells constitute the changing land use pattern of the global level (RIKS BV, 2005).

A single layer METRONAMICA model, which is the one used in this study, replaces the macro-scale model that drives the CA land use model with a user-supplied scenario. However, it preserves the constrained CA characteristic by using a simple file specifying the number of cells required to be in each state at each time period (White *et al.*, 2004).

According to Uljee *et al.* (2006) and Van Delden *et al.* (2005), all land use classes modelled in METRONAMICA should be categorized into three types namely, *vacant state, function,* and *feature.* A *vacant* land use is a land use for which the macro model does not specify the amount of cells required at each simulation time step. The *vacant* land uses exhibit reduced dynamics and they have a much reduced representation. *Vacant* land uses are the net providers of the space. On the other hand, *function* land uses are fully dynamic in both regional and local levels of the model. The amount of cells under each *function* land use class for each state of the modelling period is defined by the macro model. The number of cells under *function* land use classes can grow or shrink, and the location of cells can change as a result of the processes described in the model. The non-dynamic land uses are called *features*. *Features* do not change as a result of the Micro-scale dynamics. They do not expand or disappear, and do not change locations due to expansion of other land uses or any other dynamics in the model. Yet, they influence the dynamics of the *Functions*, and thus influence their location.

At micro level of the model, four elements act together in deciding whether a particular cell is taken up by a *function* or *vacant* land use class namely; CA transition rules (neighbourhood effect), suitability, zoning, and accessibility (Uljee *et al.*, 2006). According to Engelen *et al.* (2002), cell state transitions depend on transition potentials representing the potential to change to state k; subject to the cell demand constraint, cells change to the state for which they have the highest potential. The transition potential P_k is calculated as follows:

$$P_k = r(\alpha)\, N_k S_k A_k Z_k \quad \text{...} \quad (2.1)$$

where, for land use k,

$r(\alpha)$ = A random perturbation factor with magnitude controlled by the parameter α;

N_k = Neighbourhood effect

S_k = Suitability

A_k = Accessibility

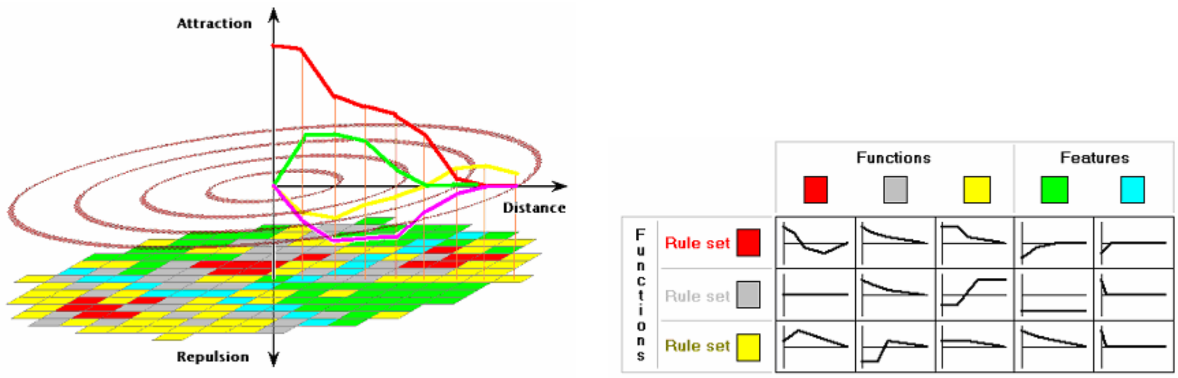
Z_k = Zoning

Further,

$$r(\alpha) = 1+[-log(rand)]^{\alpha} \qquad (2.2)$$

2.1 Neighbourhood effect (N_k)

According to Uljee *et al.* (2006), for each cell (or location), the model assesses the effect of its neighbourhood: a circular area with a radius of 8 cells containing the 196 nearest cells, by means of a set of CA rules. For each land use function, a set of rules determines the degree to which it is attracted to, or repelled by, the other functions and features present in the neighbourhood. The strength of the interactions as a function of the distance separating the different functions and features within the neighbourhood is articulated in the rules. A graphical illustration of the CA rules is given in *Figure 2.1*. If the attractiveness is high enough, the function will try to occupy the location, if not, it will look for more attractive places. New activities and land uses invading a neighbourhood over time will thus change its attractiveness for activities already present and others searching for space.



(a) *(b)*

Figure 2.1 CA rules of the METRONAMICA model

(Source: Engelen et al., 2004)

The equation (2.3) shows the calculation of the neighbourhood effect more specifically (Engelen *et al.*, 2002).

$$N_k = \Sigma_{xd}\, w_{jkd}\, I_{xd} \qquad (2.3)$$

where,

w_{jkd} = weighting parameter expressing the strength of the interaction between a cell with land use j and a cell with land use k at a distance d in the CA neighbourhood

I_{xd} = the Kronecker delta function: I_{xd} = 1 if the cell x at a distance (the concentric ring) d is in the state k, otherwise $I_{xd} = 0$

2.2 Suitability (S_k)

Van Delden and Engelen (2005) describe the suitability used in the METRONAMICA environment as the degree to which a cell is fit to support a particular land use function and the associated economic or residential activity. The suitability stated here means the *physical* suitability and it is a composite measure calculated on the basis of physical and environmental factors characterizing each cell (Engelen *et al.*, 2004). For computational purposes, the values of suitability maps are normalized to values in the range 0 to 1. Separate suitability maps should be prepared for each *function* and *vacant* land use class.

2.3 Zoning (Z_k)

Zoning can be considered as the institutional suitability. Zoning too, is a composite measure based on master plans and planning documents available from the national or regional planning authorities including, among others, ecologically valuable and protected areas, protected culturescapes, buffer areas, etc. For three consecutive planning periods, to be determined by the user (example: 2000-2005, 2005-2015, and 2015-2030), the map specifies which cells can and cannot be taken in by a particular land use (RIKS BV, 2005). The zoning or institutional suitability is also characterized by one map per *function* and *vacant* land use class (Uljee *et al.*, 2006). For each cell and land use K, the model allows to define the zoning status for three periods (Engelen *et al.*, 2004). Therefore, a zoning map for a particular land use class can contain up to four values; 0 for areas currently allowed, 1 for areas allowed starting in zoning period 1, 2 for areas allowed starting in zoning period 2, and 3 for areas never allowed.

2.4 Accessibility (A_k)

The accessibility for each land use function is calculated in the model relative to the transportation system consisting of the railways and railway stations, the navigable waterways, and the road network. It is an expression of the ease with which an activity can fulfill its needs for transportation and mobility in a particular cell. It accounts for the distance of the cell to the nearest link or node on each of the infrastructure elements, the importance and quality of that link or node, and the needs for transportation of the particular activity or land use function (Van Delden *et al.*, 2005).

2.5 Indicators

Indicators are instruments that are able to transform the output of the model to measure and represent specifiable spatial characteristics (Uljee *et al.*, 2006). An indicator in this context is a measure to make a particular phenomenon perceptible that is not or at least not immediately detectable (White *et al.*, 2004).

Indicators are processed yearly, simultaneously with the rest of the model, hence are calculated on the current state or on a selected past state of the system. Every indicator is calculated for every spatial entity (cells) of the model (Van Delden *et al.*, 2005). A user can define a set of indicators based on the algorithms currently available in the model or he can extend or modify a list of existing indicators (Engelen *et al.*, 2004).

According to RIKS BV (2005), there are some 7 built-in generic spatial indicator algorithms namely, access algorithm, cluster algorithm, count algorithm, distance algorithm, disturbance algorithm, fuzzy kappa algorithm, and KOV (habitat fragmentation) algorithm. Together they constitute important information relative to the merits of one or the other project, policy or strategy tried out with the model. Each indicator in itself is a more or less elaborate dynamic sub-model that may require specific ancillary information. Indicators include among others: cost of land (economic), built-up area and soil sealing (social), open space (social), urban sprawl (environmental), flooding risk (social), residential density (social), habitat fragmentation (environmental), land degradation (environmental), etc. Indicators calculated on a yearly basis are available in METRONAMICA in the form of dynamic maps, time charts and numeric output.

The indicator algorithms used in the RUHUNUPURA model are described in detail under the *section 4.5.6*.

3 Usability

3.1 Introduction

According to ISO 9241 (1994) usability is ‘the extent to which intended users of a product achieve specified goals in an effective, efficient and satisfactory manner within a specified context of use’. Holzinger (2005) defines usability following more or less the same line of thought, and the definition proposed by him is ‘the ease of use and acceptability of a system for a particular class of users carrying out specific tasks in a specific environment’. According to the same author, the ease of use affects the users’ performance and their satisfaction, while acceptability affects whether the product is used. For Butler (1996), on the other hand, usability is ‘the effectiveness of the interaction between humans and computer systems that can be specified in terms of how well potential users can perform and master tasks on the system’.

Strong commitment to usability can clearly benefit the software development lifecycle. For example, human productivity and performance, safety and commercial viability, etc. are among the observable benefits of usable user interfaces (Seffah *et al.*, 2006). Further, Jokela *et al.* (2003) perceive usability as one type of a quality characteristic that must come along with a product.

According to Jokela *et al.* (2003), the characteristics of the users, tasks and the organizational and physical environment define the context in which the system is used. It is important to understand and identify the details of this context in order to guide early design decisions, and to provide a basis for evaluation. The authors further identify efficiency, effectiveness, and satisfaction as the three major attributes to be measured in a usability assessment.

ISO 9241 (1994) provides definitions to the terms effectiveness, efficiency, and satisfaction. Accordingly, effectiveness is ‘the accuracy and completeness with which users achieve specified goals’, efficiency is ‘the resources expended in relation to the accuracy and completeness with which users achieve goals’, and satisfaction is ‘the freedom from discomfort, and positive attitude to the use of the product’.

3.2 Methods used in usability assessment

According to Wachowicz *et al.* (accepted) a significant number of methods have been proposed in the literature for measuring usability, and they usually focus on developing user testing based on four components namely, identification of a usability element (e.g. satisfaction, efficiency, effectiveness, and familiarity), selection of representative users, selection of representative tasks, and the measure of user performance out carrying on these tasks.

However, the identification of a core set of fundamental techniques that clearly distinguish one usability element and its specified measure(s) is a difficult task (Wachowicz *et al.*, accepted). There are only few clear guidelines about how various definitions of usability factors, rules, and criteria are related and how to select or measure specific aspects of usability for particular computer applications (Seffah *et al.*, 2006).

Holzinger (2005) categorizes the usability evaluation methods into two broad types namely, inspection methods (without end users) and test methods (with end users).

3.2.1 Usability inspection methods

Usability inspection methods are the techniques used for identifying usability problems and improving the usability of an interface design by checking it against established standards (Holzinger, 2005). Nielsen (1995), on the other hand, defines usability inspection as the generic name given for a set of cost effective ways of evaluating user interfaces to find usability problems. He further states that usability inspection methods are fairly informal and easy to use.

Heuristic evaluation, cognitive walkthroughs, pluralistic walkthroughs, feature inspection, consistency inspection, and standards inspection are some of the usability inspection methods (Nielsen, 1995). Based on the literature by Nielsen (1995) and Holzinger (2005), those usability inspection methods are explained below.

Heuristic evaluation involves having usability specialists to judge whether each dialogue or other interactive element follows established usability principles. This is the most common informal usability inspection method.

A cognitive walkthrough is a task-oriented method by which the analyst explores the system's functionalities mimicking step-by-step user behaviour for a given task. Cognitive walkthroughs use a more explicitly detailed procedure to simulate a user's problem solving process at each step through the dialogue, checking if the simulated user's goals and memory content can be assumed to lead to the next correct action. Cognitive walkthoughs emphasize cognitive issues, such as learnability, by analyzing the mental processes required of the users.

In a pluralistic walkthrough, users and developers step through a scenario, discussing each dialogue element.

Feature inspection lists sequence of features used to accomplish typical tasks, checks for long sequences, cumbersome steps, steps that would not be natural for users to try, and steps that require extensive knowledge/ experience in order to assess a proposed feature set.

Consistency inspection has designers representing multiple projects inspect an interface to see whether it does things in the same way as their own designs.

Standards inspection has an expert on some interface standard inspecting the interface for compliance.

3.2.2 Usability test methods

There are several methods for testing usability, the most common being thinking aloud, field observation, and questionnaires (Holzinger, 2005). The following descriptions of these three methods are also based on Holzinger (2005).

Thinking aloud requires the end users to continuously think about the system being used, and to verbalize their thoughts so that the developers understand the misconceptions of the users about the system. The advantages of thinking aloud include revealing why users do something, providing a close approximation as to how individuals use the system in practice, provision of a significant amount of data from a fairly small number of users, the ability to collect preference and performance information simultaneously, etc. The disadvantages of thinking aloud include a failure to lend itself well to the most types of performance measurement, the different learning style is often perceived as unnatural, distracting, and strenuous by the users, non analytical learners generally feel inhibited, higher time-consumption, etc.

Field observation, being the simplest of all methods, involves visiting one or more users in their work place. Unobtrusiveness is the key for the success of this method. Though taking down notes is the common approach used in field observation, video recording is also used rarely.

Questionnaires, which are a more common approach for usability testing, are useful for studying how end users use the system and their preferred features, but need some experience to design. Questionnaires are considered an indirect method, since they do not study the actual user interface; rather it only collects the opinions of the users about the interface. A simpler form of a questionnaire is the interview. The advantages of using questionnaires include the easy identification of subjective user preferences, satisfaction, and possible anxieties; and the ability to use them for compiling statistics (Holzinger, 2005).

3.3 Structured workshops for comprehensive usability assessment

Haklay and Tobón (2003) suggest a structured workshop method as a means to evaluate the usability. The three structured parts in the workshop are; an introductory plenary session, a practical session and a focus group discussion. The introductory session outlines the basic features of the system (software) that has been developed for the workshop. During the practical session, participants are allowed to work around a free-standing PC in groups of two or three for 90 minutes. The users are given specific tasks during the practical session, and a moderator or a facilitator helps them out during this period. The facilitators encourage users to verbalise their thoughts regarding their interactions with the software. Finally, the facilitators moderate an hour-long focus group discussion by an experienced member of the research team.

Bacic *et al.* (2006) used an alternative workshop approach, which lasted about 4 hours with the following protocol: (1) explanation of the purpose and structure of the workshop; (2) a first questionnaire (Q1) to collect general information about the participants, and to measure their knowledge and views on environmental problems caused by pig manure in the region; (3) a presentation of spatial information without discussion and interventions; (4) a second questionnaire (Q2) to test the effect of the provided information; (5) open, guided discussion; (6) a third questionnaire (Q3) to test the effect of the discussion; (7) a fourth questionnaire (Q4) to evaluate the information provided and methodology used; and (8) final remarks and conclusions. One of the important aspects of this approach is that the questionnaires were linked to each other by a sequential number in those cases where the participant preferred to remain anonymous.

3.4 A framework to evaluate the usability

Wachowicz *et al.* (accepted) propose a framework to evaluate usability in the form of a hypothesis testing. The proposed usability framework is based on five abstraction levels in a hierarchy, and they are usability hypothesis, usability typology, usability variables, usability elements, and usability measures. Usability elements can be seen as the level at which this framework overlaps with most of the other usability assessment methods found in literature. The authors define usability elements, which are also known as usability attributes or properties, as the measurable components of the abstract concept of usability. The final abstract level is related to the Usability Measures. The usability measures, according to the authors, are the parameters that are quantifiable characteristics or features of a usability element. They can be directly measured or observed during a usability test. For example, the rate of errors can be used to characterise a usability element, such as familiarity and clarity. However, the lack of specified measures for the usability elements proposed in literature (about 40) has been identified as the major problem by the authors.

The framework adopted in the usability assessment of this study is a blended version of the two workshop approaches suggested by Haklay and Tobón (2003) and Bacic *et al.* (2006). Unlike in Haklay and Tobon's method, the usability assessment followed in this study consisted of all the important usability assessment techniques namely, questionnaire survey, open discussions, practical exercises, and interview. Furthermore, the usability of the RUHUNUPURA model is assessed through an extended workshop method which consists of four main components; an introductory session, a guided training of the model for a week, an independent practical exercise, an interview with a top officer of the user organization. A detailed description of the usability assessment adopted in this study is given in Section 4.9.

4 Methodology

4.1 The user organization

For a model to be successful there has to be a user who is going to use it actively within their organization. Therefore, the Urban Development Authority (UDA) of Sri Lanka was approached to fill the role of user.

The UDA is actively involved in land use planning in almost all parts of Sri Lanka. Carrying out integrated planning and physical development of declared urban areas, formulating and submitting development plans including capital investment plans, and formulating and implementing urban land use policy are some of the activities undertaken by the UDA (source: www.uda.lk). Hence, the UDA is an ideal user organization for a land use change model like METRONAMICA. Moreover, the user organization was highly interested to cooperate in this study.

4.2 Selection of the study area

Although the model can be applied to the whole territory of Sri Lanka, setting up the model and calibrating it for such a large area could take time which would drag the process beyond the time limits of this study. Therefore, it was necessary to focus on a small area of the country yet preserving the usefulness of the model. Initial discussions conducted with the user organization were very helpful in selecting the study area. The selected case area is shown in *Figure 4.1*.

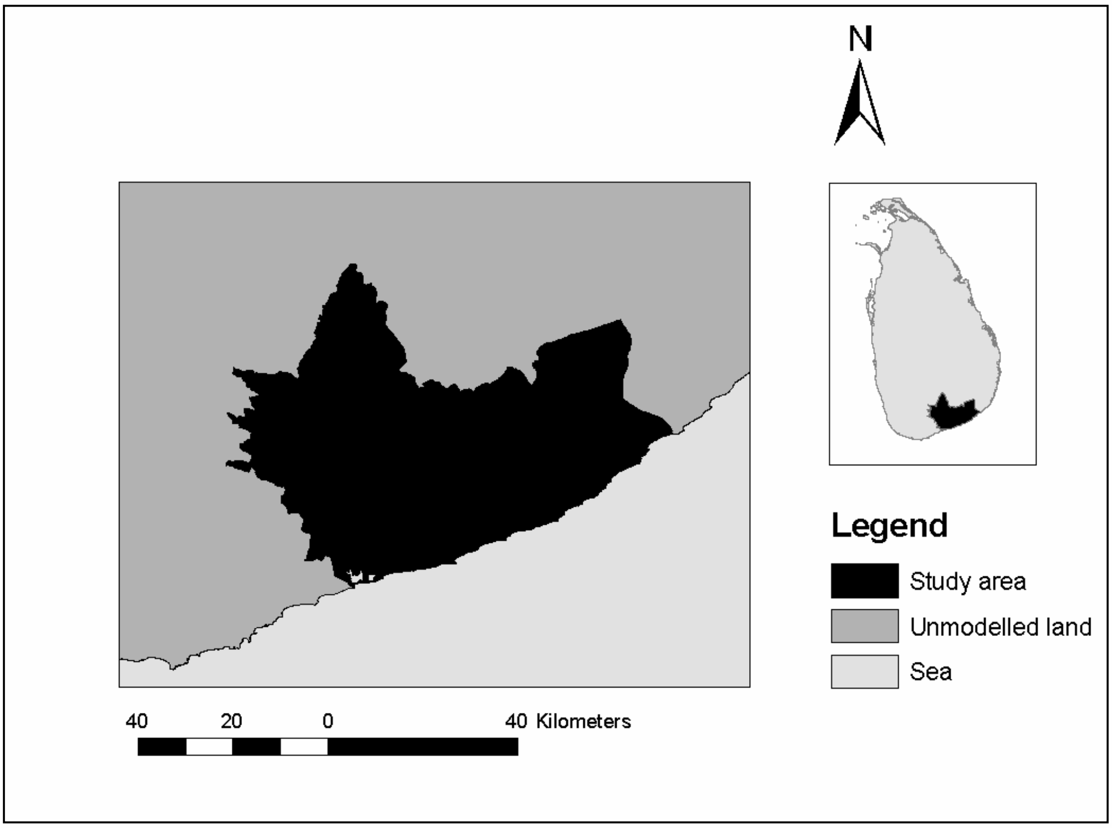


Figure 4.1 Study area

The primary cause for selecting this particular area was the interest of the user organization. This area had been given very little attention for a very long period, despite the huge potential it carries to serve the country's economy. However, the current government has identified the area as the focus for immediate development. As a result, many development projects such as construction of a new harbour, a new international airport, and related activities are going on at the moment in this area. The UDA is also busy with developing master plans, formulating policies, and so on for the upcoming developments in the area. Therefore, the user organization finds a land use change model for decision support as highly appropriate for them, especially in relation to the selected area which they named as *Ruhunupura*.

The availability of digital data was the second reason for selecting the area for modelling. At least two independent land use data sets are needed to set up and calibrate a new METRONAMICA application. There are two land use data sets available for this area for the years 1985 and 2001, whereas for most of the other areas, only the most recent land use data set is available.

The selected area consists of 10 administrative divisions called *Divisional Secretariat (DS) divisions*. Seven out of ten DS divisions preserve the full territory within the modelling area namely, Ambalanthota, Hambanthota, Lunugamwehera, Sooriyawewa, Sevanagala, Thanamalwila, and Embilipitiya. The other three, Angunakolapellessa, Tissamaharamaya, and Kataragama are only partly located in the Ruhunupura area. Unavailability of land use data was the reason to clip out parts of these three DS divisions.

4.3 Data collection

The METRONAMICA framework requires considerable amount of data for a successful development of a new model. For setting up and calibrating a *single layer* METRONAMICA model, only spatial data is essential, while statistical data may also be helpful. Land use maps for the start year and the end year of the calibration period, a digital elevation model (DEM), a soil quality map, natural hazard maps, actual zoning plans and master plans, transportation network, and a map showing borders of regions are required as spatial data.

The following data sets were collected during the field visit to Sri Lanka from the International Water Management Institute (IWMI), Colombo and the UDA:

1. Land use data sets for 1985 and 2001 (shape files)
2. Road network (shape file)
3. 90 m Digital Elevation Model (DEM) data
4. Major irrigation canals of Sri Lank (shape file)
5. Agro-climatic zones of Sri Lanka (shape file)
6. Major rivers of Sri Lanka (shape file)
7. Soil types data (shape file)
8. Administrative divisions of Sri Lanka (shape file)
9. Zoning map for the Ruhunupura area (shape file)
10. Nature reserves of the Ruhunupura area (shape file)

4.4 Primary data preparation

Initially, all the data sets were assigned with their correct projection systems, and they were later taken into a common projection system by re-projecting in ArcGIS. *Appendix I* provides the details of the common projection system assigned for all the data sets.

The polygon shape files were converted into raster layers with the cell size, 500 m. The 90 m DEM was resampled into 500 m.

The data sets were clipped to match the area of interest for the modelling exercise.

4.5 Setting up the RUHUNUPURA model

The new land use change model called 'the RUHUNUPURA model' was set up within the modelling framework of METRONAMICA.

In a number of past and ongoing projects, METRONAMICA has proven to be a generic and very flexible modelling framework which can be applied at a variety of spatial and temporal scales resolutions. No programming is required, to set-up and run a new application, but experience with GIS, spatial modelling, and the precise built-in model is very instrumental (RIKS BV, 2005).

The RUHUNUPURA model is a so called *single layer* model which represents the whole modelled area as one single region. This new model closely resembles the *BabyLOV* model which was developed for the *Visions* project of the European Union, in its settings (White *et al.*, 2004).

The cell space of the RUHUNUPURA model consists of a rectangular grid of square cells with the resolution 500m. The grid size is 160 rows by 212 columns.

A new METRONAMICA application requires many input maps and information during the process of setting it up. In the next sub sections, those input maps and information required are described in detail.

4.5.1 Region map

The region map (*Figure 4.2*) demarcates the boundaries of the modelled and un-modelled areas within a grid space. It is a categorical map in which the modelled area gets the value 1, and un-modelled area gets the value 0. Out of a total of 33920 cells, the modelled area consists of 12971 cells. It is important to note that from any edge of the modelled area to the outside boundary of the un-modelled area, there are 10 cells in between. The reason for this is that the number of cells considered in CA calculations of METRONAMICA is an 8-cell neighbourhood. Although the dynamics of un-modelled area are not calculated by the model, it is possible to impose an effect from un-modelled area on the dynamics of modelled area in CA. A gap of 10 un-modelled cells allows full span of effect on the modelled area, if the CA rule states so.

Figure 4.2 Region map

4.5.2 Land use maps

Available land use data for the year 1985 and 2001 contains two different classifications of land use in Sri Lanka. After a thorough evaluation of two land use data sets of 1985 and 2001, and considering the interests of the user organization, a new land use classification was developed (*Table 4.1*).

Table 4.1 Land use classification used in the RUHUNUPURA model

Land use ID	Land use class	Category
0	Shrub and other uncultivated area	Vacant
1	Buildup area	Function
2	Homestead	Function
3	Chena	Function
4	Forest	Function
5	Paddy	Function
6	Other crops	Function
7	Inland fresh water	Feature
8	Brackish water	Feature
9	Unmodelled land	Feature
10	Ocean	Feature

The first category *Shrub and other uncultivated area* comprises mainly of shrub jungles, grasslands and bare lands. *Buildup area*, which is the second land use class, consists of closely built buildings, which are meant for administration, commercial activities, or even for housing. *Homestead*s are a unique land use category in this area. A homestead consists of a housing unit and a large garden of about 2 ha. People cultivate a variety of crops in their large home garden, for example coconut, fruits, field crops, etc.

The land use class *chena* deserves a special description since it is a land use class with special characteristics and behaviour. In the process of acquiring extra land for cultivation in addition to the home gardens, farmers invade the edges of nearby forests, or shrub jungles. Initially, they cut and slash the trees and shrubs in a selected area, and burn the trunks, branches, twigs, and leaves in the same place. Thereafter, crops are grown non-systematically in mixed stands. This is non-irrigated, rain-fed agriculture. No fertilization or pest and disease control is done. The only thing those farmers do is to protect the crops from wild animals. When the soil fertility becomes low in the area, farmers simply move to another location abandoning the former *chena* area. Therefore, the *chena* cultivation is also referred to as shifting cultivation.

It is important to note that the unmodelled area has been classified into two *feature* land use classes; *Unmodelled land* and *Ocean.* The reason is that the land and ocean have different influences on the adjacent land uses. When they are considered as two features, this difference can be addressed by the CA rules of the model.

Two land use maps were prepared for the year 1985 and 2001 from available land use data. *Figure 4.3* and *Figure 4.4* show those two land use maps. However, for setting up the model, only one land use map is required. Therefore, the land use map of 1985 was incorporated into the model, while the land use map of 2001 was used for calibration and scenario running purposes.

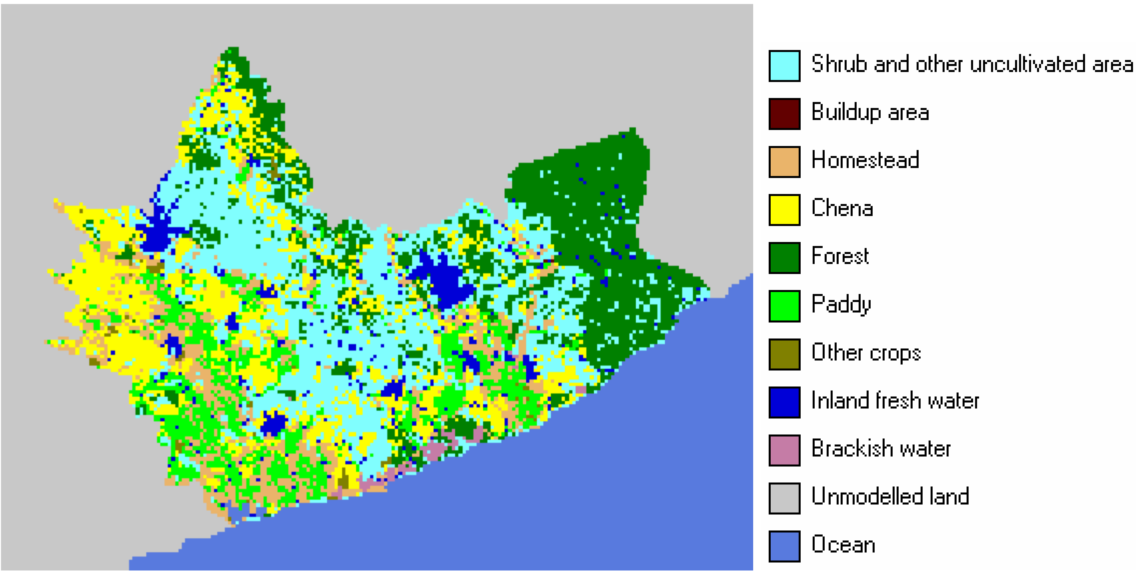


Figure 4.3 Land use map 1985

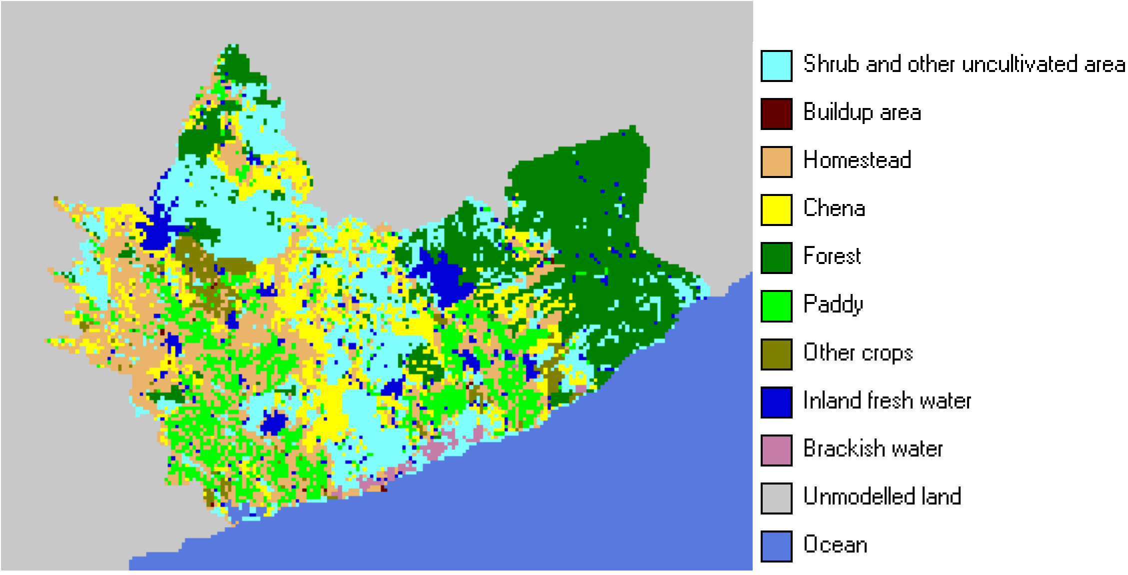


Figure 4.4 Land use map 2001

Inland fresh water land use class, which is considered a *feature,* did not match well in extent and locations in the raw data sets of 1985 and 2001. This effect was prominent in small water bodies. Therefore, *Inland fresh water* was matched in two land use maps by GIS operation. The idea was to avoid noise resulting from misclassified cells of *Inland fresh water* during calibration. Perfect matching *feature* land use classes filter out any possible, unwanted noise in calibration. Thus, it would lead to a solid basis for the establishment of a good set CA rules.

4.5.3 Suitability maps

For the preparation of suitability maps, the OVERLAY TOOL which comes along with METRONAMICA was used. It allows creating suitability maps by combining any number of factor maps. Simple slider movements are used to assign weights for each factor and its components. The factors used in creating suitability maps, and the classification of each factor is given in *Table 4.2*.

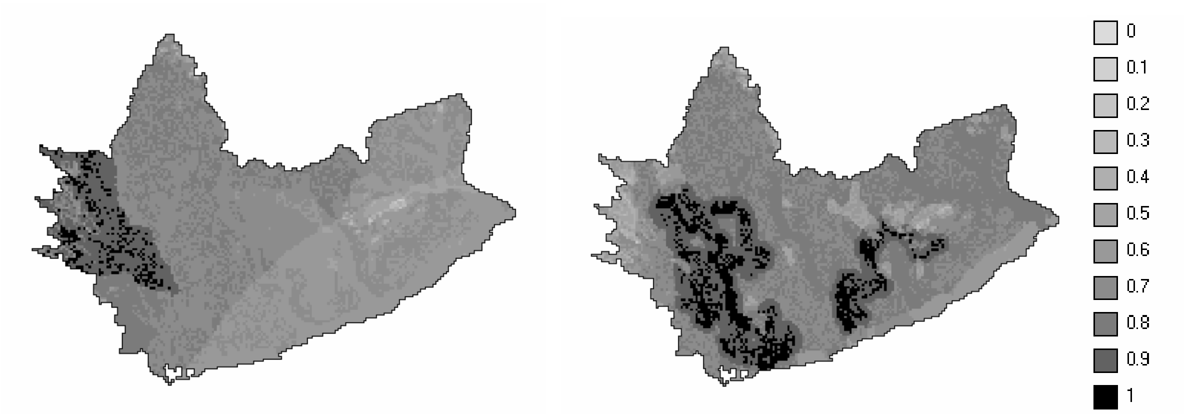
Table 4.2 Factors used in the suitability maps

Factor	Component
Slope (%)	0 – 2
	2 – 8
	8 – 18
	18 – 30
	30 – 50
	50 – 80
	>80
Soil type	Alluvial soils with variable texture and drainage; flat terrain
	Erosional remnants steep rock land and various lithosols
	Major Tanks
	Reddish Brown Earths and Immature Brown Loams; rolling and hilly
	Reddish Brown Earths and Low Humic Gley Soils
	Red-Yellow Lotosois; gently undulating terrain
	Red-Yellow podzolic soils with prominent A1 or semi-prominent A1
	Red-Yellow podzolic soils, steeply dissected, hilly and rolling terrain
	Regosols on recent beach and dune sands
Agro-climatic zone	Semi-arid
	Dry
	Intermediate
River buffer	0 – 500m
	500 – 1000m
	Rest
Canal buffer	0 – 1000m
	1000 – 2000m
	Rest
Divisional Secretariat (DS) divisions	Ambalanthota
	Angunakolapellessa
	Hambanthota
	Lunugamwehera
	Sooriyawewa
	Tissamaharamaya
	Sevanagala
	Kataragama
	Thanamalwila
	Embilipitiya

Canals referred to in *Table 4.2* are man made irrigation canals providing irrigation water for mainly *paddy*. The modelled area contains well managed irrigation schemes, which are an integral part of the livelihood of the area.

Each factor used in the suitability was prepared as a categorical map by using ArcGIS and Idrisi software. Thereafter, all the factor maps were imported into the OVERLAY TOOL. For each *function* and *feature* land use class, a suitability map was prepared by assigning weights to all influencing factors and its components. A value ranging from 0 to 10 can be assigned as the weight for each factor and its components, within the OVERLAY TOOL. Not all factors were considered important in deciding suitability for each land use class. The factors which are not important were assigned the weight 0. A detailed description of the factors used in generating suitability maps for selected land use classes, assigned weights for both the factors and their components can be found in *Appendix II.*

The output of the OVERLAY TOOL is a suitability map which has the values from 0 to 1 with 1 being the highest suitability. *Figure 4.5* shows some important suitability maps generated by the OVERLAY TOOL.



(a) Homestead **(b) Paddy**

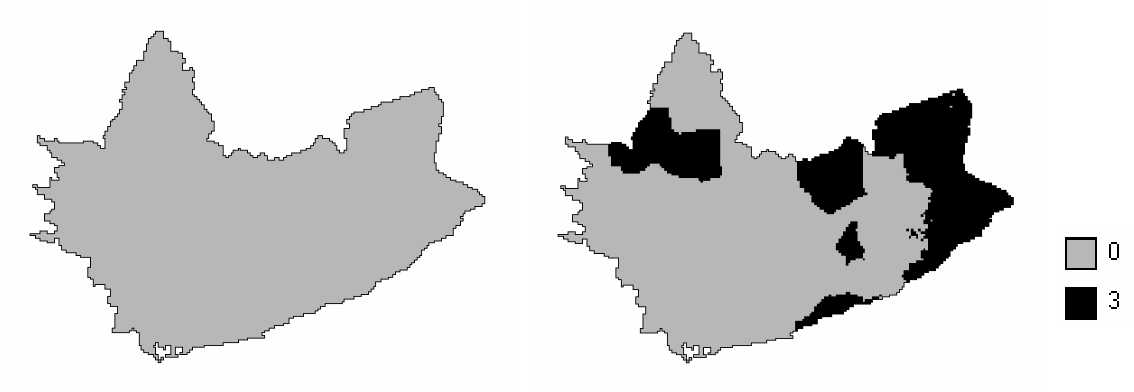
Figure 4.5 Suitability maps

In *Figure 4.5 (a)*, the top left area shows the highest suitability for *homestead*. This is because that particular area belongs to the DS division, Embilipitiya which is preferred by people over the other DS divisions for living. Better infrastructure, mild climate, good market for crops, etc. are some of the reasons for the higher preference by people. The quality of the raw data set, *Agro-climatic zones of Sri Lanka* was not that good. This creates abrupt changes of suitability, and forms unrealistic, sharp boundaries within the map.

Figure 4.5 (b), which is the suitability map for *paddy*, shows characteristic dark areas. Those areas are the buffer zones created around the main irrigation canals. Obviously, the immediate surrounding of the main irrigation canals is highly suitable for *paddy* due to abundant water supply for the cultivation. These irrigation canals are specifically designed to provide water for *paddy*.

4.5.4 Zoning maps

Zoning maps were prepared for each *function* and *vacant* land use class modelled. However, there was no data available about zoning and master plans for the expected calibration period (1985 to 2001). Therefore, only nature conservation areas were considered in preparing zoning maps. For the land use classes *shrub and other uncultivated area* and *forest*, the entire region modelled was considered open for use at any time (map with value 0 only) during the calibration period. For all the other *function* land use classes, nature conservation areas were given value 3 (never allowed), and the rest value 0. This leads to only two different zoning maps (*Figure 4.6*). Zoning maps were prepared using ArcGIS software. For scenario applications, a separate set of zoning maps was prepared (2001 – 2030) in addition to the simple zoning maps explained above, and the details are given under Section 4.8.



(a) for *Shrub* and *Forest* **(*b*) for all other *function* land uses**

Figure 4.6 Zoning maps

4.5.5 Accessibility

The study area has only a road network for the accessibility. Neither railway network nor waterway is available in the area. There were four types of roads available in the raw data set. These were footpaths, tracks, secondary roads, and main roads in ascending order of importance. However, the road network used in the model contains only the last three road types. Footpaths are of very minor importance, and those were neglected in turn. The model requires the road network to be in the form of an ESRI shape file with a special field called *AccType*. The field *AccType* contains values 0, 1, and 2 consecutively for main roads, secondary roads, and tracks. *Figure 4.*7 shows the road network used in the model.

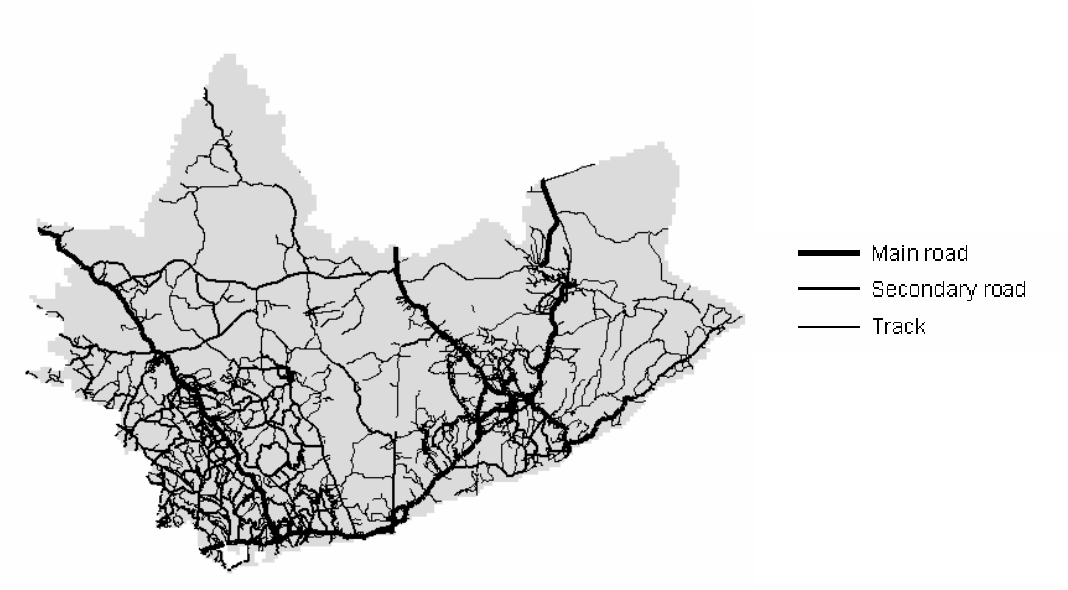


Figure 4.7 Road Network

Two parameters namely, *Relative importance* and *Distance decay* of each road type for each land use class have to be assigned. These two parameters were calibrated, and the details are given under Section 4.7.

Note that the relative importance gets a value in-between 0 and 1, whereas the distance decay gets an integer which actually denotes the number of cells after which the importance becomes half of the initial value.

4.5.6 Indicators

Three indicators were developed for the RUHUNUPURA model namely, *Landscape identity, Self sufficiency,* and *Disturbance of Nature reserves*.

Landscape identity is a straightforward and simple indicator to measure the change in land use given that almost any change of the kind will affect the identity of the original landscape (Van Delden *et al.*, 2005). Landscape identity is calculated as a Fuzzy Kappa statistic. However, not only the distance within which changes of land use occur is taken into account, but also the importance of state transitions are considered in this indicator calculation. For example, a cell state transition from *forest* to *buildup* can be considered much more important, compared to a state transition from *shrub* to *chena*. *Table 4.3* describes the weights given to each state transition in the Landscape identity indicator.

Table 4.3 The matrix of cell state transitions used in the Landscape identity indicator

From \ To	Shrub	Buildup area	Homestead	Chena	Forest	Paddy	Other crops
Shrub	1	0	0.3	0.7	1	0.7	0.7
Buildup area	0	1	0	0	0	0	0
Homestead	0	0.7	1	0	0	0	0
Chena	1	1	1	1	1	0.5	1
Forest	0	0	0	0	1	0	0
Paddy	0	0	0	0	0	1	0.3
Other crops	0	0.7	0.5	0	0	1	1

The radius of the neighbourhood used in calculations of landscape identity indicator is 8 cells, and the halving distance 2 cells. Note that a value 1 in the above matrix means no change, where as value 0 means an extreme change.

The self sufficiency indicator aims at finding the ability of *paddy, other crops, chena, forest,* and *homesteads* itself to support *homesteads*. Technically, this is a *Count* indicator used to calculate figures consisting of the ratio of sums of weights associated with land uses in the vicinity of each cell (Uljee *et al.*, 2006). In this indicator, *paddy* was assigned the highest weight, which is 100, since *paddy* is the staple food of Sri Lankan people. *Chena* and *Other crops* were given the value 50, while *homesteads* and *forest* received the values 10 and 5 respectively. *Homesteads* were also given a weight, because the people in this area cultivate field crops such as chillies, cucumber, etc. and plantation crops such as coconut in their large gardens for consumption. Moreover, the villagers depend on forest for fuel wood, honey, medicinal plants, etc. Therefore, forest was also given a small weight when calculating the Self sufficiency indicator.

Disturbance of Nature Reserves indicator simply estimates how the human induced activities could disturb the existing nature reserves in the modelled area. This indicator uses an underlying map of nature reserves, and calculates the disturbance those nature reserves received by *buildup, homestead, chena, paddy*, and *other crops*. In other words, all the land use classes having human influence were considered a threat to the nature reserves. The base map of nature reserve areas is a categorical map with two categories, nature reserves and the rest.

4.6 Model adaptation

METRONAMICA contains three pre-defined algorithms to calculate the transition potentials of the dynamically modelled cells at micro level. The three forms of the algorithm are slight deviations from the basic algorithm given in the *Equation 2.1*. All the three forms contain four main factors namely, Neighbourhood effect, Accessibility, Suitability, and Zoning, on which the calculation is based.

Initially, all the three pre-defined algorithms were tried for simulating the dynamics of land use change in the RUHUNUPURA model. Though almost all the other parameters were adjusted, the dynamics of *chena* could not be simulated satisfactorily with any of the pre-defined algorithms. Ultimately, it was decided that the available algorithms are not capable of simulating the proper *chena* dynamics.

Chena, which is also referred to as *slash and burn cultivation* or *shifting cultivation*, is a very important land use class present in the modelled area. *Chena* cultivation in Sri Lanka has distinct characteristics.

Forests which are in the vicinity of villages are preferred for the *chena* cultivation. Farmers first clear those forest areas, burn the trunks and the branches in the same place, and start to cultivate. *Chena* areas are therefore, highly fertile at the early stages of the cultivation. However, as no fertilizer is subsequently added the soil fertility of *chena* lands decreases over time. Hence, farmers are compelled to abandon the *chena* after five or six years of cultivation to find new locations. Abandoned *chena* areas are subsequently fallowed allowing the land to regain the fertility. It is important to note that abandoned *chena* lands are first occupied by shrubs and grasses.

Due to the increased pressure on land, farmers either have to reduce the fallow period or have to cultivate in the same place for prolonged periods. Some forty to fifty years ago, farmers could fallow the abandoned *chena* for 10 – 12 years, which is a sufficient time period for the natural regaining of soil fertility. Due to the increased pressure on land, the fallowing period has shortened drastically, and will continue to be shortened. As the other alternative, farmers tend to cultivate in the *chena* lands for prolonged periods.

Hence, a new simulation algorithm, which can address the two requirements of *chena* dynamics, was essential. The potential of the already *chena* lands for *chena* (itself) should decrease with the age of *chena*, and should reach a minimum value after a certain period (e.g. 6 years). Further, the *shurb and other uncultivated area* which are younger than a certain age should possess a lower potential for *chena.* But, this potential should increase with the age of *shrub,* and reach a maximum after a certain period (e.g. 5 years).

A new user defined algorithm was developed to address the dynamics of *chena*. *Equation 4.1* shows the user defined algorithm used to calculate the transition potential in the RUHUNUPURA model.

If $\boldsymbol{N_k \geq 0}$

$$P_K = r(\alpha).N_K.S_K.A_K.Z_K.T_C \quad \text{.......................................} \quad (4.1\text{ a})$$

If $\boldsymbol{N_k < 0}$

$$P_K = r(\alpha).\ N_K\ .\ (1\text{-}S_K\ .A_K.\ Z_K.\ T_C\ ) \quad \text{(4.1 b)}$$

Where

$r(\alpha)$ = A random perturbation factor with magnitude controlled by the parameter α;
N_k = Neighbourhood effect
S_k = Suitability
A_k = Accessibility
Z_k = Zoning
T_C = *Time* or *Age* coefficient:

If $Age \leq \ Period_{K,L}$

$$T_C = T_{initial,K,L} + (T_{end,K,L} - T_{initial,K,L})\ Age/Period_{K,L}$$

If $Age > Period_{K,L}$

$$T_C = T_{end,K,L}$$

Where,

K is the land use for which the potential is calculated
L is the land use found at the location, contributing to the potential

Generally this coefficient is neutral, thus:

$$T_{initial} = T_{end} = Period = 1$$

There are two exceptions, both related to Chena:

For *K* = Chena and *L* = Chena

$\text{T}_{\text{initial,Chena, Chena}} = 1$
$\text{T}_{\text{end,Chena, Chena}} = 0.2$
$\text{Period}_{\text{Chena, Chena}} = 6$

For *K* = Chena and *L* = Shrub

$\text{T}_{\text{initial,Chena, Shrub}} = 0$
$\text{T}_{\text{end,Chena, Shrub}} = 1$
$\text{Period}_{\text{Chena, Shrub}} = 5$

The additional factor called *Age* available for the algorithm development in METRONAMICA framework was used successfully for the first time in this study, to capture the true behaviour of *chena.*

According to the algorithm used in the RUHUNUPURA model, if a cell is occupied by *chena*, the potential of that cell for *chena* land use class (itself) decreases year by year, and at the age of 6, the potential becomes the lowest. Once *chena* is abandoned, those cells are taken up by the only *vacant* land use type '*Shrub and other uncultivated area*'. In reality abandoned *chena* lands are fallowed for few years, i.e. *Shrubs* which are younger than a certain age should not be taken up by *chena*. This fallow period is incorporated in to the algorithm by stating that *Shrubs* which are younger than 5 years of age have very low potential for *chena*. Note that the age 6 for *chena,* and the age 5 for *shrubs* were found as the best values during the calibration.

The effect of the *Age* factor is graphically illustrated in *Figure 4.8* and *Figure 4.9*. Note that the highest value P_{max} can reach is 1.

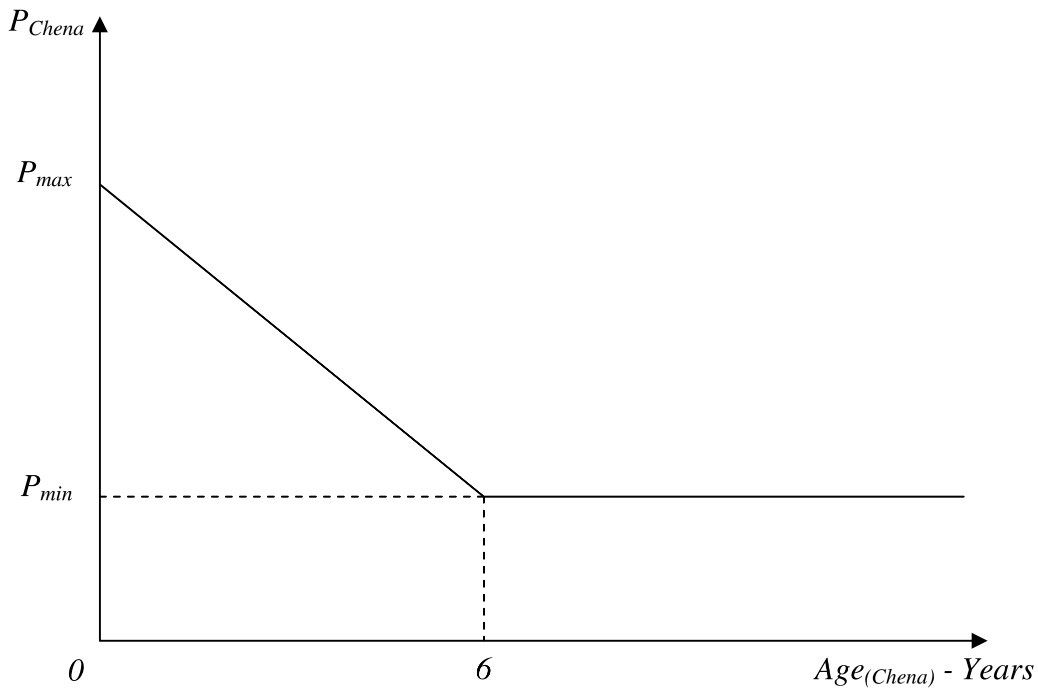


Figure 4.8 Change of potential of chena areas for itself with the age of chena

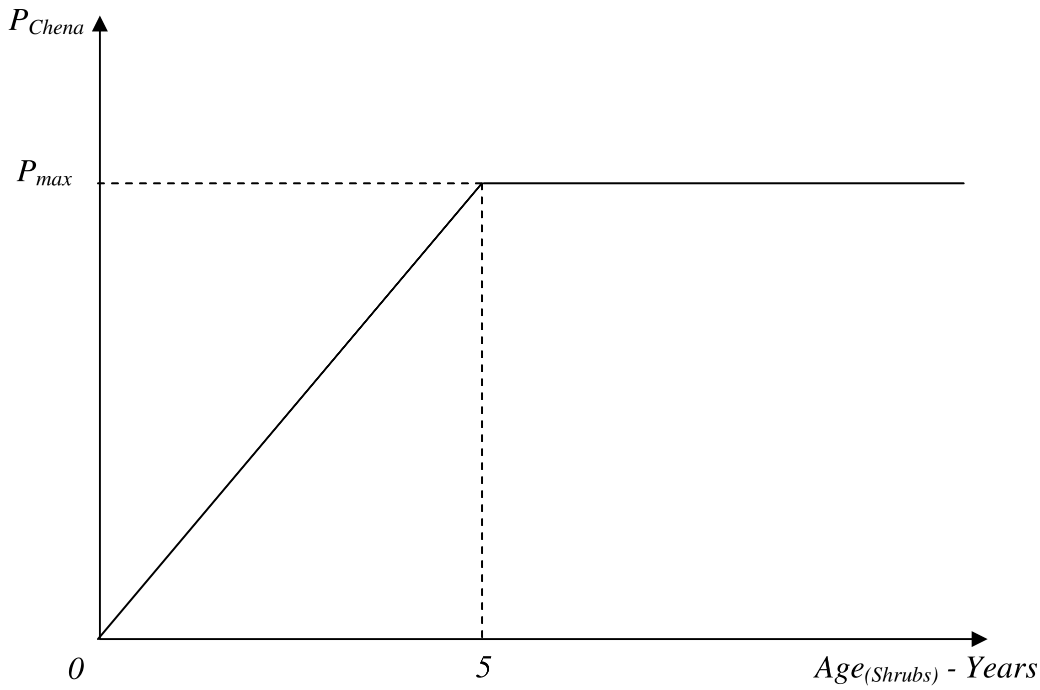


Figure 4.9 Change of potential of shrub areas for chena with the age of shrubs

4.7 Model calibration

Prime goal of this study is to assess how the RUHUNUPURA model can improve policy decision making in Sri Lanka. Therefore, the model was only calibrated, and the historical data validation, which requires additional independent data and a long period to accomplish, was omitted. In fact, there was no additional and independent land use data set available for the study area to perform a validation. However, the usability assessment should be considered as a form of social validation of the model, and essentially contains the characteristics of '*Face validation*' explained by Sargent (1998).

Calibration of a METRONAMICA application like the RUHUNUPURA model involves finding suitable values for the parameters α, which controls the magnitude of the random perturbation factor, and w_{jkd}, which is the weighting parameter in CA rules (*Equation 2.1 and 2.3*) as well as the parameters that determine the magnitude of accessibility (Engelen *et al.*, 2002; White and Engelen, *n.a.*).

The calibration period of the RUHUNUPURA model is a 16 year period starting from 1985 untill 2001. The model was calibrated to get as much resemblance as possible between the actual land use map of 2001 and the model forecasted map for 2001.

The model was calibrated manually in a series of steps. Although calibration was done in steps, the procedure was more like a cycle rather than a flow of steps one after the other. It was always necessary to change parameter values cycling back to previous steps. The extensive knowledge about the area was heavily used in calibration. Next sub-sections describe the calibration procedure in detail.

4.7.1 Macro model data

Since the RUHUNUPURA model is a single layer model, the number of cells of each *function* land use for each state modelled (each year) is the only requirement at macro level. Cell counts for each land use for both 1985 and 2001 were obtained from respective land use maps generated in a previous step. A linear change between 1985 and 2001 was assumed. *Table 4.4* lists the number of cells for each *function* land use for both years.

Table 4.4 Macro model data

Land use	**Cell count**	
	1985	**2001**
Buildup	2	17
Homestead	1362	2395
Chena	2488	1879
Forest	2909	2873
Paddy	1490	1547
Other crops	95	386

4.7.2 Accessibility parameters

Two important accessibility parameters namely, *Relative importance* and *Distance decay* were calibrated. The best values for those two parameters were found for each road type in the road network and for certain *function* land use classes. The accessibility was considered important only for *buildup, homestead, paddy,* and *other crops* land use classes. For all the other land use classes, accessibility was set to *not important* by giving value 0 for relative importance of all road types. *Table 4.5* shows the values assigned for each parameter for the land use class *homestead.*

Table 4.5 Accessibility parameters for Homestead land use class

Road type	**Relative Importance**	**Distance decay**
Main road	0.75	10
Secondary road	0.75	10
Track	0.1	2

4.7.3 Qualitative calibration of the neighbourhood influence parameters, w_{jkd}

According to Engelen *et al.* (2004), the influence parameters represent attraction and repulsion effects between pairs of land uses. Moreover, the absolute magnitude of these parameters has no intrinsic significance; only their relative values are important.

For the calibration of w_{jkd} or the CA rules of the model, a common understanding of the geographical area was heavily used. Initially, a set of land use pairs having a prominent interaction was selected. The rules were crafted to match the observed interactions in the system, by using the knowledge available from previous model calibrations. Thereafter, the model was run until the end of the calibration period, and the final land use map generated by the model (for the year 2001) was compared with the actual land use map of 2001. Visual observation and two statistics; Kappa and Fuzzy kappa (Hagen, 2003) were used to check the similarity between two maps. When the maps did not approximate enough, the rules were fine tuned, and the model was run again. When it was realized that the selected set of rules were not sufficient for a good calibration, new rules were introduced either with or without previous rules. This iterative process was continued until a predetermined degree of similarity was achieved between the model output and the real map. However, the extra care was taken not to calibrate too many rules. The idea was to calibrate the model sufficiently using a minimum number of rules as possible. *Figure 4.10* shows the matrix of interactions among land use classes, and an enlarged version of a selected rule in the right side of the same figure. Note that the cells with a line in the matrix are the interactions for which rules were defined in the model, whereas the empty cells coincide with the interactions for which the rules were not defined.

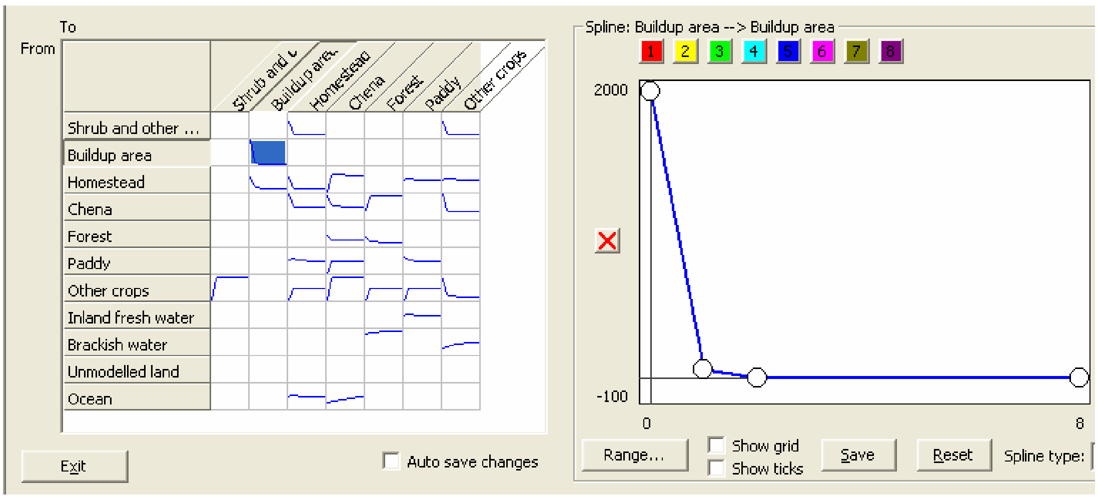
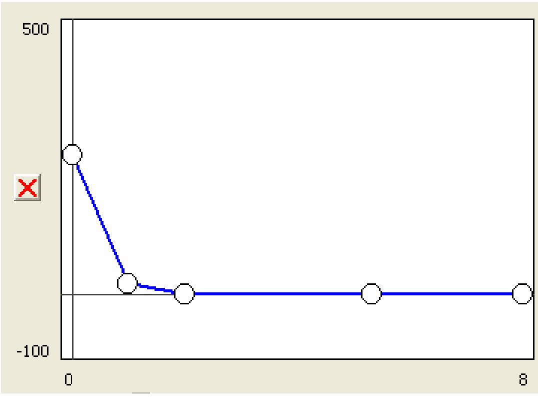


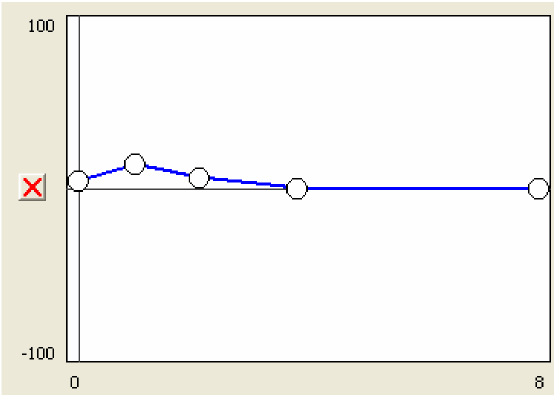
Figure 4.10 The matrix of CA rules

The enlarged rule shown in the right side of *Figure 4.10* is the interaction between *buildup* and itself. At $x = 0$, note that the y value is very high. The implication of the high y value is that the inertia of the buildup land is very high. Therefore, once an area is occupied by *buildup*, it is very hard to replace the area with another land use class.

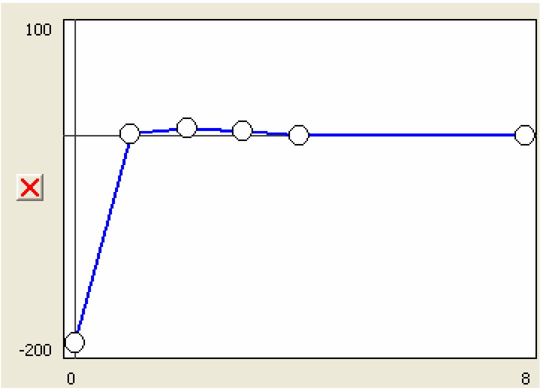
Some important rules are shown in the *Figure 4.11*. Those rules closely match with the observed processes of the system.



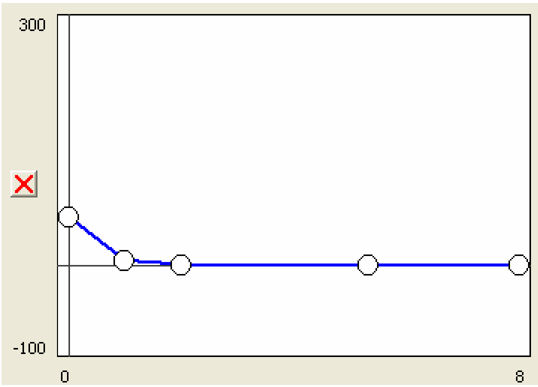
(a) Homestead on buildup



(b) Paddy on homestead



(c) Homestead on Chena



(d) Forest on Chena

Figure 4.11 Some important CA rules

The rule shown in *Figure 4.11 (a)* can be interpreted as; the *homestead* tends to become *buildup* land in a subsequent time step at a considerable rate, and *buildup area* tends to occur in the proximity of the available *homesteads*. However, the attraction of *homestead* on *buildup* becomes neutral after a certain distance from the *homesteads*.

The rule on *Figure 4.11 (b)* shows the effect of *paddy* on *homestead*. There is a small tendency for turning *paddy* areas into *homesteads*. However, *paddy* tends to attract *homesteads* to the proximity in greater degree. *Homesteads* can occur from a considerable distance away from *paddy* as well.

On the other hand, *homestead* areas are less likely to become *chena* in a subsequent stage. This has been indicated by the rule given in *Figure 4.11 (c)* by a high negative value at $x = 0$. But, *homesteads* attract *chena* to the proximity. Therefore, the rule gets a positive value at $x = 2$.

Forest areas in the modelled region are converted into *chena* at a considerable rate. This effect is indicated by a positive value in the rule on *Figure 4.11 (c)* at $x = 0$. Usually, the outskirt areas of the forests become *chena*, because the farmers do not like to go deep inside the forest to cultivate as it is very difficult to safeguard the crop from wild animals and due to many other reasons. This has been emphasized in the rule by assigning a positive value at $x = 1$.

4.8 Scenario analysis

Four scenario were developed to explore the implications of those scenario on the modelled area. The first scenario is a kind of validation exercise for the model. The second and third scenario are policy relevant, while the fourth one is more of a storyline. The starting year for all the scenario was 2001, and the end year was 2030.

4.8.1 Scenario 1

The purpose of this scenario is to check whether the model is capable of producing an ever shortening fallow cycle for *chena* as well as the ever increasing cultivation period of *chena* in a particular land parcel, over time. In other words, the age of *chena* at abandonment should be ever increasing, and the age of *shrub* when it is taken up by *chena* should ever be decreasing. If the model is able to fulfil these two requirements, it is an indication of good performance of the model.

The growth trends of all function land use classes except *chena*, were assumed similar to those used in the calibration. The growth trend of *chena* was kept at a constant level. *Table 4.6* shows the macro model data (cell counts) used in this scenario.

Table 4.6 Macro model data for scenario 1

Land use	**Cell count**	
	2001	**2030**
Buildup	17	51
Homestead	2395	4345
Chena	1879	1879
Forest	2873	2500
Paddy	1547	1447
Other crops	386	977

Zoning maps and suitability maps were also similar to what were used in the calibration. No change was made to accessibility parameters either.

When the model was being run, the land use maps and the age maps were saved for each year of the entire simulation period.

4.8.2 Scenario 2 and Scenario 3

These two scenario are policy relevant. The aim of these two scenario is to explore the effect of the zoning plan proposed by the UDA for the modelled area against the simpler zoning explained under calibration (Section 4.7). Scenario 2 has been assigned the simpler zoning with only nature reserves as a constraint, while Scenario 3 has been assigned the more complex zoning developed by the UDA.

The accessibility parameter and accessibility map, and the suitability maps are similar to those used in Scenario 1. However, the growth trends were modified to be in line with the development that could be brought about by the proposed massive development plan for the area. *Figure 4.12* shows the trend lines used for all function land use classes.

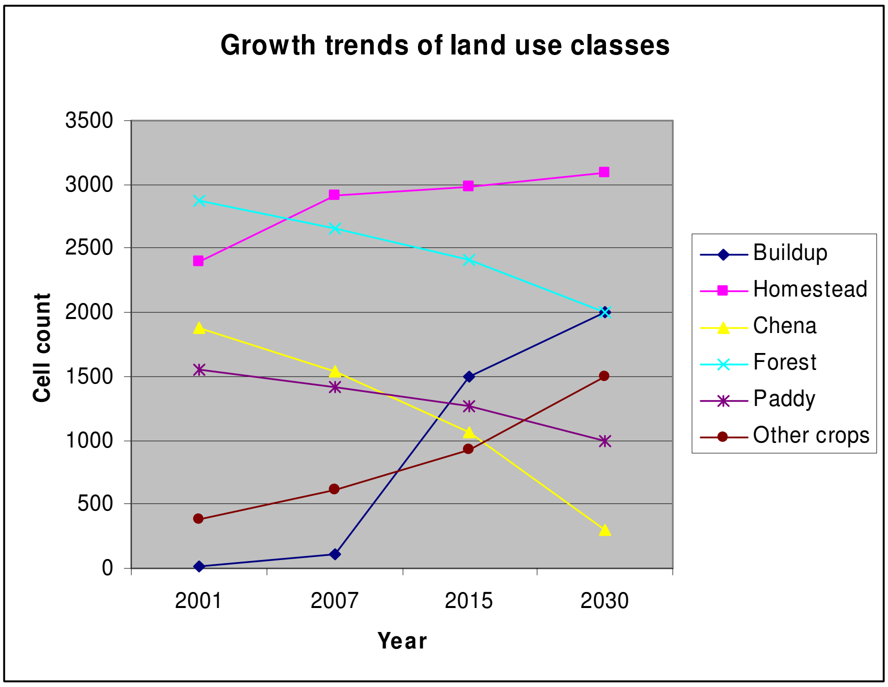
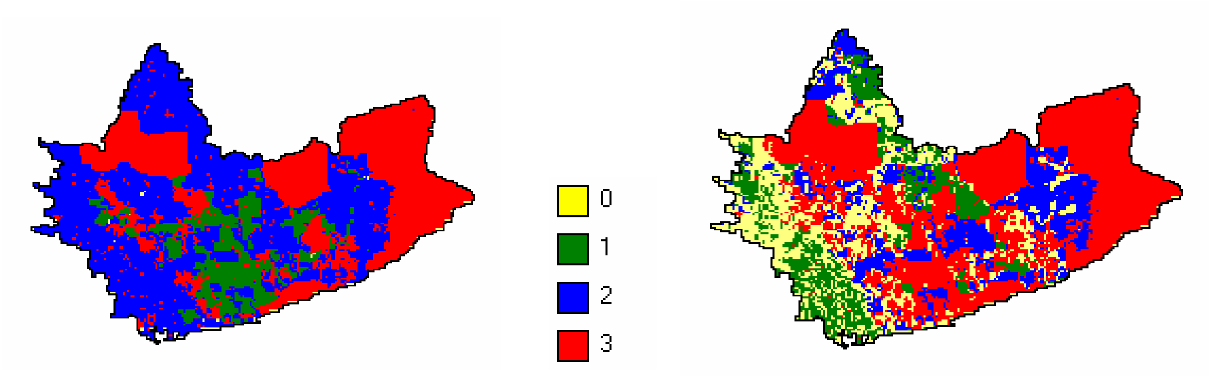


Figure 4.12 The growth trends of land use classes for Scenario 2 and 3

The government of Sri Lanka is currently implementing two massive projects in the study area; a new international airport and related activities, and an international harbour and related activities. Due to these two projects, the *buildup area* will increase rapidly from the beginning year of the project, 2007, untill the end of the project, roughly around 2015. Although the momentum of constructing new *buildup area* can persist, after the end of the project the rate of construction is expected to decline a by a small amount. The rate of expansion of *homestead* areas will definitely have a negative impact by the increasing growth of *buildup* in the area. With urbanization, people will not have sufficient lands to expand *homesteads*. Instead, they will have to move into compact housing schemes with a much smaller home garden area.

Chena cultivation is already in the declining phase in Sri Lanka. Farmers prefer intensive agriculture over the *chena* cultivation, because of the higher income the former can generate, the unavailability of land for *chena*, and the restrictions imposed by the government to clear the forests for *chena*. *Forest* and *paddy* areas are also declining continuously. *Other crops* are preferred over *chena* and *paddy*. Therefore, other crop area will increase continuously.

Zoning maps were developed in the OVERLAY TOOL using the zoning option available. The main input for the zoning maps was the zoning plan developed by the UDA. Land use map of the year 2001 and the nature reserves map were the other two inputs used. The zoning maps for *buildup* and *homestead* land use classes, which were used in Scenario 3, are shown in *Figure 4.13*.



(a) Build up (b) Homestead

Figure 4.13 Zoning maps used for Scenario 3

Note that the number 0 in the legend of *Figure 4.13* indicates the areas which are currently occupied by the corresponding land use class; number 1 indicates the areas that are currently not allowed, but will be opened in the time step 1 (2007), number 2 indicates the areas that will be opened in time step 2 (2017), and number 3 indicates areas that are never allowed for the particular land use class.

The animations of change of land use and change of indicator maps, the graphs of summary statistics for each indicator were obtained while running two scenario.

4.8.3 Scenario 4

This scenario is so called a storyline. Since the coastal belt of the study area was severely damaged by the Indian Ocean tsunami, it is interesting to explore the likely development of the area if another tsunami struck. Therefore, it was assumed that another tsunami will hit the coastal area of the region in 2012, and all *buildup* and *homestead* areas within 4 km from shore will be destroyed. If such a thing happens, it is likely that the government will ban any construction inside the affected area. Hence, it was further assumed that there will not be any *buildup* or *homestead* occurring in the affected area subsequently.

Accessibility and suitability maps were similar to those used in Scenario 3. The macro model data of *buildup area* and *homestead*s were modified, and the trend lines of those two classes are given in *Figure 4.14.* The trend lines of all the other function land use classes were assumed similar to those of the scenario 3.

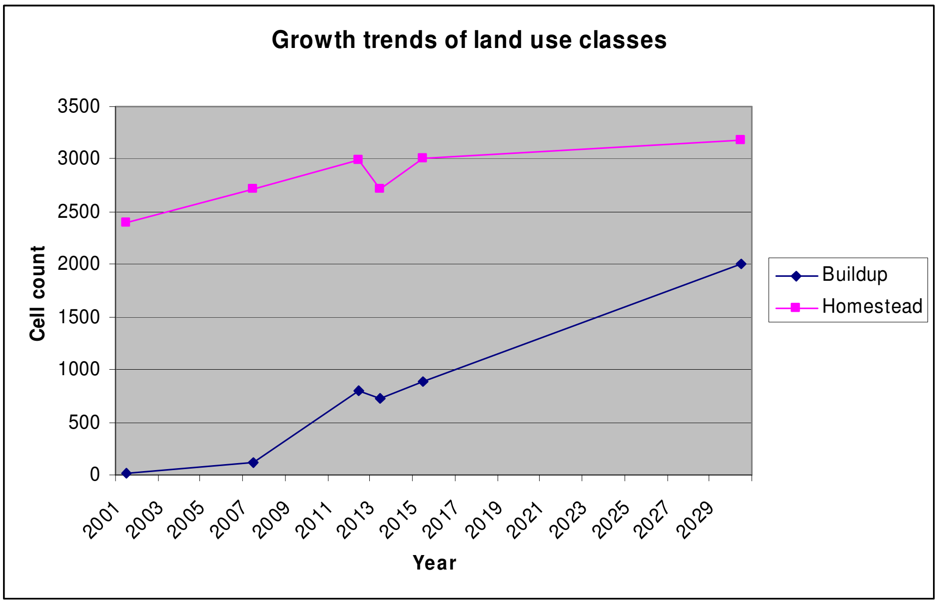


Figure 4.14 Growth trends of land use classes for Scenario 4

Zoning too is different for *buildup* and *homestead* land use classes, while the zoning for all the other land use classes are similar to Scenario 3. The requirement for this scenario is that before the tsunami, the zoning for *buildup* and *homestead* should work similar to Scenario 2 for the entire area modelled, but after 2012 the value of the zoning term for *buildup* and *homestead* should be 0 only in the affected areas. For other land use classes, there should not be any effect on zoning by the impact of the tsunami.

This complex requirement was achieved by creating an additional map of tsunami hit area, introducing that map into the model, and modifying the model's algorithm. A categorical map of 2 categories; 4 km buffer zone from the coast (value 1) and the rest (value 0) was created. The new map was given the name *C*. The zoning term of the algorithm was modified as follows.

$$Z_{new} = Z_k \times TF$$

Where $TF = Tsunami\ factor$

If *{(state = buildup OR state = homestead) AND C = 1 AND T > 10}* Then

$TF = 0$

Else $TF = 1$

4.9 Usability assessment

Usability assessment of the RUHUNUPURA model for the user in Sri Lanka is considered a important aspect of this study. Therefore, a usability assessment was conducted at the Urban Development Authority of Sri Lanka with the participation of a representative group of 10 people. The representatives for the assessment were selected in consultation with the user, but with special attention paid for the knowledge the participants should possess about GIS, modelling, and urban planning. In fact, all the participants were planners by designation.

Out of many usability elements, efficiency, effectiveness, and user satisfaction were selected to be used in this study. In addition to those elements, the possibility to uptake the model into the organization was also examined. The measures used to quantify these elements are discussed in the next paragraphs.

Note that the ISO 9241 (1994) provided definitions for the terms usability, efficiency, effectiveness, and satisfaction were used in this study.

The framework adopted in the usability assessment of this study is a blended version of the two workshop approaches suggested by Haklay and Tobón (2003) and Bacic *et al.* (2006). Unlike in Haklay and Tobon's method, this usability assessment consists of all the important usability assessment techniques namely, questionnaire survey, open discussions, practical exercises, and interview. The assessment was conducted in 4 steps.

1.An introductory plenary session to introduce the model to the participants

This introduction consisted of two PowerPoint presentations and a software demonstration. The first presentation was about the concepts of land use modelling, whereas the second presentation focused on the RUHUNUPURA model. Before delivering any of the presentations, Questionnaire 1 (*Appendix III*) was filled in by the user. The first questionnaire aims at finding the level of knowledge of the users about land use modelling. Each participant was assigned a number (1 to 10), and they were asked to indicate the number in all the questionnaires they were evaluating.

In the software demonstration, it was emphasized how the scenario were transformed into simulations of the model, in addition to illustrating the frequently used features of the model. The outputs of the model (suitability maps, maps of indicators, land use change maps, etc) and their implications were also described.

After the introductory presentations and the software demonstration, Questionnaire 2 (*Appendix IV*) was filled in by the users. This questionnaire checks the users' understanding of the RUHUNUPURA model. That was followed by an open discussion. Altogether, three hours were spent for the introductory session.

It is important to note that both questionnaires were tested before using by three independent persons from Sri Lanka who have sufficient GIS related knowledge. Based on their comments, two questions of the Questionnaire 2 had to be modified slightly.

2. Individual assistance for the users to get acquainted with the model

After the introduction, the users were given the chance to try out the model for a week. On average, about 1 hour per day was spent on this. During this period, individual assistance was provided where necessary. A user manual [on CD] was made available to guide the participants during this period.

3. Practical exercise which allows the participants to use the model to formulate and run a scenario

After a week of guided use of the model, the users were asked to develop and run a simple scenario in the model, individually. No support was given during this exercise. A half an hour time slot was given to carry out the exercise. The guidelines given to formulate the scenario are given in *Appendix V*. The users were asked to save their outputs. The time spent by each user to complete the exercise was recorded, and the outputs of each user were examined for completeness and accuracy. After the exercise, Questionnaire 2 was filled in by the users for the second time. The idea behind the second time evaluation is to measure the change of attitude of the users towards the model. This was followed by a group discussion which aimed at finding the broader views of the users on the usability issues such as user satisfaction, further improvements required to the model, pros and cons of the model, etc.

4. Interview with the Director of the UDA's GIS centre

After all, it was necessary to check if the model can actually be absorbed into the institute, and if it is possible, under which section of the institute the model can be best used. In order to explore those aspects, an unstructured interview was held with the Director of the UDA's GIS centre. The points highlighted in the interview were;

- Do they like the model?
- If not, why?
- If yes, what are the added values of the model for the UDA?
- Is it possible to use the model in the UDA?
- If not, what are the potential problems in the uptake of the model?
- How can/ should they use the model?
- Who will use it within the organization?
- In what way will they use it?
- What are the weaknesses of the model?

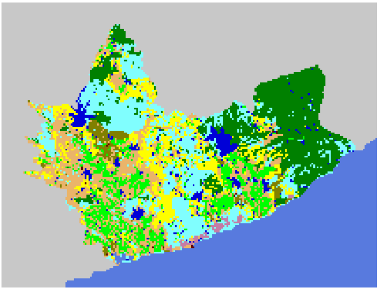
In addition to the proper usability assessment conducted at the UDA, two other seminars on the RUHUNUPURA model were also held at two recognized institutes in the country namely, the International Water Management Institute (IWMI), Colombo, Sri Lanka and the International Centre for Geoinformatics Applications and Training (ICGAT), University of Moratuwa, Sri Lanka. These two seminars were used to popularize land use modelling in the country, and to gather the thoughts of the leading research community in the country on the RUHUNUPURA model.

5 Results and Discussion

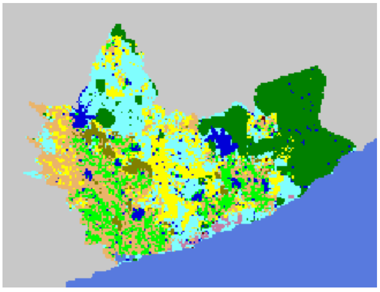
5.1 Calibration results

The calibration period was from 1985 to 2001. Four categorical raster maps were used in the analysis of the calibration results namely, the actual land use map of 1985 (Map 1), the actual land use map of 2001 (Map 2), the model generated land use map for 2001 (Map 3), and a reference map for 2001 (Map 4) created using Random Constraint Match (RCM) model available in the software called the *Map Comparison Kit* (*MCK*). *Figure 5.1* shows those four maps used in the analysis.

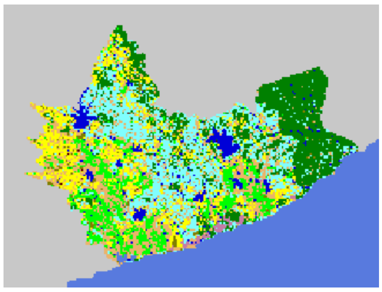
(a) Land use 1985 - actual (Map 1)



(b) Land use 2001-actual (Map 2)



(c) Land use 2001-Model (Map 3)



(d) Reference map 2001 (Map 4)

Figure 5.1 Land use maps used for calibration accuracy assessment

Neutral models of land use change provide a reference to assess the goodness of fit of a given land use change model (Hagen-Zanker and Lajoie, to be published). Random Constraint Match (RCM) model is one of the two neutral models supported by the MCK (Hagen-Zanker *et al.*, 2006).

RCM model creates a reference map (Map 4) by minimally adjusting the initial map (Map 1) in order to achieve the same composition as the target map (Map 2). It first assesses the Map 1 and Map 2, and identifies how many cells of each land use class are over represented or under represented in Map 1 compared to Map 2. Thereafter, it selects the surplus cells of the over represented classes in Map 1. Finally, it randomly allocates the under represented classes on selected cells of Map 1. The resulting map (Map 4) is a ‘speckled map’ of small clusters (Hagen-Zanker and Lajoie, to be published; Hagen-Zanker *et al.*, 2006).

Calibration results were evaluated using three methods; Fuzzy kappa statistic, visual interpretation of maps, and the wavelet verification. Each method is described in detail under the next sub-sections.

5.1.1 FuzzyKappa statistic

Fuzzy kappa statistic is preferred over the ordinary Kappa statistic as the criterion for optimizing the match between the reality and the model output. Usually, it is impossible to predict the land use changes at exact locations. Therefore, not only the exact location overlaps between the actual land use and the model generated output should be considered in verification of models, but also the neighbourhood should also be taken in to account. Unlike in the ordinary Kappa statistic, the Fuzzy Kappa statistic credits the exact cell-to-cell agreement, as well as the near cell-to- cell agreement (Hagen-Zanker *et al.*, 2005).

The Fuzzy Kappa values for two comparisons, the actual land use of 2001 vs. the predicted land use for 2001 by the RUHUNUPURA model (goodness of fit) and the actual change of land use from 1985 to 2001, are given for all the *vacant* and *function* land use classes in *Table 5.1.*

Table 5.1 Fuzzy Kappa statistic

Land use	**Fuzzy Kappa value**	
	Map 2 vs. Map 3 (goodness of fit)	**Map 1 vs. Map 2 (actual change)**
Shrub and other uncultivated area	0.42071	0.39089
Buildup area	0.30769	0.24423
Homestead	0.55521	0.51071
Chena	0.32531	0.21216
Forest	0.69726	0.66265
Paddy	0.71287	0.79049
Other crops	0.24666	-0.00552

The Fuzzy Kappa values for *homestead, forest* and *other crops* are considerably high; meaning the agreement for these land use classes between the model and the reality is well acceptable. However, it is important to note that the actual changes of these land use classes are not extreme. This is indicated by higher Fuzzy Kappa values for the actual change.

The compliance between the actual and the model output for *buildup area* is low, and it is indicated by the Fuzzy Kappa value of 0.30769. However, the number of cells occupied by *buildup area* in both maps is very little. Therefore, it is very difficult to go for a higher accuracy in calibration. On the other hand, the accuracy of calibration for such a land use class does not mean much.

Chena is the land use class that shows the greatest dynamics among all the land use classes modelled. The distinct pattern of cultivation with continuous crop for few years, subsequent abandonment for few more year, and re-cultivation makes the dynamics of *chena* extremely complex. The degree of match between the actual *chena* areas and the modelled areas is comparatively low, in it is indicated by a Fuzzy Kappa value of 0.32531. However, the actual change of *chena* is very high as denoted by far lower value of Fuzzy Kappa (0.21216). When the real change is extremely high, obviously the capability of a model to predict the dynamics of that kind becomes hampered. Therefore, the agreement between the model output and the reality for *chena* is within the acceptable limits. This argument is further supported by the results of the wavelet verification, which is described in a subsequent section.

The goodness of fit of the model for the land use class *other crops* is not sufficient (Fuzzy Kappa = 0.24666). However, the lowest Fuzzy Kappa value for the actual change hints that the change of *other crop* areas between 1985 and 2001 is massive. It is also important to note that the number of cells come under *other crops* in 1985 is only 95, while for 2001 it is 386. Therefore, the rate of change of other crop areas is extremely high, compared to all other land use classes, except for *buildup area*. *Table 5.2* suggests that the new development of other crop areas is fairly independent from the locations of those in 1985. Due to all of these reasons, it is clear that the model is not capable enough to capture the dynamics of other crop areas.

After all, it is important to note that a very high calibration accuracy was not expected right from the beginning of this exercise due to two reasons. Apart from calibration, two other considerably large components namely, scenario analysis and usability assessment had to be carried out within the time frame of this study. Therefore, spending a lengthy time period to achieve very high calibration accuracy was not feasible. The other reason is that a possible over calibration had to be prevented, because a historical data validation was not possible due to lack of independent data.

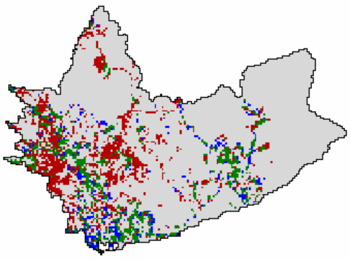
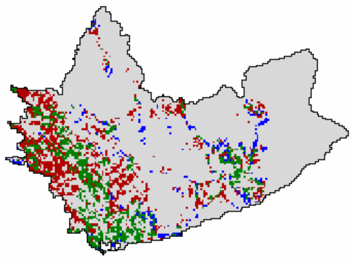
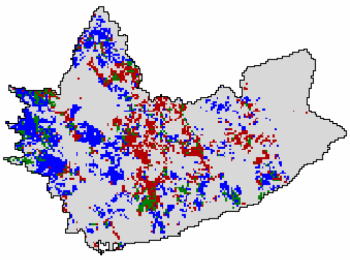
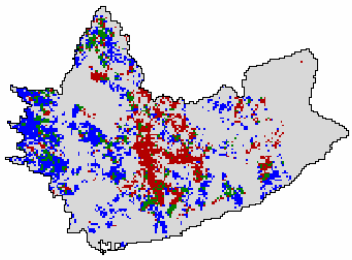
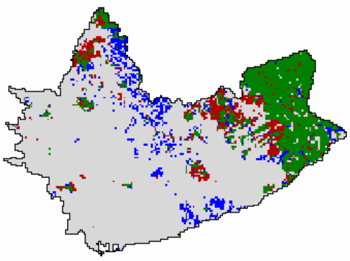
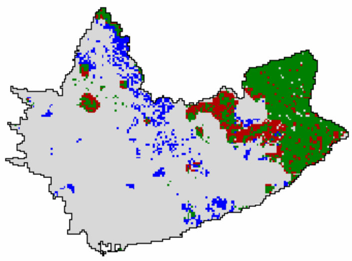
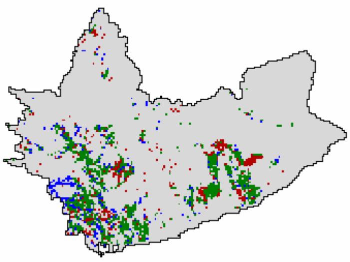
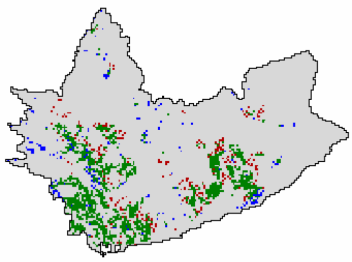
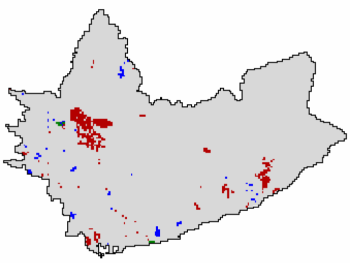
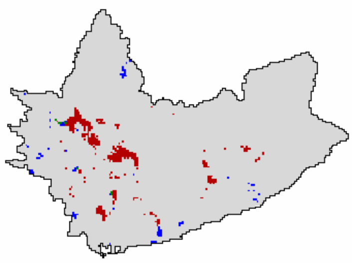
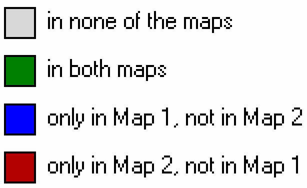
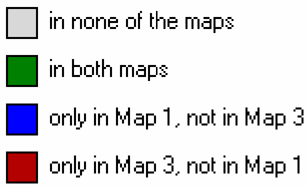
5.1.2 Visual interpretation

If the land use change predicted by the RUHUNUPUA model can be compared with the observed real change from 1985 to 2001, a clear picture could be derived about the capability of the model. *Table 5.2* illustrates the real land use change from 1985 to 2001 against the predicted change by the model for the same period.

It is obvious from the maps shown in the *Table 5.2* that the model has generated the same patterns of change as the observed change for almost all the land use classes except for *other crops*. This is true even for the land use classes having low Fuzzy Kappa value, except for *other crops*. Although the predicted cluster sizes of other crop areas appear to be similar to those of the reality, the predicted locations for those clusters are not so accurate to generate a higher Fuzzy Kappa value.

The change maps for *paddy* clearly suggest that *paddy* areas are the least dynamic among all the land use classes. This is the case in real practice as well. The *paddy* areas in Sri Lanka can not be filled or converted into other land use class, and it is stated by law. On the other hand, traditional farmers have a spiritual bond with *paddy* cultivation. Therefore, they are reluctant to revert from *paddy* to another crop. Due to these reasons, *paddy* areas show reduced dynamics.

Table 5.2 The real and the predicted land use change for the period 1985 - 2001

Land use	Real change (Map 1 vs. Map 2)	Predicted change (Map 1 vs. Map 3)
Homestead		
Chena		
Forest		
Paddy		
Other crops		
		

5.1.3 Wavelet verification

Technically, the wavelet transformation transforms an original signal consisting of *n* values to an accumulation of the same number of *n* coordinates, each corresponding to one from a family of wavelets (Hagen-Zanker and Lajoie, to be published). Briggs and Levine (1997) discuss the mathematics behind wavelet transformation in detail. In this exercise, wavelet transformation is the basis used to derive a set of maps at different scales starting from a mother image.

Wavelet transformation is one of the multi-scale analysis methods used in model verifications. Moreover, wavelet transformation can separate out an image into different layers at different scales which are independent from each other. This is the advantage the wavelet transform offers over the other multi-scale analyses, such as moving windows aggregation (Hagen-Zanker and Lajoie, to be published).

The simplest form of wavelet transform called the *Haar* wavelet, which is a discrete wavelet transform, has been used in this study. The multi-scale verification of the model results has been coupled with a comparison between the RUHUNUPURA model (Model) and a reference model (Random Constraint Match - RCM).

Mean Squared Error (MSE) is the statistic used in the analysis. The analysis was done separately for each vacant and function land use class. MSE was obtained for three pairs of land use maps at 9 scales (aggregate levels). The three pairs of comparisons are Map 1 vs. Map 2 (actual change from 1985 to 2001), Map 2 vs. Map 3 (actual land use 2001 and model prediction), and Map 2 vs. Map 4 (actual land use 2001 and the reference map - RCM). Thereafter, MSE for the RUHUNUPURA model and the RCM model was normalized, by dividing MSEs of the former two with MSE of the actual change (from 1985 to 2001). The aggregate level of 1 × 1 denotes the *no aggregation* or the highest resolution (single cell level), 2 × 2 indicates the aggregation of two cells, so on and so forth. Note that the largest aggregation level 256 × 256 covers the entire modelled area (120 × 212 cells) by *one large cell*. In other words, the entire modelled area is considered as a map of one cell at 256 × 256 aggregate level.

Relative MSE for the model and the RCM for the land use class *homestead* at different scales is given in *Figure 5.2* (non cumulative) and *Figure 5.3* (cumulative).

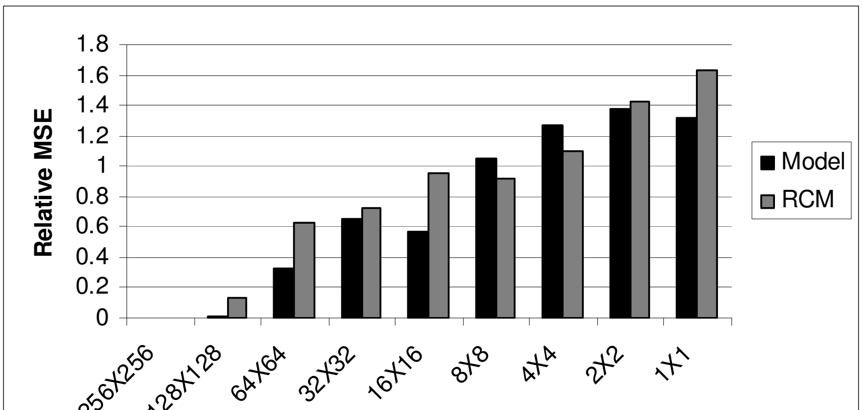


Figure 5.2 Non cumulative Relative MSE for homestead at different scales

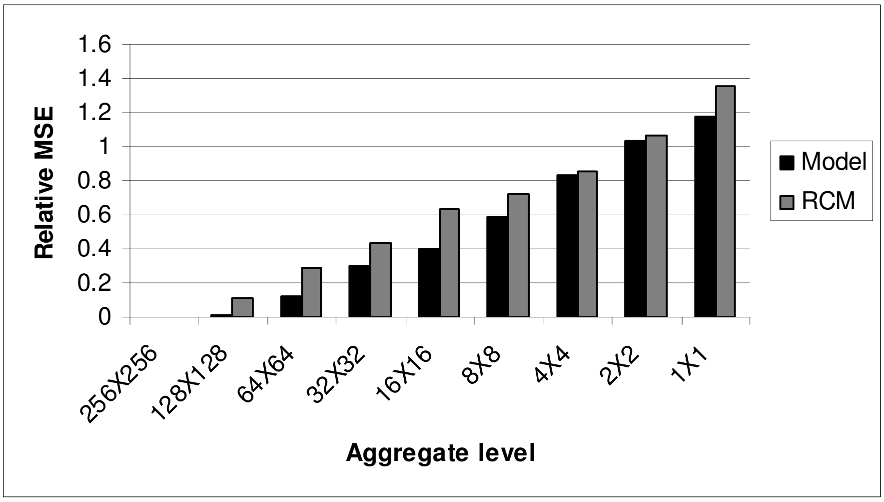


Figure 5.3 Cumulative Relative MSE for homestead at different scales

From *Figure 5.2*, it is clear that the RUHUNUPURA model has a lower relative MSE than the RCM model for *homesteads* at coarse and fine scales, whereas the visa-versa happens at medium scales. The implication of the incidence is that the model out performs RCM at coarse and fine scales. Therefore, the RUHUNUPURA model can provide an added value to study the dynamics of *homesteads* at coarse and fine resolutions.

However, it is important to note that the cumulative relative MSE of the RUHUNUPURA model is always lower than that of the RCM. The essence of that phenomenon is that the RUHUNUPURA model can complement for lower accuracies at medium scales by higher accuracies at coarse and fine scales.

For the land use class *chena*, cumulative and non cumulative relative MSEs appear to be very similar to those of *homestead*. However, for *chena*, relative MSE of the model is drastically lower than that of the RCM at coarser scales (*Figure 5.4*).

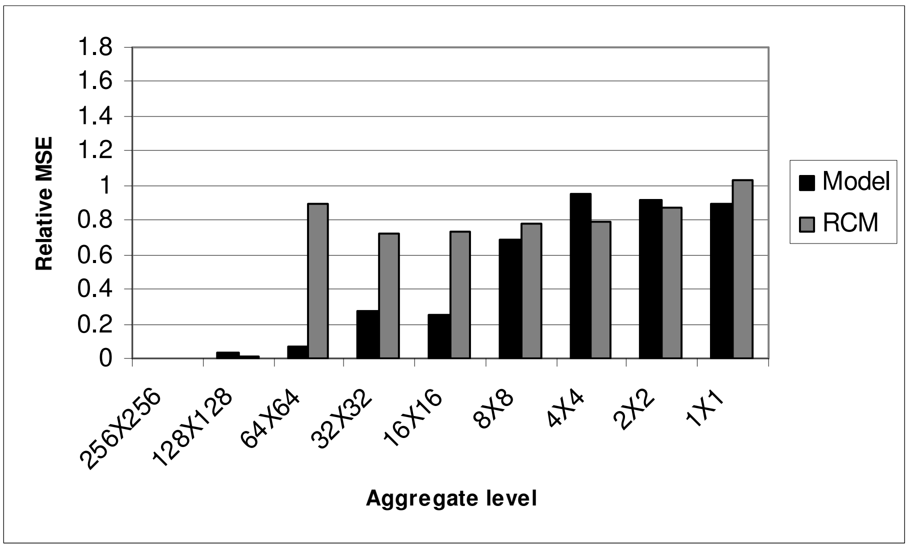


Figure 5.4 Non cumulative Relative MSE for chena at different scales

For the land use class *forest*, the behaviour of the relative MSE is similar to *chena* and *homestead*. But, the RUHUNUPURA model well out performs the RCM model at very low and very high resolutions.

For *other crops*, the model poorly performs at all scales, except at very fine scales. Low Fuzzy Kappa value, visual interpretation, and the results of wavelet verification suggest that the usage of the model to study the behaviour of *other crops* should be done with extra care.

For *paddy*, the model performs over the RCM only at coarser scales (*Figure 5.5*).

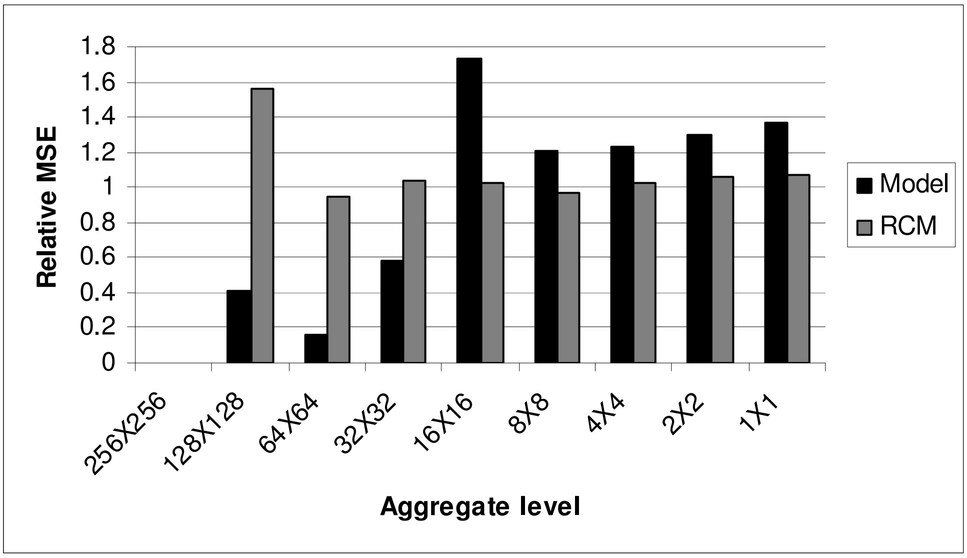


Figure 5.5 Non cumulative Relative MSE for paddy at different scales

5.2 Results of the scenario analysis

5.2.1 Scenario 1

Scenario 1 serves as a test for validating the RUHUNUPURA model. If the period of continuous *chena* cultivation in a certain land parcel increases over time and the fallow period is shortening ever in the model predictions, the model can be considered a well adaptable system. Not only that, it further supports the new transformation algorithm developed for the RUHUNUPURA model.

The model was run from 2001 to 2030, and the land use maps and the age maps generated for each year were saved. Each dynamically modelled cell gets an age value depending on the occupied land use. If the same land use remains in the same cell in the next time step of the model run, the age is increased by 1 year. If the land use of the cell is replaced by some other land use, age becomes ‘0’ immediately for that particular cell. Since the model can save both land use maps and age maps for each year, the age of individual land use class can be tracked. Once the *chena* is replaced by *shrub and other uncultivated area*, it was assumed that the *chena* in those cells were abandoned. With the help of Idrisi software, the average age of *chena* when it is abandoned was calculated for each year (*Figure 5.6*).

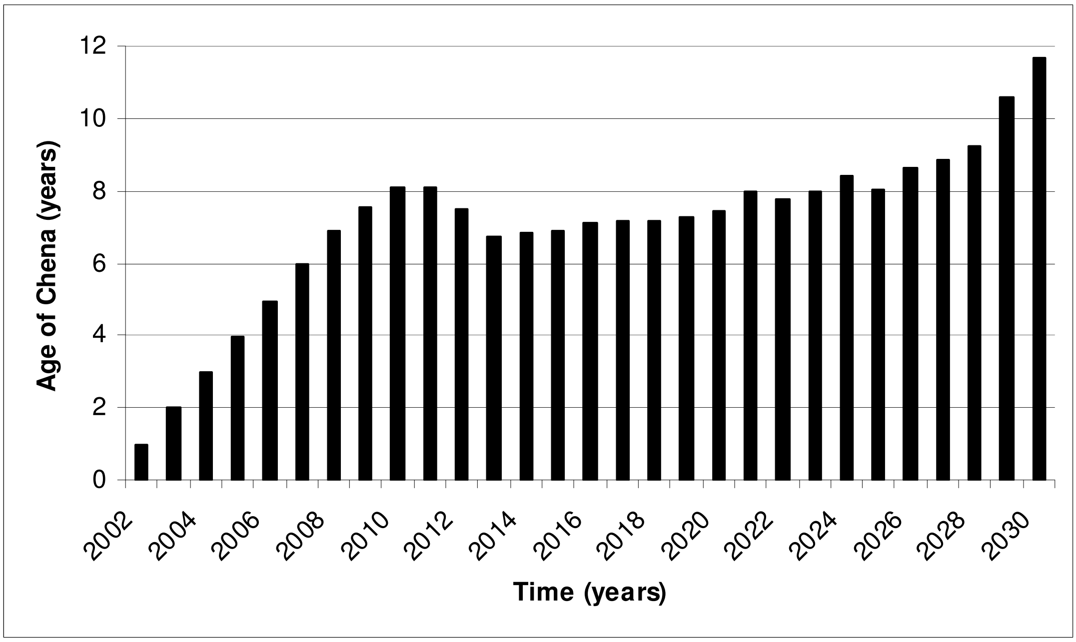


Figure 5.6 Average age of chena at abandonment

It is important to note that the age of *chena* is everywhere the same at the beginning of the simulation. Therefore, a warm up period of few years is required until a considerable age distribution of *chena* is achieved, before the model can predict increasing ages at the abandonment of *chena*. Note in the *Figure 5.6* that the period from 2001 till about 2013 is the warm up period. After 2013, the age at the abandonment of *chena* is increasing continuously. This is a very important evidence to claim that the model can simulate the real system to a greater degree.

The next evidence could be the ability to simulate the ever shortening fallow period of the abandoned *chena* areas. Since the abandoned *chena* areas are occupied by shrubs, the age of *shrub and other uncultivated area* just before those areas are taken up by *chena* for the next time, can be considered as equivalent to the fallow period. The average age of *shrub and other uncultivated area* when it is taken up by *chena* is shown in *Figure 5.7.*

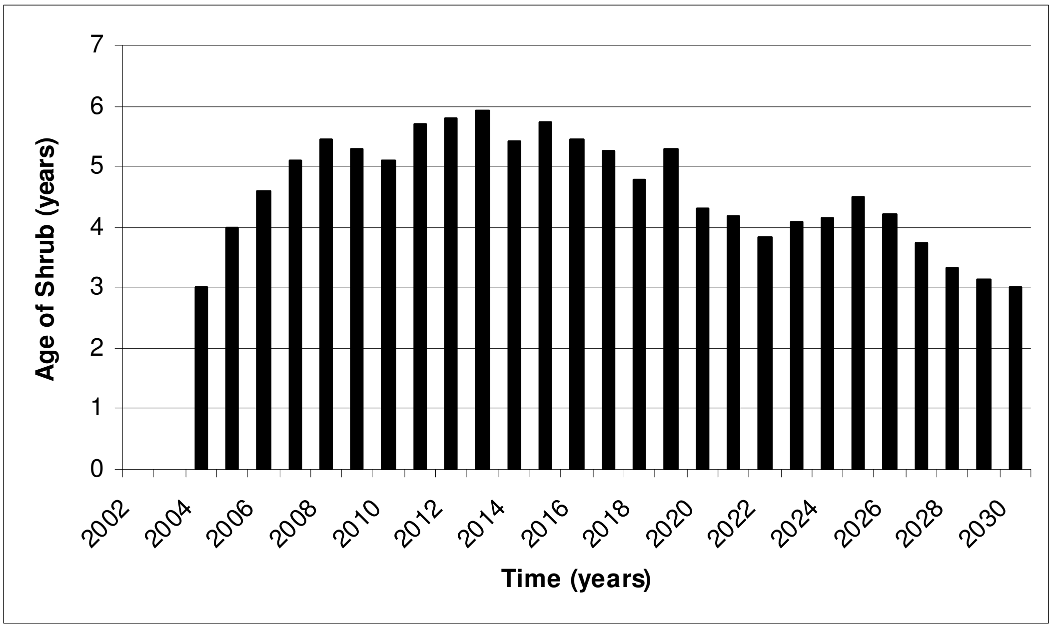


Figure 5.7 Average age of shrub and other uncultivated area before taken up by chena

The time period from 2001 to 2013 is again the warm up period. It is clear from *Figure 5.7* that the average age of shrubs is in a decreasing trend after 2013. This is a clear indication for the ability of the model to predict shortening fallow cycles.

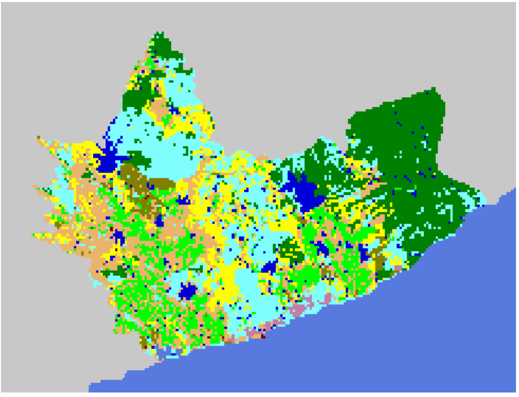
Both the increasing continuous cultivation of *chena* and decreasing fallow period do confirm that the RUHUNUPURA model is a valid land use change model for the study area.

5.2.2 Scenario 2 and Scenario 3

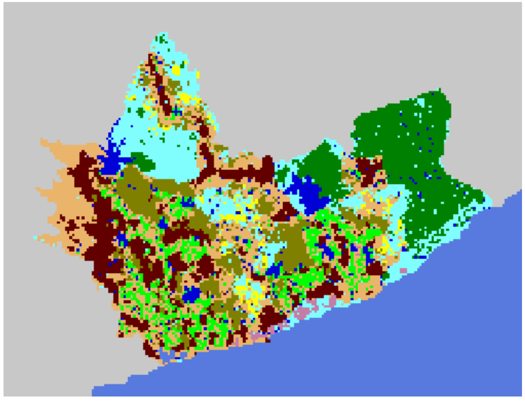
These two scenario were formulated to evaluate the possible outcomes of two alternative policy options for the modelled area. The first policy could be to let the system develop on its own without intervention by means of strict zoning regulations, and it is incorporated in the scenario 2. The second policy, on the other hand, aims at directing the development of the area by means of strict zoning regulations, and it is studies via the scenario 3.

Figure 5.8 compares the possible land use maps for 2030 lead by two policy options. From the predicted land use maps for 2030, it is clear that the evolution of *buildup area* is strongly related to the distribution of *homesteads*, if strict zoning regulations are not applied. The natural tendency is to convert the *homesteads* into *buildup area*. It is also important to note that the new *buildup area* follows the accessibility network as well, when the zoning is not strict. It is likely that the new development would take place mainly in the western part of the map, where *homesteads* are predominant, if the system is allowed to function without too many regulations.

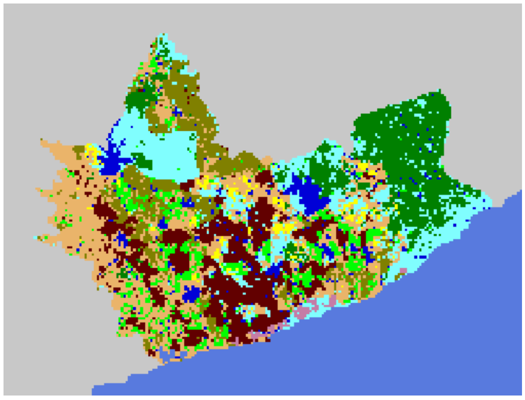
On the other hand, strict zoning regulation can direct the development to a certain area, which is the central part of the map, under the government's policy in this case. However, diverting the development artificially to an area where the natural tendency for such a development is low can hamper the rising of better and more suitable areas. The predicted land use map for 2030 under the scenario 3 supports that argument.



(a) Land use 2001 - actual



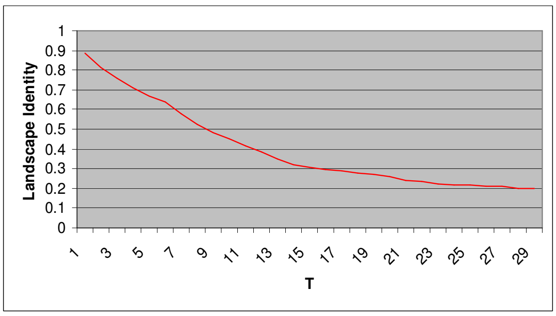
(b) Land use 2030 – without strict zoning



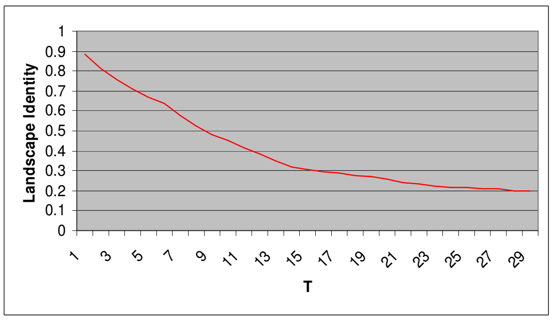
(c) Land use 2030 – with strict zoning

Figure 5.8 Likely land use in 2030 by scenario 2 and 3

The two indicators, the landscape identity and the self sufficiency show continuously decreasing summary statistics during the simulation period (2001 to 2030) for both scenario. However, there is no clear difference for those indicators between two scenario. The implication of the similarity between two scenario in their summary statistics is that the landscape change and the decline of self sufficiency have no special influence by the strict zoning regulations. *Figure 5.9* and *Figure 5.10* comparatively show the trend lines of the summary statistics for the two indicators.

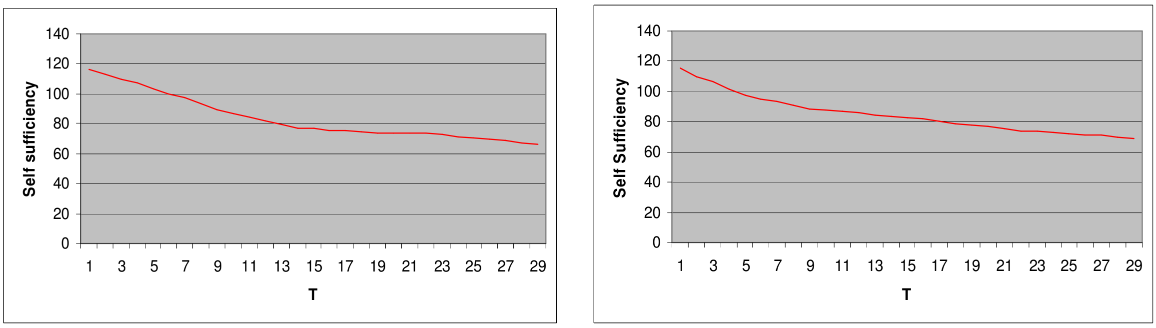


(a) Landscape identity - Scenario 2



(b) Landscape identity - Scenario 3

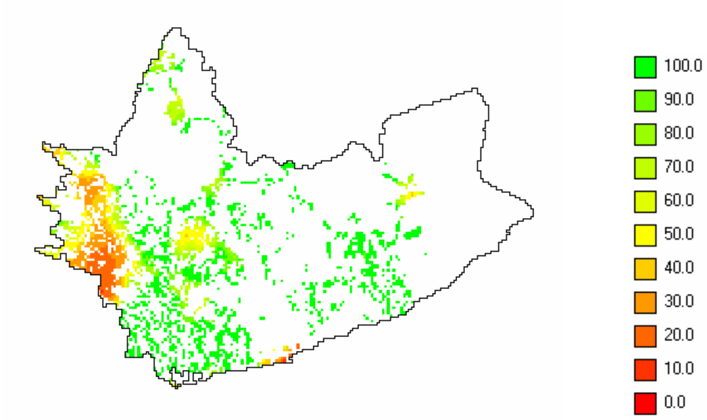
Figure 5.9 Summary statistics of the Landscape identity indicator



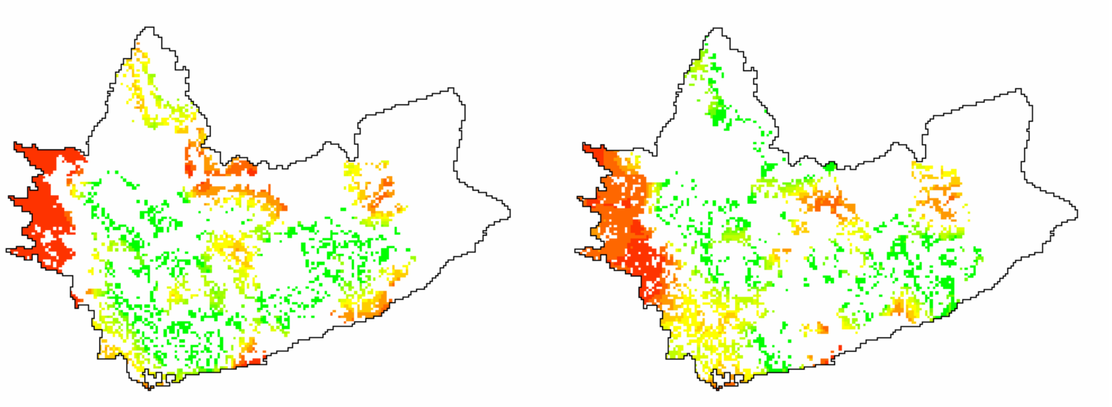
(a) Self sufficiency - Scenario 2 (b) Self sufficiency - Scenario 3

Figure 5.10 Summary statistics of the Self sufficiency indicator

The model can generate maps for each indicator per each year of the simulation. A comparison between the indicator maps of the indicator self sufficiency at the beginning and the end of the simulation for two scenario are shown in *Figure 5.11*.



(a) Self sufficiency at 2001 (for both scenario)

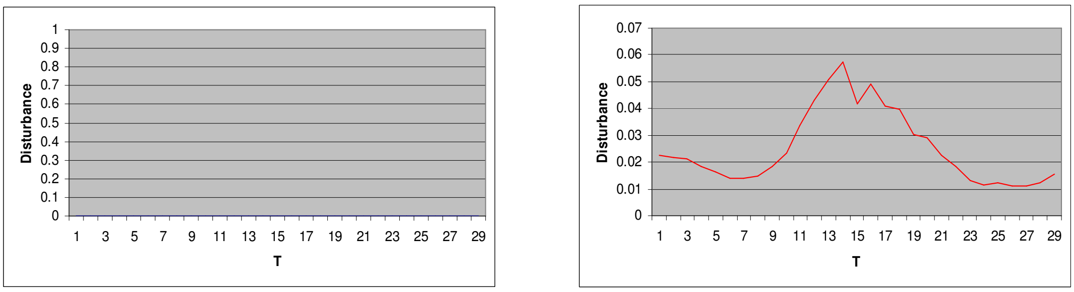


(b) Self sufficiency at 2030 - Scenario 2 (c) Self sufficiency at 2030 – Scenario 3

Figure 5.11 Maps of the self sufficiency indicator for Scenario 2 and 3

Both scenario suggest that the self sufficiency of the *homesteads* located towards the western tip of the map can drastically reduce over time. Therefore, it is very likely that these areas in reality will have to depend on mainly food items imported from somewhere else.

While the nature reserves are unlikely to be disturbed by adopting the simple zoning (scenario 2), the complex zoning plan proposed by the UDA (scenario 3) is likely to disturb those nature reserves considerably. The comparison of the summary statistic of the indicator *Disturbance of nature reserves* between two scenario clearly shows the effect of the complex zoning plan proposed by the UDA on the nature reserves (*Figure 5.12*). Therefore, the UDA has to be more careful about the impact of the new zoning policy on nature reserves.



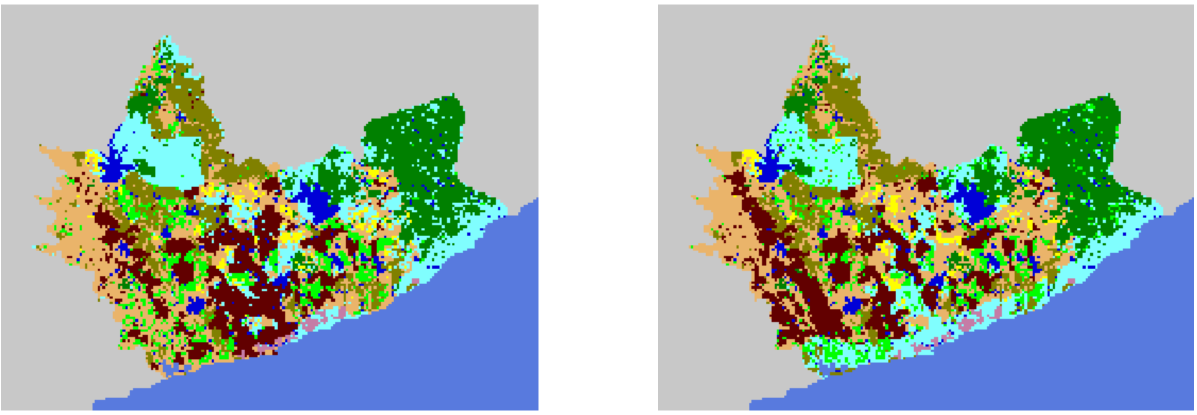
(a) Scenario 2 (b) Scenario 3

Figure 5.12 Summary statistics of the Disturbance of nature reserves indicator

5.2.3 Scenario 4

The model's ability to explore the likely impacts of a once experienced tsunami on the study area has been tested under this scenario. This is a story line scenario which can highlight the value of the RUHUNUPURA land use model for unconventional applications.

The simulation developed under the scenario 4 should be studied in comparison with the scenario 3. Because scenario 4 tries to oversee the possible future of the new development aimed by the government through strict zoning regulations and by massive construction projects, if the coastal belt of the study area is hit by another tsunami. *Figure 5.13* shows the projected land use maps for the year 2030 under scenario 3 and scenario 4.



(a) Land use 2030 – Scenario 3 (b) Land use 2030 – Scenario 4

Figure 5.13 The possible effect of a hypothetical tsunami on land use change

Two things are clearly visible from *Figure 5.13.* The first aspect is that another tsunami hit on the coastal belt of the study area can hamper the expected development. Most probably it will change the focus area of the development. It is clear from the maps that the *buildup area* tends to occur mainly in the western part of the region where it is occupied by *homesteads*, instead of concentrating on the central part of the map as expected by the government. The other aspect is the heavy disturbance to the nature reserves of the area after the tsunami. Lack of land for new settlements and for cultivation, people might have to reach the land belongs to the nature reserves. The indicator, *disturbance of nature reserves* illustrates the effect of nature reserves (*Figure 5.14*).

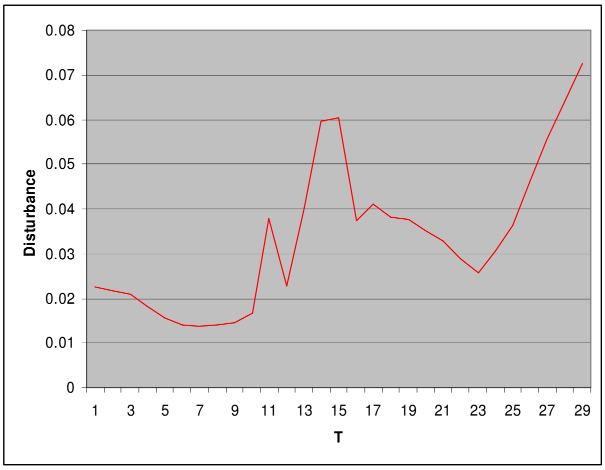


Figure 5.14 Disturbance of nature reserves - Scenario 4

It is obvious that the aftermath of the disaster can generate a lot of unsettlement in the area, leading to higher disturbance of the nature reserves. But interestingly, the trend of disturbing nature reserves gets further increased according to the outputs of the scenario 4. One of the explanations for this effect is the likely policy of the government to ban any construction in a 4 km width coastal belt (an assumption of the scenario). The conclusion which can arrive at by referring to the outputs of this scenario is that the government needs to be more innovative when drafting policies to manage a disaster response so that it can balance the safety of the people, protection of nature reserves, and the expected development.

5.3 Results of the usability assessment

The results of the usability assessment are described in the following sections under four titles; results of the questionnaire survey, results of the practical exercise, results of the group discussion, and results of the interview.

5.3.1 Results of the questionnaire survey

Questionnaire 1

Questionnaire 1 (*Appendix III*) explores the participants' knowledge about the concepts of land use modelling, as well as the intensity at which those concepts are used in their working environment. Out of 15 questions of Questionnaire 1, six (numbers 1, 2, 5, 6, 7, and 8) check the factual understanding of the participants in land use modelling, whereas the rest of the questions measure the degree of usage of those concepts in day-to-day work. There are some questions included to verify if a participant answers questions with a good sense of understanding. For example, answers to question numbers 9 and 10 should not be contradictory. Because, there is less sense of answering '*Yes*' to the statement '*You have used a cellular automata based application at least once*' (*question number 10*), given that the participant has answered '*No*' to the statement '*Cellular Automata (CA) is a familiar term to you*' (*question number 9*).

Table 5.3 illustrates the profile of participants by evaluating the answers they provided for Questionnaire 1. Note that the percentage of correct answers is calculated based on the six factual questions. Furthermore, the answers of either *Yes* or *No* for questions were considered *firm*, while the answer *I don't know* was considered *not firm*. The percentage of correctly answered factual questions and the number of firmly answered questions are the two indicators which demonstrate participants' profile.

Table 5.3 Participants' profile through Questionnaire 1

Participant	**No. of correctly answered factual questions (out of 6)**	**% of correctly answered factual questions**	**No. of firmly answered questions (out of 15)**
1	5	83	12
2	4	67	12
3	3	50	10
4	1	17	13
5	3	50	04
6	1	17	01
7	5	83	15
8	3	50	12
9	3	50	15
10	4	67	15
Average	**3**	**50**	**11**

The participants bearing numbers 5 and 6 are obvious outliers. The participant number 5 has answered *I don't know* for 11 questions, and the participant number 6 has given the same answer for 14 questions. Therefore, those two participants were not considered in subsequent analyses.

The average of 50 % correctly answered factual questions might suggest that there is a considerable lack of knowledge in land use modelling among the participants. However, without the two outliers, this average increases up to 67 %..

Almost 50 % of the participants have confirmed that they are not familiar with the key terms used in the presented type of modelling, such as cellular automata, calibration, validation, scenario, etc. Furthermore, three of the participants have given contradictory answers for cross-checking questions.

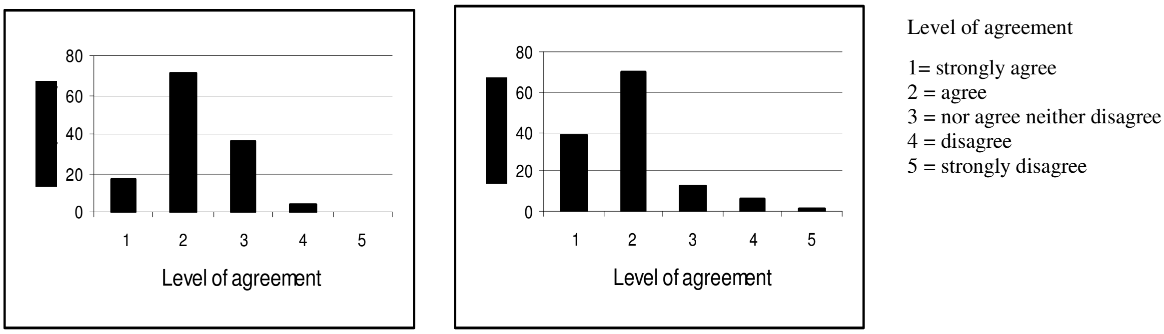
Given that the two outliers are removed, the rest forms a sample of which the deviation is minimal. Therefore, the sample size of 8 would be enough for an unbiased analysis.

In general, the analysis of Questionnaire 1 reveals that the participants must be strengthened with the additional knowledge on land use modelling. Therefore, delivering a presentation on land use modelling concepts at the beginning of the usability assessment is rightly justified.

Questionnaire 2

Questionnaire 2 mainly aims at investigating the user satisfaction of the RUHUNUPURA model. By evaluating the same questionnaire twice (at the beginning and at the end of the usability assessment), the change of attitude of the users towards the model was also measured.

Figure 5.15 shows the total number of responses received by each level of agreement for two evaluations of the Questionnaire 2, in comparison. The level of agreement 1 implies a strong agreement, while 5 means strong disagreement. The proportions of the levels of agreement serve as the overall user agreement of the model. First evaluation was done right after the introductory presentation and the model demonstration, whereas the second evaluation was conducted after a week of individual usage and a practical exercise.



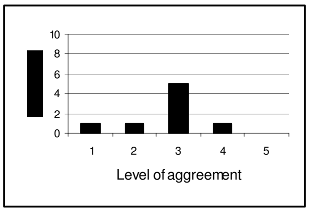
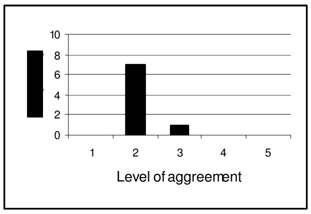
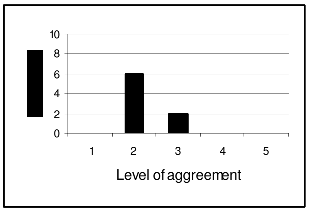
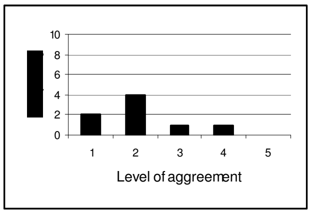
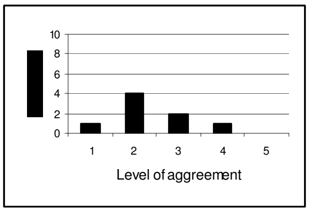
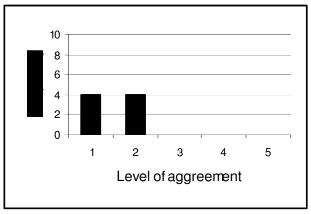
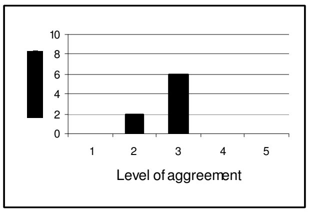
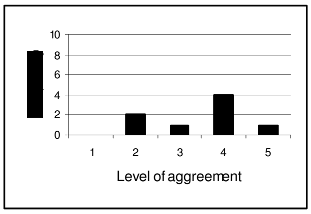
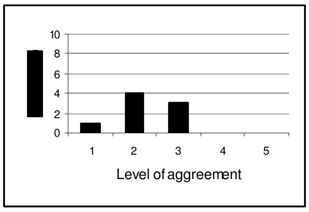
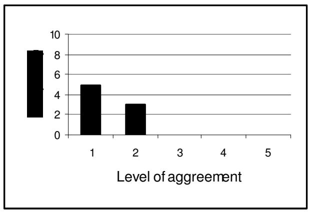
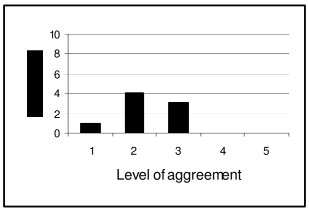
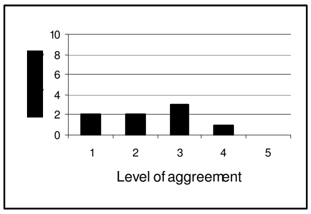
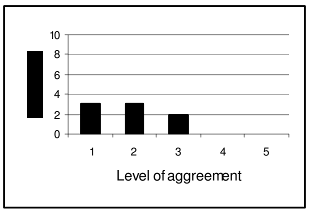
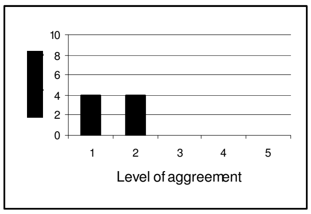
(a) First evaluation (b) Second evaluation

Figure 5.15 Overall user agreement for the model

It is interesting to observe that the responses for the first evaluation of Questionnaire 2 lie mainly in the agreement side. These results imply that the presentation and the software demonstration of the RUHUNUPURA model have been successful in giving better insights to land use modelling. However, a considerable number of responses were neutral for the first evaluation. After the users became more familiar with the model, they showed a higher level of agreement with the model and its functionalities. This is clear by the results of the second evaluation of Questionnaire 2. Here, the proportion of neutral responses has been. Yet, the proportion of disagreement has been slightly increased in the second evaluation, compared to the first. The reasons for those changes could be traced by analysing the responses given to individual questions by the users. In general, however, it could be safely stated that the users' positive attitude towards the model had been amplified when they became more familiar with the model and its functionalities.

Table 5.4 compares the distribution of responses for some of the individual questions in Questionnaire 2 for the two evaluations.

Table 5.4 Distribution of responses for the two evaluations of Questionnaire 2

<table>
<tr><th>No.</th><th>Aspect</th><th>First evaluation</th><th>Second evaluation</th></tr>
<tr><td>1</td><td>Agreement with the underlying principles and assumptions of the model</td><td></td><td></td></tr>
<tr><td>2</td><td>User trust in model outcomes</td><td></td><td></td></tr>
<tr><td>3</td><td>An easy-to-learn tool.</td><td></td><td></td></tr>
<tr><td>4</td><td>The model contains all the functionalities and capabilities needed by the user.</td><td></td><td></td></tr>
<tr><td>5</td><td>The model can help plan the spatial policy decisions.</td><td></td><td></td></tr>
<tr><td>6</td><td>The model can improve the communication.</td><td></td><td></td></tr>
<tr><td>7</td><td>Overall satisfaction</td><td></td><td></td></tr>
</table>

Note that Questionnaire 2 covers 16 aspects, and the most important aspects are given in the *Table 5.4.* For most of the aspects covered in Questionnaire 2, the shift of user attitude is positive, for example aspect number 1, 3, 5, and 7. However, the participants have increasingly realized that the functionalities and capabilities of the model are not sufficient, as explained under the aspect 4. That is a contrasting negative result. Furthermore, a few participants have changed their attitude towards disagreement with the aspects *trust in the model outcomes* (aspect number 2) and *ability to improve the communication by the model* (aspect number 6). Overall, the users are satisfied with the model.

According to the rest of the responses provided to Questionnaire 2, every participant stated that they are clear about the way the model works. Furthermore, all the participants believe that the model has captured the main processes of the real system, and the model can help them better understand the real world problems. They are highly satisfied with the user interface of the model, and the way the information is organized on the model's windows. Although one user declares that the model can not provide any added value to the UDA in the first evaluation, everyone says otherwise in the second evaluation. They increasingly believe that the RUHUNUPURA model can be adopted by the UDA.

The reasons for those contrasting changes were discussed in the group discussion with the participants, and are described in the subsequent sections.

5.3.2 Results of the practical exercise

Through this practical exercise, it was expected to measure the efficiency and the effectiveness of the users when handling the model. The efficiency was measured in terms of the time spent to complete the exercise, and the effectiveness was measured in terms of the number of completed tasks during the exercise. *Table 5.5* shows the time spent by each user to complete the whole exercise.

Table 5.5 The efficiency of the users in handling the model

Participant	Time spent (minutes)
1	21
2	19
3	26
4	23
7	23
8	30
9	26
10	24
Average	**24**

The average time spent by the participants to complete the exercise was 24 minutes. The minimum time spent by a participant was 19 minutes, while the maximum was 30 minutes.

There were 8 tasks altogether for the participants to complete. *Table 5.6* illustrates the number of participants who have completed a particular task, and the number of tasks completed by each user. Note that the value 1 in the *Table 5.6* means that a participant has completed the particular task, whereas 0 means otherwise.

Table 5.6 The effectiveness of the users in handling the model

No.	Task	Participant No.							
		1	**2**	**3**	**4**	**7**	**8**	**9**	**10**
1	Save new simulation as a package with the correct name	1	1	1	1	1	1	1	1
2	Change Macro model data (trend lines for 6 *function* land uses)	1	1	1	1	1	1	1	1
3	Edit the zoning map for buildup area	1	0	1	1	1	1	1	1
4	Add a new main road to the road network	1	1	1	1	1	1	1	1
5	Save *logs* of land use maps for every 5 years	1	1	1	1	1	1	1	1
6	Save *logs* of Indicator maps for every 5 years	1	1	0	0	1	0	1	1
7	Save the *animation* of land use change	1	1	1	1	1	0	1	1
8	Save the *animations* of Indicator maps' change	1	0	1	0	1	0	1	1
Tasks completed by participant		**8**	**6**	**7**	**6**	**8**	**5**	**8**	**8**

Four participants have been able to complete all the tasks belonging to the given exercise. The lowest number of tasks completed by a participant was 5, while the average number of tasks completed by a user was 7, which is very significant. Except the tasks number 6 and 8, which have been completed by only 5 participants, all the other tasks have been accomplished by at least 7 participants. The reason for the lesser number of participants who have completed the task number 6 could be the lack of attention paid as both task 5 and 6 look similar. Since the task number 7 and 8 also look similar, the same reason could be applied for the lower number of participants having completed the task 8. It is also important to note that the task number 5 and 6 should be accomplished in one dialog window of the model. It is the same for task number 7 and 8.

In general, the participants have shown a very high effectiveness in carrying out the exercise. This result goes hand-in-hand with the answer the participants have provided to the statement '*the model is an easy-to-learn tool*' in Questionnaire 2. All the participants have agreed with that statement, and it has been reflected in the results of the practical exercise.

5.3.3 Results of the group discussion

The participants of the usability assessment acknowledged the freedom the model provides to run different scenario for the future as the major advantage. The fancy features of the model such as an attractive user interface, easy editing of maps, animations, etc were also highly valued by the participants. However, the enthusiasm participants possessed during the first group discussion was seen slightly declined during the final group discussion. The main disadvantage of the model, according to the participants was the large cell size (500 m). Most of the participants have limited experience at working with rasters. They seemed to have been slightly bothered with the locational accuracy of the output maps of the model. It was obvious that many of the participants still believe that a land use change model should predict the future with great accuracy. Generally, the participants liked the model, and there is a high possibility that they will use land use models as a decision support tool in the future.

There were interesting suggestions by the participants to improve the RUHUNUPURA model. One of the suggestions was to reduce the cell size of the model at least to 25 m. Some of the participants were of the opinion that an option to change the cell size of the model could improve the model drastically. Another interesting suggestion by the participants was to modify the indicator *Disturbance of nature reserve area* by accounting for not only the changes within the nature conservations, but also within a defined buffer zone outside those reserves.

5.3.4 Results of the interview held with the Director of the UDA's GIS centre

The UDA likes the model, not only because it can guide its decision making to a new level supported by a Spatial Decision Support System, but also because it motivates the people to look more into raster data handling, which is fairly lacking in their institute according to the director. He also perceives the ability of the model to make people search for new knowledge rather than being trapped inside the traditional paper based decision making as another advantage. The model's ability to improve the communication among stakeholders such as the UDA, environmental agencies, road development authorities, politicians, etc. given that they work together in a project, was also acknowledged as an added value.

The RUHUNUPURA model can be absorbed into the UDA given that the officers responsible to handle the model are provided with more knowledge and skills on land use modelling and its usage in decision making through a considerable programme of formal education. The limited raster data handling by the staff was also considered a major barrier by the director, for the proper usage of the model.

The RUHUNUPURA model should be based in the southern regional centre of the UDA which is mainly responsible for decision making on the Ruhunupura area, if the model is adopted by the UDA. The UDA's head office in Colombo shall only carry out the knowledge transfer to the regional staff and the coordination activities.

The director identifies the larger cell size (500 m) as the major weakness of the model. He prefers it to be reduced at least up to 25 m. The other major disadvantage mentioned was the lack of detailed classification of build up area. The director thinks that the land use class build up area should be further categorized into sub classes residential, commercial, industrial, and cultural.

The other two seminars held outside the user organization were also found appealing. The main concern of the researchers at the International Water Management Institute was the possibility to apply the model to the entire country, or to another country. Another issue raised by them was the lack of economic indicators in the model, such as the employment rate, cost of water used in agriculture, etc. They too suggested to use a buffer zone around the nature reserves and to study the changes that occur in the buffer zone over time. Overall, they were very much satisfied about model. The staff of the International Centre for Geoinformatics Applications and Training (ICGAT) was also highly interested in the model, because there are ongoing projects on land use modelling in their organization. Their main concern about the model was the accuracy of calibration.

6 Conclusions and Recommendations

6.1 Conclusions

The prime objective of this study was to find out how a land use change model, more specifically the RUHUNUPURA model developed within the METRONAMICA modelling framework could enhance the spatial policy decision making in Sri Lanka. In order to achieve the main objective, four tasks were identified to be accomplished. Each task required answers for specific research questions which ultimately lead to achieve the overall objective of the study. The answers to those research questions are elaborated in the following sections.

Task 1: Setting up the RUHUNUPURA model within the METRONAMICA modelling environment

i) What are the required data to set up the model, and which data are available for the study area?

   Setting up a new model within the METRONAMICA modelling framework requires at least two independent land use data sets (the second data set is for calibration) for two years with a considerable time gap. Other than that the elevation data in the form of a DEM, accessibility network data, input factor maps which can be used to create suitability maps and zoning maps/master plans are also required. There were two independent land use data sets (year 1985 and 2001) available for the study area. A DEM of 90 m, the road network data, and significant amount of data to be used for creating suitability maps and zoning maps were also available. Therefore, the RUHUNUPURA model could be set up successfully.

ii) What are the important land use classes in the study area?

   The land use classes *build up area, homesteads, chena, forest, paddy,* and *other crops* were considered the most important land uses in the study area. Those were listed under the *function* land use classes which show the full dynamics over time. The land use class *shrub and other uncultivated area* was kept as the only *vacant* land use type which shows reduced dynamics in the model. *Inland freshwater* and *brackish water* were considered static over the simulation period of the model, and listed as *feature* land uses in the model. Altogether, there were eleven land use classes in the model including the *unmodelled land* and *ocean* as a part of the study area.

   Out of all the land use classes, *chena* shows a distinct pattern of dynamics over time. All predefined algorithms given in the METRONAMICA framework to calculate the transition potential of cells failed to simulate the dynamics of *chena*. Therefore, a new algorithm was developed to capture the dynamics of *chena*, and was found highly successful.

Task 2: Calibrating the RUHUNUPURA model

i) What is the appropriate method to calibrate the RUHUNUPURA model (manual or semi-automated)?

   Although there is an automated calibration procedure available in the METRONAMICA framework, manual calibration was preferred over that. The reason was that the automated calibration came up with rules which were difficult to explain in terms of the observed processes in the real system. Manual calibration, on the other hand, enables the developer to define rules which can be explained in terms of the observed processes of the real system.

ii) What is the level of required accuracy in calibration?

By considering the time available to carry out the entire study having four major components, the time period that could be used for the calibration was limited. Therefore, the calibration accuracies were not set to high levels. The calibration period was from 1985 to 2001. Fuzzy Kappa statistic, visual interpretation, and wavelet verification were the methods used to anlyse calibration results. These three methods complement each other well when it comes to evaluating the calibration results. The Fuzzy Kappa values obtained for the comparison between the actual land use map of 2001 and the model predicted map of 2001 were 0.42, 0.31, 0.56, 0.32, 0.70, 0.71, and 0.25 respectively for the land use classes *shrub and other uncultivated area, buildup area, homestead, chena, forest, paddy,* and *other crops*. It is impossible to achieve a high calibration accuracy for *buildup area* since there are only few cells in both maps (1985 and 2001) belonging to *buildup area.* Visual interpretation confirms that the model prediction has been able to resemble the observed pattern of change from 1985 to 2001 for all the other land use classes, except for *buildup area* and *other crops*. The wavelet verification of the model prediction carried out in comparison with the reference model *Random Constraint Match* also reveals that the RUHUNUPURA model can be safely used to study the dynamics of all the land use classes except *other crops*.

Task 3: Applying the RUHUNUPURA model to assess the impact of different policy decision scenario with the aim of exploring the spatial and temporal dynamics of the land use developments

i) What are the key policy decisions made by the user organization?

The Urban Development Authority is responsible for crafting the zoning plans and master plans for the entire country. With regard to the study area, they have the task of creating a new zoning plan for the proposed development project by the government of Sri Lanka for the study area known as the Ruhunupura area. Therefore, the UDA needs to try out few zoning options for the Ruhunupura area with the model. Therefore, two scenario (scenario 2 and 3) were developed within the RUHUNUPURA model to see the impact of an already drafted complex zoning plan for the area in comparison with a simple zoning where only the nature reserves are strictly closed for any non-natural land use activity. The results revealed that the simple zoning might allow the *homestead* areas to be converted into *buildup area*, whereas the complex zoning proposed by the UDA might limit that transformation significantly. The complex zoning plan porposed by the UDA is highly likely to disturb the nature reserves.

The results of the fourth scenario, which is more of a storyline, suggested that the expected localized development (the central part of the Ruhunupura area) could be thoroughly hampered if another tsunami hits the coastal area, and the development could be diverted to other areas where there are more *homesteads* at present. The protected areas might also be disturbed heavily if such a situation occurs, according to the scenario results.

The first scenario ran with the model was not much policy relevant. But it serves as a validation test of the model. The results of the first scenario reveal that the model predicts continuously shortening fallow cycles and continuously lengthening cultivation periods of *chena*, which are the observed distinct characteristics of *chena* in the real system.

ii) How can a set of policy relevant indicators be developed so as to link the policy questions to model inputs, and model output to policy relevant information?

Three indicators were developed for the model namely, Landscape identity, Self sufficiency, and Disturbance of nature reserves. The landscape identity tries to capture the significance of land use transformations among the seven *vacant* and *function* land use classes, based on the Fuzzy Kappa calculation. The self sufficiency is an indicator which estimates the ability of *paddy, chena, other crops, forest,* and *homesteads* itself to support *homesteads* (housing units) mainly for food. It is a simple ratio calculation based on cell counts within a given neighbourhood. The indicator, Disturbance of nature reserves simply estimates how much the protected nature reserves are affected by land use activities other than *forest* and *shrub and other uncultivated area*. All the three indicators were found imperative to explain the outcomes of the scenario.

Task 4: Assessing the usability of the RUHUNUPURA model for the user organization, the Urban Development Authority in Sri Lanka

i) What does the user see as the main function(s), advantages, and disadvantages of the model?

The main function of the model as seen by the user was the assistance it could provide to try out alternative policy scenario through simulations. Therefore, the user organizer believes that *the support for decision making* is the main function of the model. The induction the model provides to look beyond traditional paper based policy making and push for raster data handling are seen as advantageous by the user. The larger cell size (500 m) is the main disadvantage of the model, according to the user.

ii) How efficient, effective, and satisfied are the users in handling the model?

The average time a participant spent to complete the given exercise was 24 minutes. Although the users' efficiency in handling the model is not so high, still there is a plenty of potential for them to increase their efficiency through intensive usage of the model. The average number of tasks accomplished by a participant during the practical exercise was 7, out of total 8 tasks. Therefore, the participants can be considered highly effective, and this goes in line with the fact that all the participants agreeing with the statement 'the model is an easy-to-learn tool'. Questionnaire survey and results of group discussion reveal that the users are satisfied about the model in general, though they think that there are some areas to be improved.

6.2 Recommendations

- Since the major concern of the user is the larger cell size of the RUHUNUPURA model and the model was developed aiming the particular user organization (the UDA), a smaller cell size could be tried as an option. Obviously, the calibration of the model becomes increasingly difficult with the decreasing cell size. Therefore, the time allocated for the calibration should also be increased.

- The quality of some of the data used to create the suitability maps was not of high quality. For example, the agro-climatic map has boundaries between any given two zones as smooth lines. By using high quality data, the model can definitely be improved. For example, the agro-climatic zone data could be replaced with the agro-ecological region data.

- An independent historical data validation, if carried out, has definite ability to increase the trust in the model. Since there are no other independent land use data sets available at the moment for the study area, except the two data sets used in this study, an alternative land use data set could be derived by classifying a satellite image such as a Landsat image.

- Especially for the land use class *chena*, the model required a *warm up* period to get the age distribution of *chena*, before it can predict the *chena* dynamics properly. If it is possible to get a map of the age of *chena* at the beginning of the simulation, it could drastically improve the calibration accuracy of *chena*, and could provide better predictions on *chena* dynamics. Either using remote sensing techniques or field surveys, it might be possible to develop an age map of *chena*, and in tern can improve the model.

- The indicator *Disturbance of nature reserves* can be modified to include not only the nature reserves, but also a buffer zone around the nature reserves to study the changes going on in the proximity of the nature reserves.

- It would be handy to explore the possibility of incorporating a few economic indicators such as *cost of water used in agriculture, income generated by other crops,* etc.

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Appendix I

Spatial reference information of the data sets

Horizontal coordinate system

Projected coordinate system name: sri lanka_kadawala_new
Geographic coordinate system name: GCS_Kandawala

Details

Map Projection Name: Transverse Mercator

Scale Factor at Central Meridian: 0.999924
Longitude of Central Meridian: 80.771711
Latitude of Projection Origin: 7.000480
False Easting: 200000.000000
False Northing: 200000.000000

Planar Coordinate Information

Planar Distance Units: meters
Coordinate Encoding Method: coordinate pair

Coordinate Representation

Abscissa Resolution: 0.001024
Ordinate Resolution: 0.001024

Geodetic Model

Horizontal Datum Name: D_Kandawala
Ellipsoid Name: Everest_Adjustment_1937
Semi-major Axis: 6377276.345000
Denominator of Flattening Ratio: 300.801700

Bounding coordinates

Horizontal

In decimal degrees

West: 79.636757
East: 81.885333
North: 9.831793
South: 5.923802

In projected or local coordinates

Left: 75518.864196
Right: 322141.173076
Top: 513089.501121
Bottom: 81076.500275

Appendix II

The factors, components and weights used for suitability maps

Not all 6 factors were used in creating suitability maps for all land use classes. The combination of factors was different for different land use classes. Used factors, their assigned weights, components of each factor and assigned weights are described in this document separately for *buildup* and *homestead* land use *functions*. Note that the factors which are not mentioned under each land use class were given the weight 0.

1. Combination of factors for Buildup area

Factor	Weight	Component	Weight
Slope %	10	0 – 2	10
		2 – 8	8
		8 – 18	6
		18 – 30	4
		30 – 50	2
		50 – 80	0
		>80	0
Soil type	4	Alluuvial soils with variable texture and drainage; flat terrain	4
		Erosional remnants steep rock land and various lithosols	0
		Major Tanks	0
		Reddish Brown Earths and Immature Brown Loams; rolling and hilly	2
		Reddish Brown Earths and Low Humic Gley Soils	10
		Red-Yellow Lotosois; gently undulating terrain	8
		Red-Yellow podzolic soils with prominent A1 or semi-prominent A1	8
		Red-Yellow podzolic soils, steeply dissected, hilly and rolling terrain	2
		Regosols on recent beach and dune sands	3
Climatic zone	3	Semi-arid	6
		Dry	9
		Intermediate	6
River buffer	2	0 – 500m	7
		500 – 1000m	10
		Rest	10

2. Combination of factors for Homestead

Factor	Weight	Component	Weight
Slope	10	0 – 2	10
		2 – 8	9
		8 – 18	8
		18 – 30	6
		30 – 50	3
		50 – 80	1
		>80	0
Soil type	1	Alluuvial soils with variable texture and drainage; flat terrain	6
		Erosional remnants steep rock land and various lithosols	0
		Major Tanks	0
		Reddish Brown Earths and Immature Brown Loams; rolling and hilly	5
		Reddish Brown Earths and Low Humic Gley Soils	10
		Red-Yellow Lotosois; gently undulating terrain	8
		Red-Yellow podzolic soils with prominent A1 or semi-prominent A1	7
		Red-Yellow podzolic soils, steeply dissected, hilly and rolling terrain	9
		Regosols on recent beach and dune sands	0
Climatic zone	5	Semi-arid	3
		Dry	8
		Intermediate	10
DS division	8	Ambalanthota	4
		Angunakolapellessa	5
		Hambanthota	4
		Lunugamwehera	3
		Sooriyawewa	4
		Tissamaharamaya	4
		Sevanagala	4
		Kataragama	1
		Thanamalwila	4
		Embilipitiya	10

Population data for the year 1985 and 2001 were used in deciding the weights for DS divisions. Embilipitiya DS division has a very high attractiveness for residential activity compared to all other DS divisions due to variou reasons, such as good infrasturcture and intensive agriculture.

Appendix III

Questionnaire to assess participants' knowledge about concepts of land use modeling

Number: ……

	Statement	Yes	No	I don't know
1	Almost all systems in the world (e.g. a city, forest, etc.) will never come to an equilibrium state.			
2	A model is always a simplification of a complex system.			
3	Spatio-temporal modelling is a frequently heard term in your working environment.			
4	Land use modelling is a frequently heard term in your working environment.			
5	Do you agree with the fact that land use models are a kind of spatio temporal models?			
6	Models should always be able to forecast future with great accuracy.			
7	Simulation is the method that enables models to generate different possible futures.			
8	A simulation is dynamic and open-ended.			
9	Cellular Automata (CA) is a familiar term to you.			
10	You have used a cellular automata based application at least once.			
11	You are familiar with the term 'calibration'.			
12	You are familiar with the term 'validation'.			
13	Difference between calibration and validation is clear to you.			
14	The term 'scenario' is frequently used in your working environment.			
15	Evaluating scenario with a model can stimulate discussions and debates about possibilities for future.			

Appendix IV

Questionnaire to assess the usability of the model

Number………..

	Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree
1	The way the model works is sufficiently clear to me.					
2	I agree with the underlying principles and assumptions on which the model is based.					
3	The outcomes of the model are reasonable.					
4	The model has captured main processes of the real system.					
5	The model help to better understand the processes/ problems of the real world situation.					
6	The user interface of the model is attractive.					
7	The organization of information on the model windows is clear and understandable.					
8	This model is an easy-to-learn tool.					
9	This system has all the functions and capabilities I expect it to have.					
10	This model can provide an added value to the UDA's normal working procedures.					
11	The model can help plan the spatial policy decisions in some way.					
12	This model will be accepted in the UDA.					
13	I personally like to use the model in the future.					
14	I think that someone else in the UDA might find this model useful.					
15	The model would improve communication amongst people working in different disciplines.					
16	Overall, I am satisfied with the model.					

Appendix V

Guidelines to formulate the new scenario used in the usability assessment

Task 1 – Opening an existing simulation and saving it with another name

- Start the Ruhunupura model
- Open the simulation file 'Ruhunupura_scen3.sim'
- Save the simulation as a new package. Name the new simulation file as 'Usability_*yournumber*.sim'

Task 2 – Editing inputs and parameters of the new simulation

- Change the Macro model data based on your own ideas as to how the future may evolve; i.e. modify trend lines for 6 function land use classes
- Edit the zoning map for *Buildup area* within the model as below.
    - Modify the areas of Udawalawa park where you think will be opened for buildup in time step 1 (T_1) and time step 2 (T_2)
- Add a new *Main road* to the road network. Use your own thoughts about the likely future developments to decide the place for the new road.

Task 3 – Saving outputs of the model

- Set the options of the model for saving *logs* of **Land use maps** and **Indicator maps** for every 5 years.
- Set the options of the model for saving *Animations* of **land use change** and **Indicator change**.

Task 4 – Run the new simulation