An Integrated Stock-flow and Agent-based Model for Simulating Land Use and Environmental Change in Peri-urban Area

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Abstract: Peri-urbanization is not only triggered by socio-economic development but also resulted from interactions between humans and their environment. An integrated model that links a stock-flow model with an agent-based model can enhance our understanding of the interactions among land use, human decision-making, and environmental change. In this paper, we provide an illustration of a joint application of stock-flow and agent-based modelling to simulate land cover change from agricultural landscape to an urbanized system via the integration of biophysical approach and decision making bodies of land cover change. Therefore, a case study is used to demonstrate the change patterns of agricultural land and urban land. The major stocks and flows and their interactions can be represented in the conceptual energy diagram. The rate of urban asset accumulation determines the amount of areas which should be converted to urban built-up lands. Three main agents of the study area have been chosen and their action rules are used to allocate land use activities on the most suitable places which can reveal the results of decision making. Results indicate that the dynamic changes of the peri-urbanization in the study region arise from lands adjacent to built-up lands or along the roads where are easily accessible to plain agricultural lands with flat topography.

Keywords: peri-urban; an integrated model; stock-flow modelling; agent-based modelling; land use change

Introduction

Urban systems can be distinguished from agricultural areas in terms of land use and land cover change. These changes are driven by complex interactions among socio-economic attributes; and stocks and flows of energy and materials. In order to understand the impacts and interrelationships between human activities and global environmental change, the International Human Dimensions Programme on Global Environmental Change (IHDP) launched the Urbanization and Global Environmental Change (UGEC) project in 2005. The Global Land Project (GLP) was also launched in 2005 by the IHDP and the International

Geosphere-Biosphere Programme (IGBP). Both UGEC and GLP focus on improving our understanding of the interactions between human systems and ecosystems under conditions of global environmental change; land use changes resulting from the impacts of global environmental change; and feedbacks from the interactions of social systems and ecosystems (UGEC, 2005; GLP, 2005). A major focus of the GLP is an emphasis that integrated land use change modeling of ecosystems and socio-economic systems as an important tool for analyzing and simulating the interactions between humans and environment (GLP, 2005).

Currently, a number of modelling approaches are available that simulate dynamic land use change. These include empirical statistical models (Verburg et al., 1999, 2002; Serneels and Lambin, 2001), ecological models (Voinov et al., 1999; Boumans et al., 2001; Costanza and Voinov, 2004), agent-based models and cellular automata (Batty, 2001; Parker et al., 2003; Loibl and Toetzer, 2003; Matthews, 2006). Agent-based modelling has been applied to model various problems at various spatial scales by including actors into dynamic spatial models of decision making. Agent-based models use bottom-up techniques of non-linear dynamic systems, taking an object-oriented approach (Huigen, 2003; Borshchev and Filippov. 2004; Castle and Crooks. 2006). In agent-based modelling, a system is modeled as a collection of agents with autonomous decision making entities; each agent makes decisions based on its current state and presumed decision rules. An agent-based model not only consists of a system of agents but also the relationships between agents to exhibit complex behavior patterns and to provide valuable information about a real world system (Bonabeau, 2002). Based on empirical data and specific values, analyzed agents are intended to mimic real-world systems, while the natural environment can be designed or analyzed to represent a real-world location (Bonabeau, 2002; Brown, 2006; Castle and Crooks, 2006).

In order to effectively analyze and model the interactions between socio-economic systems and ecosystem services as they related to land use under conditions of global environmental change, human decision making needs to be formally addressed. Agent-based models have been incorporated into land use change models to simulate the effects of human decisions (Huigen, 2003; Semuelson, 2005; Castle and Crooks, 2006). Ligtenberg et al. (2004) developed a multi-agent system (MAS) to simulate spatial scenarios of land use change based on modelling multi-actor decision making within a spatial planning process. For assessing urban sustainability, Zellner et al. (2008) developed a simple agent-based model of a hypothetical urbanizing area that integrates data on spatial economic and policy decisions, energy and fuel use, air pollution emissions and assimilation. The model has been used to test how different residential preferences and landscape characteristics shape the development of urban areas, and in turn impact energy use and pollution patterns. Zeller et al. (2008) were also able to use this model to examine how different policies can affect these relationships. Bonabeau (2002) reviewed the benefits of agent-base modelling over other modelling techniques. Agent-based models are able to capture emergent phenomena, can provide a natural description of the modeled system, and most importantly, are flexible. Viewed from a bottom-up perspective, agent-based models have become one of the more effective methods to explore the evolution of the urban landscape.

Huang et al. (2007) have shown that the evolution of an urban landscape system depends not only on its previous and surrounding states, but also on exogenous conditions and driving forces such as renewable energy flows and imported goods and services. Their stock-flow model made use of ecological energetic principles proposed by Odum (Odum, 1983; Odum and Odum, 2000) to model the dynamic behavior of ecosystems. In this stock-flow model, all materials in the system are represented by storage tanks, producers or consumers and the interactions among them are linked by energy flows. The modeled system can be drawn as an energy system diagram, which can be translated into a set of first order differential equations for simulation (Huang, 1998; Lee et al., 2008). Huang (1998) developed a stock-flow model to simulate the evolution of urban zones in relation to energy flows. An urban-ecosystem model was developed by Huang and Chen (2005) to investigate the relationships between energy flows and urban development.

During the last decade, GIS (Geographic Information System) has been extensively used for spatial analysis. The increase in computational power extended the analytical capabilities of GIS to model dynamic process of spatial system (Alberti, 1999; Voinov et al., 1999; Costanza and Voinov, 2004; Huang et al., 2007, Lee et al., 2008). With the improvement of the modelling capabilities in GIS, GIS system such as Model Builder within ArcGIS, can simulate spatial and temporal analyses via an interactive process (Castle and Crook, 2006). Lee et al. (2008) employed the Model Builder function of ArcGIS to develop the SEMLUC (Socio-Economic Metabolism and Land-Use Change) model to simulate interrelationships between land-use change and socio-economic metabolism from a biophysical viewpoint.

Land use change and the resulting patterns in land use come about not only from different human uses of land, but also are influenced by biophysical features and processes (Bizuwerk et al., 2004). While agent-based models can represent agents at an elemental or individualistic level, reflecting their behaviors through space and time to reveal the results of human decision-making; stock-flow models, however, can simulate dynamic interactions between system components and thereby allow for the analysis of changes of environment and land cover as a response to changes in other driving forces. An alternative to making use of two discrete models is to integrate different modelling approaches. Borshchev and Filippov (2004) showed how an agent based model can be built from or added on to an existing system dynamics model. This integrated model can capture more complicated behavior, dependencies and interactions thereby providing deeper insight into the system being modeled. However, previous efforts to integrate stock-flow and agent-based models have rarely focused on the interaction between stock-flow and agent-based models. Taylor et al. (2006) developed a power structure toolkit (PSTK) to analyze different agents and their stock and flow of capital in different spatial-temporal processes, but interactions between land use and capital were ignored. Gaube et al. (2009) combined an agent-based module with a system dynamic module to simulate farm households and land use change as they related to nitrogen flows. In this approach the effects associated with material flow changes on the behavior of agents were neglected.

This paper illustrates how the joint application of stock-flow and agent-based modelling can be used in the simulation of land cover change in a region moving from an agricultural landscape to an urbanized system. The next section describes the case study used for simulating land use and land cover change. Section 2 presents the framework and methodology developed for integrating the stock-flow and agent-based models. The results of the land cover simulation and discussion of the modelling effort are presented in Section 3. In section 4, we conclude with a discussion of the future prospects of this modelling effort and the implications and applications of this model to spatial planning.

1. Study area

The most rapidly urbanizing area in northwestern Taiwan was selected as the case study (Figure 1). The area covers 846.68 km2 and includes 12 townships in Taoyuan County and 9 townships in Taipei County. Elevational differences in the region range from sea level along the coast to about 597m in the most southern portion of the area. The population of the study area is growing rapidly and the area is quickly becoming more urban in character. In 35 years (1971-2006), the study area's population has increased 177% from 1.18 million to 3.27 million. Although the study area has historically been a rich rural-agricultural region, it has undergone a major transformation from rural to a more industrialized and urban uses. From 1971 to 2006, urbanization increased by more than 1.64 times (from 192.92 km2 to 510.13 km2), while the amount of agricultural lands decreased by 51% (from 417.29 km2 to 202.79 km2). Using satellite images and socio-economic statistic data Wang and Chang (2009) suggested that the driving forces for increased urbanization in the study area were different for the periods from 1971-1990 and 1990-2006. Prior to 1990, urban sprawl was highly correlated with economic development. Since 1990, urban sprawl has been correlated with the distance to urban centers. In addition, the correlation between urban sprawl and the location of non-urban planned districts is more apparent during 1990-2006 period than during 1971-1990 era.

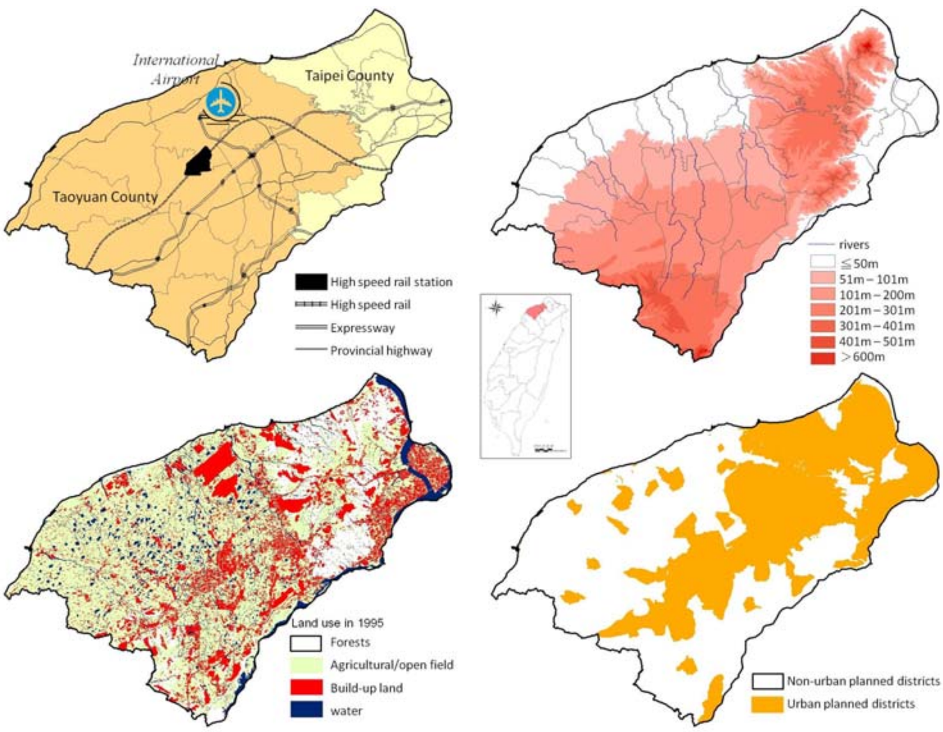

Figure 1. The geographic context of the study area

In order to cope with the rapid economic and urban development in Taiwan, a number of government funded, island-wide transportation corridors (North-South expressways) and public facilities (Taoyuan International Airport) were built in the study area. A result of these investments was the conversion of agricultural lands to built-up lands. The agricultural land release action announced by the government in 2000 also triggered the conversion of agricultural land to built-up lands. Both land owners and developers played key roles in converting agricultural lands to urban build-up lands. One of the characteristics of agricultural lands in the study area is that they are all located in the plain with flat topography which is suitable for development. Furthermore, many of agricultural lands which are along the roads and the main transportation corridors or adjacent to existing urban built-up lands were converted to built-up lands by land owners. In addition, developers also searched big parcels of land to develop dwelling sites.

The study area currently consists of roughly 24% agricultural land and 60% built-up and urban land. Paddy rice fields are a prominent feature in the area. There were more than 8,000 farm ponds in the case study area in 1963. Agricultural lands were located adjacent to these ponds. However, the number of farm ponds has been reduced to less than 500 due to industrial, transportation and urban development. The dynamics of rural landscape change throughout Taiwan are fully expressed in this area, making it ideal for studying the transformation from an agricultural economy to a post-industrial region.

2. Methods

This section describes the framework of the integrated stock-flow and agent-based land use model. The model framework includes three parts: (1) a stock-flow module to represent the interactions of environmental components through energy and material flows; (2) an agent-based module that defines the rules and actions of the key agents; and (3) a GIS platform for linking and simulating the land cover change through an integrated ecosystem and agent-based model (Figure 2).

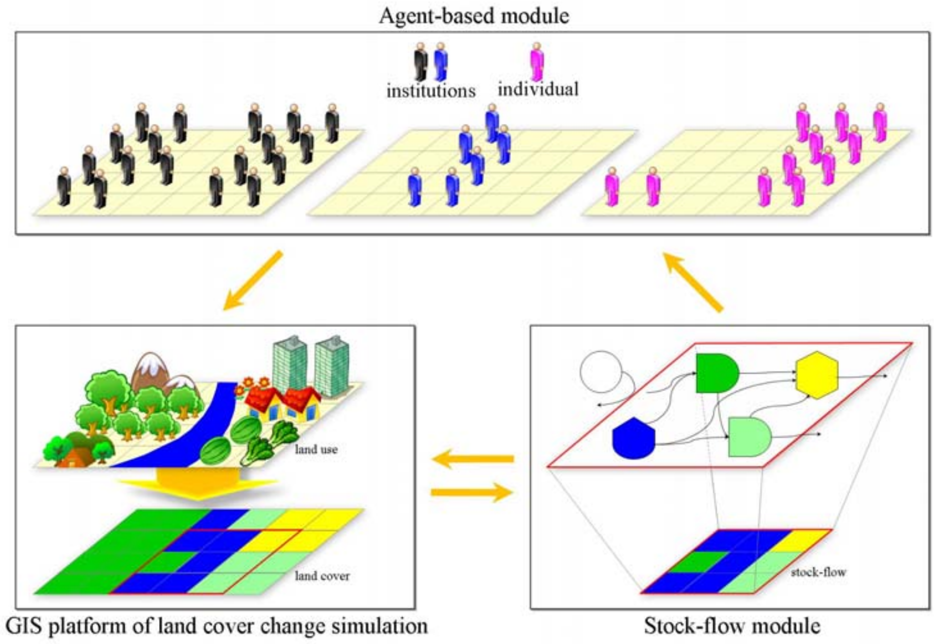

Figure 2. The concept of integrated model

2.1. The stock-flow mechanism

In a system model, the system is presented in terms of stocks (e.g. biomass, asset, people etc.), flows between these stocks, and information that determines the values of the flows. To approach a problem using system modelling one has to describe the system behavior as a number of interacting stocks with feedback loops. Our case study area is a mixed agricultural-urban landscape. A conceptual energy diagram of this system is shown in Figure 3. Agricultural land is the main subsystem with agricultural assets (Aa). Its major inflows include environmental inflows (E), non-renewable energy (N) and agricultural land (La), which will affect the accumulation of agricultural assets. The other important component is urban subsystem which includes stocks of urban assets (Au) and population (Pu). Inflows to the urban subsystem come from the environment, non-renewable energy and urban land (Lu). The production of urban assets is a function of renewable energy, including of non-renewable energy, population, and urban assets. An increase in urban assets will stimulate the conversion of agricultural lands to urban lands. The areas of agricultural land and urban land will affect the rates of both renewable and non-renewable inflows. Mathematically, a system or a stock-flow model is a system of differential equations. The system equations for the two subsystems are represented in Table 1. It is important to point out that the stock-flow model in this research works on an aggregate spatial scale with the cell size 1km x 1km.

Table 1. System equations of the peri-urban model

Agricultural land	Ra: environmental remainder of agricultural land $Ra=E\times La/(1+k101\times Aa\times(N\times Aa))$ Aa: agricultural asset $dAa/dt= k102\times Ra\times(N\times La)\times Aa-k103\times Aa-k104\times Aa$
Urban land	Ru: environmental remainder of urban land $Ru=E\times Lu/(1+k201\times Au\times Pu\times(N\times Au))$ Au: urban asset $dAu/dt=k202\times Ru\times(N\times Lu)\times Pu\times Au+k205\times Aa-k203\times Pu\times Au-k204\times Au$ Pu: urban population $dPu/dt=k206\times Au\times Pu+k208\times P\times Au-k207\times Pu$

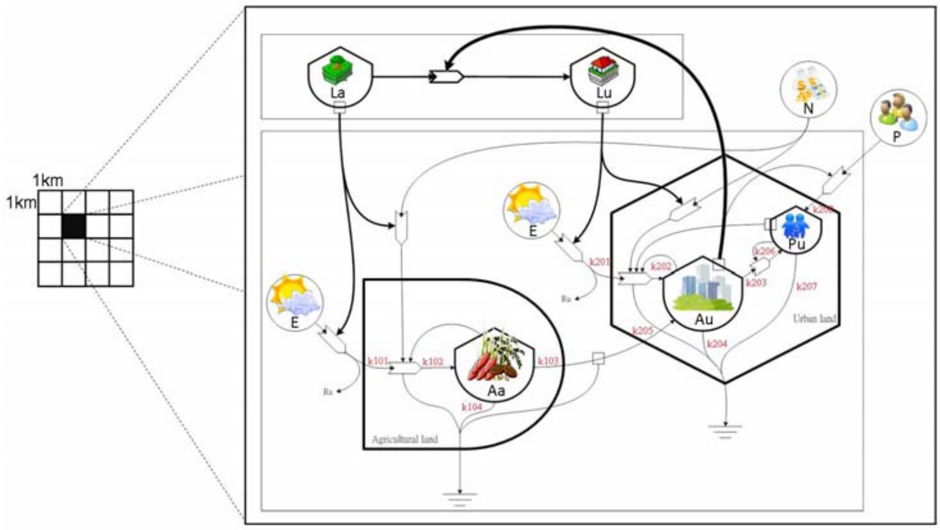

Figure 3. Energy diagram of peri-urban system

2.2. Definition of key agents and their action rules

An agent-based model is a decentralized model, which defines system behavior at individual level. Agents act according to cognitive models that link their autonomous goals to the environment through their behavior (Parker et al., 2002; Castle and Crooks, 2006). There have been various applications of agent-based modelling to spatial models of land use and land cover change (Huigen, 2003; Ligtenberg et al., 2004; Brown, 2006; Ngo et al., 2008).

The important characters of different groups of agents are autonomous, heterogeneous, active and flexible (Parker et al., 2002; Huigen, 2003; Castle and Crooks, 2006; Hanley and Hopkins, 2007; Pereira, 2007). There are three types of agents in our model, each of which have attributes and rules of behavior corresponding to the location of development. Land owners of agricultural land are expecting to convert their farmland into built area if their land can meet the criteria for developing the land. Table 2 shows the rules and actions of agents. The rules and actions of land owners are easier accessibility, whether land is adjacent to exiting built-up lands and flat topography. Developers' action rules include a minimum development size, the distance to transportation corridors of farm land and the steepness of the slope. Public facility investments, release of agricultural land and slope land conservation and utilization action are the action rules of the government. Land owners' actions can be used to identify the locations of agricultural lands which could be converted to urban built-up lands. Another agent, the developer, is seeking relatively big parcels of land with close proximity to existing urban areas and with good accessibility. The behavior of developers reflects importance of profitability in the conversion of agricultural lands to urban lands. In order to maintain a public interest in spatial development, the third agent in the model, the government, makes strategies and acts to regulate land use and development. Government institutions play the role of safe guarding the public interest and prohibiting development on environmentally-sensitive areas.

Table 2. The rules and actions of agents

Agents	Rules and actions		
Land owner	◆ Easier accessibility	◆ Adjacent to exiting built-up lands	◆ Flat topography
Developer	◆ Minimum development area	◆ Farm land - Distance to transportation	◆ Slope land - Elevation
Government	◆ Public facility investments	◆ Release of agricultural land	◆ Slope land conservation and utilization act

Each agent can evaluate a spatial system, which consists of a spatial environment influenced by dynamic processes, and then allocate land use activity on the most suitable places. The decisions of development by landowners and developers are also affected by economic prosperity and agricultural development strategies. The agents' actions and rules are reflected at a spatial resolution of 50m×50m raster cells.

2.3. Integration of stock-flow and agent-based modules

2.3.1. Determining the amount of agricultural lands to be converted to urban built-up lands

As shown in Figure 3, the accumulation of urban assets will trigger the development of additional urban areas. In another words, the rate of urban asset accumulation determines the number of cells which will be randomly selected and evaluated for changing from agricultural land to built-up land at each time step. Based on the analysis of socio-economic statistical data from 1971 to 2006 (Figure 4), the amount of increase of urban lands can be calculated on the basis of the urban asset accumulation:

$Lu_t = 590 \times \ln(\Delta Au_t)$

where Lu_t is the quantity of urban land (Lu) in the t year; ΔAu_t is the increase of urban assets (Au) between the t-1 and t year; and 590 is the multiple of the logarithmic relationship between ΔAu_t and Lu_t.

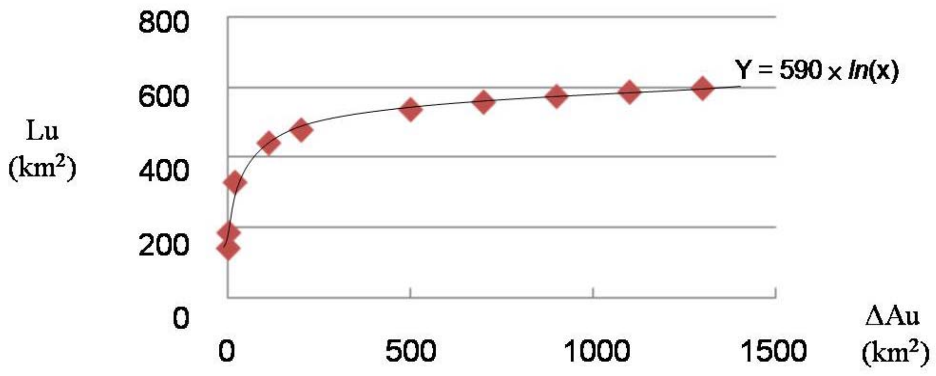

Figure 4. The relationship between urban assets and urban lands

Agents' decisions on allocating urban built-up lands will then affect the energy and material flows of the agricultural and urban subsystems of the next time step.

2.3.2. Process of simulation

The modeled system is represented as a two-dimensional lattice of cells containing the natural environment, land cover, infrastructure and policy attributes such as zoning. Cells are created at the model initialization and assigned a land cover type based on land cover from 1971. Agent decisions on the selection of cells that will be converted are affected by their individual preferences for location (e.g. proximity to roads, proximity to existing urban area, etc.). This model is operationalized using a raster-based GIS, IDRISI Taiga (Clarks Lab, 2009). IDRISI Taiga has a macro function which can enable iterative calculations of the spatial-temporal changes of material and energy flows to be made. Equations and parameters of flows can be transferred into Macro language (Figure 5). The sequence of events for simulating the model is shown in Figure 6. The first step of the simulation procedure is to calculate and sum up the values of the five stocks (shown in Figure 3) for each 1km x 1km grid from the land cover map for the base year t (the upper left part of Figure 6). Using the system equations (Table 1) derived from energy diagram of peri-urban system (Figure 3), stocks of the next year (t+1) can be simulated (the upper right part of Figure 6). The quantity of area to be converted from agricultural land to built-up lands of each time step can be determined based on the statistical relationship between the accumulation of urban assets and the increase of urban land use (the bottom left part of Figure 6). Land cover values for the whole study area are then recalculated from the 1km×1km grids. Using the agents' rules and actions, the additional built-up lands are then allocated on the scale of 50m x 50m grid size

(Table 2). The combination of the relationship between the accumulation of urban assets, the increase of urban built-up lands, and agents' rules are then used to simulate the land cover map of the next year (the bottom right part of Figure 6). Land cover changes can then be simulated, using IDRISI, through an iterative process of calculation until a designated year is reached.

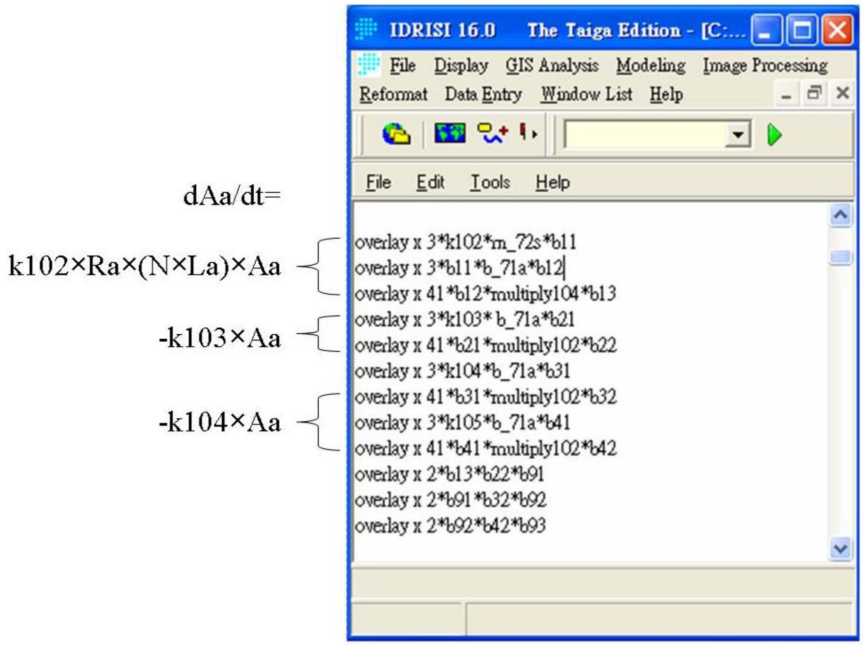

Figure 5. an example of Marco language

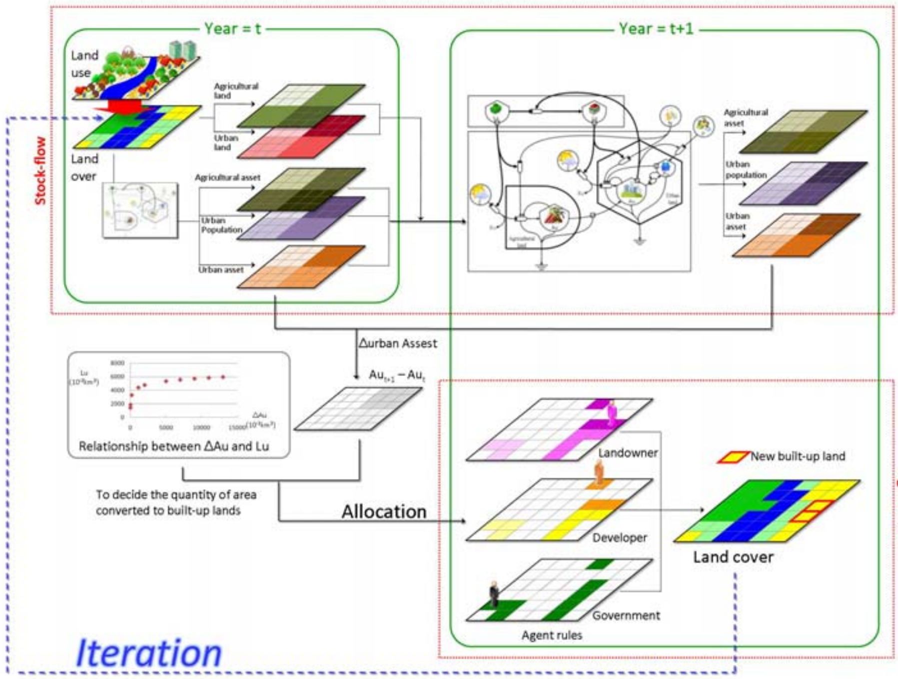

Figure 6. Procedure for the integrated model

3. Results and discussion

3.1. A macroview of the development of the study area

Coefficients in the system can be calibrated from the assumed flows and the values of stocks by dividing the stock values by the flow rates. A land cover map from 2006 was interpreted from a SPOT image and was used as a basis for estimating the stock values (areas and assets) in each grid cell (Figure 7). The assumed flows in each cell are consistent with known turnover times when inflows and outflows are equal and storage is at a maximum. Table 3 summarizes the values of stocks and values of assumed flows. The land cover of 1971 is used to estimate initial values of each stock for simulation.

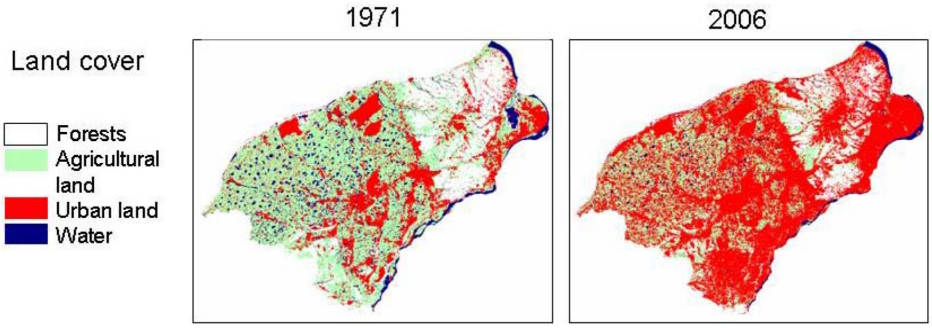

Figure 7. Land cover maps of 1971 and 2006

Table 3. Values of storages and flows

Name	Mathematical expression	Value and basis
Environmental input	E	2.11×10^6 m^3 km^{-2} $year^{-1}$ (rain = 2100 mm $year^{-1}$ × 10^{-3} m mm^{-1} × 10^6 m^2 km^{-2})
Environmental remainder of agricultural land	Ra = E×La - k101×Ra×Aa×N×Aa	1.49×10^5 m^3 (60% of environmental input on agricultural land = 0.6 × 2.11×10^6 m^3 km^{-2} $year^{-1}$ × 1.18×10^2 km^2)
Environmental remainder of urban land	Ru = E×Lu - k201×Ru×N×Au×Pu×Au	11.76×10^5 m^3 (90% of environmental input on urban land = 0.9 × 2.11×10^6 m^3 km^{-2} $year^{-1}$ × 6.19×10^2 km^2)
Non-renewable emergy	N	8.59×10^{21} sej (Consumption of electricity)
Population immigration	P	1.85×10^5 people (consumed P×Au to be 5% of Pu)
Total area	L	8.47×10^2 km^2
Agricultural land	La	1.18×10^2 km^2
Urban land	Lu	6.19×10^2 km^2
Other land	Lo	1.10×10^2 km^2
Agricultural asset	Aa	6.05×10^4 ton (assumed agricultural asset = 513 ton × 1.18×10^2 km^2)
Urban asset	Au	12.38×10^4 km^2 (floor area of urban structure = 200% of urban land)
Urban population	Pu	33.49×10^5 people (Maximum population)
Environmental use by agricultural land	k101×Ra×Aa×N×Aa	1.00×10^5 m^3 (40% of environmental input on agricultural land = 0.4 × 2.11×10^6 m^3 km^{-2} $year^{-1}$ × 1.18×10^2 km^2)
Production of agricultural land	k102×Ra×N×La×Aa	0.34×10^4 ton (based on a growth rate of 5.6%)
Agricultural asset consumed by urban asset	k103×Aa	0.22×10^4 ton (assumed to be 3.6% of agricultural asset)
Depreciation of	k104×Aa	0.12×10^4 ton (based on a turnover period of

agricultural land		50 years)
Environmental use by urban land	k201×Ru×N×Au×Pu×Au	1.31×10^5 m^3 (10% of environmental input on urban land = 0.1 × 2.11×10^6 m^3 km^{-2} $year^{-1}$ × 6.19×10^2 km^2)
Production of urban land	k202×Ru×N×Lu×Pu×Au	0.31×10^4 km^2 (assumed growth rate of 2.5%)
Urban asset consumed by people	k203×Pu×Au	0.35×10^4 km^2 (assumed to be 2.8% of urban asset)
Depreciation of urban land	k204×Au	0.06×10^4 km^2 (based on a turnover period of 200 years)
Conversion of agricultural asset to urban asset	k205×Aa	0.10×10^4 km^2 (assumed to be 0.8% of urban asset)
Population growth	k206×Au×Pu	5.93×10^5 people (based on a 18% growth rate)
Death or emigration	k207×Pu	12.91×10^5 people (based on a rate of 38%)
population emigration	k208×P×Au	6.97×10^5 people (assumed to be 20% population)

3.2. Simulation results

Figure 8 shows the results of the spatial simulation of land cover, storages of assets, and population in the study area from 1971 to 2006. Due to rapid socio-economic development, urban assets (Au) and urban population (Pu) increase rapidly and triggered the conversion of agricultural land (La) to urban built-up land (Lu). Agricultural land (La) decreased in an area extending from the east to the center and north part of the study area leading to a reduction of agricultural assets (Aa) in these areas. Conversely, urban assets (Au) increase from the area close to Taipei City to the western part of the study area, especially in the center and the northern areas. The increase of urban assets resulted in an increase of urban built-up land (Lu), especially during the period from 1992 to 2006. Urban population (Pu) increased from the eastern part of the study area to the southwest, reflecting the changes in urban built-up land (Lu) and urban assets (Au). Figure 9 shows the spatial distribution of land cover changes. Prior to 1992, most of the increased urban built-up lands were concentrated in the eastern part of the study area, closer to Taipei City. As urban assets accumulated after 1992, urban sprawl became more obvious from the eastern part to the western part of the study area. A significant amount of agricultural lands were converted to urban built-up lands from 1971 to 2006. The spatial pattern of simulated land cover for 2006 is similar to the land cover interpreted from satellite image (Figure 7).

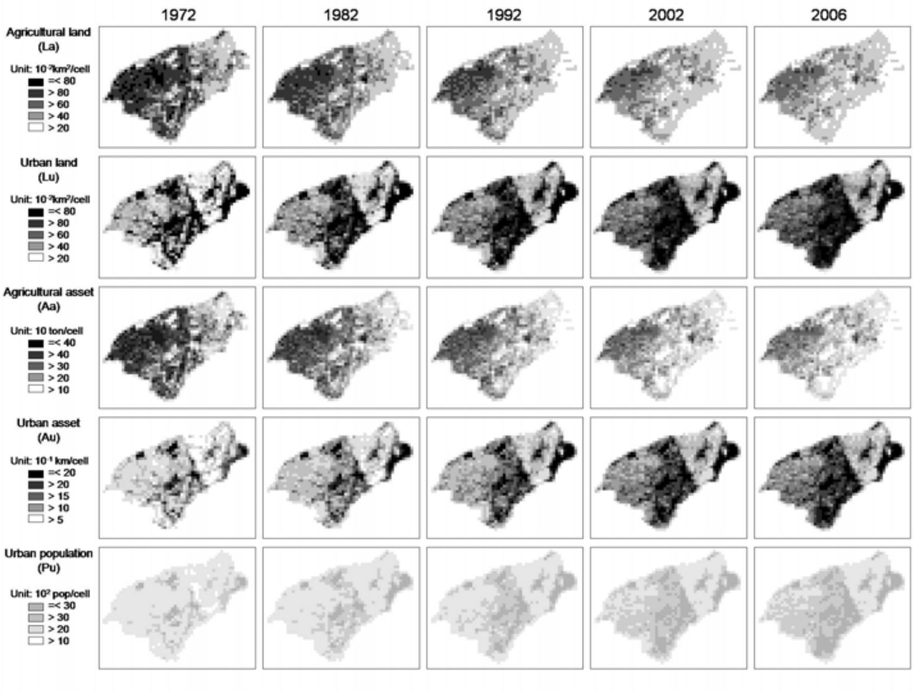

Figure 8. Simulation results of storages

The specified actions and rules of agents are reflected in the simulated locations of urban land. Three broad characteristics were associated with these simulated patterns. First, and not surprisingly, the simulated locations of development tended to be on lands which were easily accessible to other places (e.g. near to Taipei City). Second, much of the agricultural lands adjacent to built-up lands were converted to urban built-up lands by land owners. And, finally land owners tended to develop lands in the plain areas with flat topography (Figure 9). Conversely, lands converted by developers were basically located in the western part of the study area before 1992. After 1992, the increased urban lands converted by developers are located on the southern part of the study area. The simulation results of the integrated model successfully represent the spatio-temporal dynamics and the evolution of land cover change in the study area. The simulation results suggest that the agricultural lands were affected by increased material and energy flows due to increased urbanization. These lands ultimately were converted to urban built-up lands, with the result being sprawl development extending from urban planned districts into the non-urban planned zones in the peri-urban area.

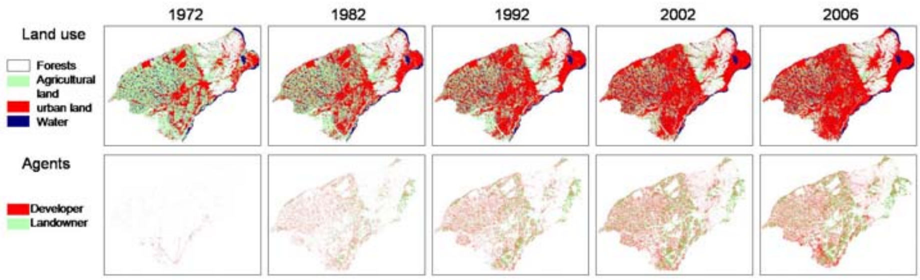

Figure 9. Simulation results of land cover change

Conclusion and future research

Our overall goal in this research effort was to develop an integrated model by combining stock-flow and agent-based modelling approaches to simulate spatial land cover change in peri-urban areas. This integrated model was not conceived as a forecasting model; rather this model was built on general principles with explanatory capability for policy evaluation. Agent-based approach is a general and powerful tool for aiding in the simulation of land cover change because it enables the analyst to capture more complex interactions at a very local level. The selection of stock-flow modelling was because our research questions require an understanding of the complex interactions between different land coverages, renewable energies, and inflows of goods and services. Agent-based modelling also allowed us to incorporate decision-making by different actors involved in the allocation of land use. The use of a stock flow model enables us to simulate the interaction between land cover change and environmental system from a biophysical perspective. We believe that the inclusion of agent-based models leads to an improved insights on land cover change as effected by agents on the land.

In this paper, the integration of a stock-flow model and an agent-based model can exhibit interactions between energy flows and agents' action rules. The simulations generate efficient and interesting tests that demonstrate the application of the integrated methodology and procedure by using multi-scale cell space. The simulation results demonstrate that urban expansion and urban sprawl in the study area were related to the increased accumulation of urban assets due to the rapid economic development. The results of different agents' preferences on land allocation are reflected in the spatial patterns of increased urban built-up lands.

The integrated stock-flow and agent-based model developed in this paper is still being refined. In order to further complete the development of this integrated model and use it analyze impacts of land cover change on the effects of ecosystem services in the peri-urban area several lines of research are being pursued.

In our model only the agricultural system and the urban system are taken into account. However, natural areas (e.g., forests and water bodies) are also the important system components in Taipei's peri-urban area. The component of natural areas needs to be included in the model system, along with interactions among agricultural lands, urban lands, forests and water bodies. Agents' rules and actions will also need to be adjusted according to the new system diagram.

The resilience of a system has been defined as its capacity to persist in the face of disturbances (Anderies et al, 2002; Ludwig and Smith, 2005). Resilience also provides a framework for assessing response to global environmental change (Chapin et al., 2001). Therefore, the issues of global environmental change should be included in the scenarios for simulating land use change and analyze the resilience of peri-urban environment.

In order to ensure that the model can replicate existing patterns in peri-urban areas, verification and validation of the model performance are needed. Verification can test the logic of model results to analyze whether a model behaves as expected when key components or their interactions are changed. Accuracy assessment is a common way of validation tests, which requires use of multiple complementary methods. The validations of the accuracy of changes between different land covers should be emphasized.

Acknowledgement

Financial support for this research was provided by the National Science Council of Taiwan (Grant No. NSC96-2415-H305-012-MY3).

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