Simulation of Land-Cover Change in Taipei Metropolitan Area under Climate Change Impact

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Abstract. Climate change causes environment change and shows up on land covers. Through observing the change of land use, researchers can find out the trend and potential mechanism of the land cover change. Effective adaptation policies can affect pattern of land cover change and may decrease the risks of climate change impacts. By simulating land use dynamics with scenario settings, this paper attempts to explore the relationship between climate change and land-cover change through efficient adaptation policies. It involves spatial statistical model in estimating possibility of land-cover change, cellular automata model in modeling land-cover dynamics, and scenario analysis in response to adaptation policies. The results show that, without any control, the critical eco-areas, such as estuarine areas, will be destroyed and people may move to the vulnerable and important economic development areas. In the other hand, under the limited development condition for adaptation, people migration to peri-urban and critical eco-areas may be deterred.

Keywords: human impact, spatial statistical model, cellular automate, adaptation policy

1. Introduction
Climate change causes environment change and shows up on land covers. Extreme events frequently results in significant hazard and vital losses. Intergovernmental Panel on Climate Change 4 (IPCC 4, 2007) points out that probability of consequence extreme events occurrence may increases from 66\% to 90\%. Science Report of Taiwan Climate Change 2011 also indicates that Taiwan is located close to the main route of typhoon in northwest Pacific Ocean area and belongs to high disaster risk area for natural disasters. Among them, extreme rainfall and typhoon significantly impact Taiwan environment. In the past, Typhoon Morakot (2009) and Typhoon Sinlaku (2008) resulted over 6.5 million losses for Taiwan. Moreover, over 80\% population is concentrated in urban area, and exhibits extensive activities in social and economic. This phenomenon infers importance of land use planning and management in urban area, and it is necessary to actively adapt to extreme events. In the other hand,
in regional scale, unsuitable land uses also bring out vast impact on eco-system. It makes the whole environment more vulnerable, especially in population, economic and agricultural sectors. Many approaches have addressed the problem of climate change impact. Generally it includes two dimensions, “Mitigation” and “Adaptation”. “Mitigation” means decreasing greenhouse gas emission to reduce rate of climate change or by man-made interventions. “Adaptation” expresses under predicted climate impact, how natural system or human adjust to this challenge. Recently spatial planning tools have been critical in approaching adaptation responses. That is, through planning, land use adaptive strategies may be developed to handle the threat of climate change. Such approach is described in Figure 1.

![Spatial planning strategy and climate change](image)

Figure 1. Spatial planning strategy and climate change (Chan and Huang, 2010)

Land cover can represent human living pattern and characteristics. Through observing the land use change, researchers can find out the trend and potential mechanism of the land cover change. Knowing the mechanism, some policies to manage the behavior of people can change the rate of land use change and the pattern of land use, and may decrease the risks of climate change for both emission reduction and adaptation to unavoidable impacts. By simulating land use dynamics with scenario settings, this paper attempts to explore the relationship between climate and land-cover changes through efficient adaptation polices. It involves spatial statistical model in estimating possibility of land-cover change, cellular automata model in modeling land-cover dynamics, and scenario analysis in response to adaptation polices.

2. Materials and methods

2.1. Research design and methodologies

This paper takes Taipei metropolitan area as a case study. It considers the changes of land cover from 1996 to 2006 and predicts the dynamics until 2106. Overall the paper consists of two stages of land-cover change probability estimations and land-cover dynamics with scenario comparison. There are two kinds of methodologies applied in the process: land-cover change model (LCCM) and land dynamic model (LDM) with cellular automata.

Application of LCCM is the first step and is based on Land-Use and Land-Cover Change (LUCC) structure. LUCC modeling is the most applied approach in the analysis of land use change (Huang and Chan, 2009). It helps in recognizing the determinants and driving force of land use change, such as biophysical factors, social-economic factors, spatial interaction and spatial policies, and identifying the critical factors (Seto and Kaufmann, 2003; Verburg et al., 2004; Batisani and Yarnal, 2008). This paper uses spatial statistical model Geographically Weighted Regression (GWR) as the analysis tool in stage I. GWR emphasizes spatially varying relationships. GWR expands traditional regression model structure and adds spatial characteristics into equation as the equation (1) and equation (2). Through the estimation process in GWR, significant driving forces can be found and then conversion probability of land cover for each analysis unit may be calculated by the estimated function. The 1st outcome may be used as the kernel parameters for land cover dynamic simulation.

\[
y(g) = b_0(g) + b_1(g)x_1 + b_2(g)x_2 + \cdots + b_n(g)x_n + e(g) \quad (1)
\]
\[ b' = \left(X^TW(g_j)X\right)^{-1}X^TW(g_i) \]  
where \( W(g_i) \) is the weight given to data point \( i \) for estimating local parameters at location \( g \)

Stage II is about land cover dynamic mechanism and scenario simulation related to land use management policies for mitigation and adaptation. In this part, LDM is used with specified function composed of significant driving forces and other parameters. Land conversion probability is set up as random factor to determine whether to generate land cover change or not. By simulating LDM baseline settings, land dynamics will be illustrated with trend chart and spatial distribution to adaption policies simulation. The model converts climate trend information, Taiwan Climate Change Projection and Information Platform A-1B (TCCIP-A1B) into specified coefficient for assuming individual scenarios conditions. Integrating these settings and LDM structure, there are three kinds of scenario outcomes generated. Finally, scenario comparison may helpful to realize land cover change dynamics under climate impact. In the simulation process, Netlogo acts as an important tool for compiling land dynamic system and modeling land dynamics. It is a programmable modelling environment for simulating natural and social phenomena (Wilensky, 1999). It includes three kernel components as turtles, patches and observer. Under this interface, researcher can construct the interaction rules and simulate the trend by setting various attributes for agents, environment and the whole system. This makes it possible to explore the relationship between the micro-level behavior of individuals and the macro-level patterns that emerge from the interaction of many individuals.

Figure 2. Structure of integrated land cover dynamic model

2.2. Data and material properties
This integrated model applied four types of databases: satellite images, statistical data, climate trend information and spatial information. Satellite image SPOT 4 is the major source for land cover. By supervised recognition, land cover is categorized as vegetation, water, abandoned and built-up area. Statistical data is to gather all variables as driving forces list. It involves official social and economic
statistics, such as census data and regional statistics abstract and unofficial investigation. Climate trend information comes from TCCIP in Taiwan. The platform offers climate downscaling data for analyzing various scenarios. TCCIP-A1B is adopted for climate trend modeling. Spatial information includes fundamental GIS dataset, such as hazard potential area and environment sensitive area from National Geographic Information System (NGIS) and value-added data for additional needs.

3. Exploration of Local Land-Cover Change Probability

3.1. Variable list and driving forces recognition
The changes of land cover between 1996 and 2006 are assumed as dependant variable in LCCM. It treats administrative area, village, as basic analysis unit and considers social economic (SE), natural environment (NE), local policy (LP), and spatial characteristics (SC) to survey probable driving forces. There are 31 factors split as independent variables. Through stepwise regression and operation of GWR, driving forces estimation model for land cover is constructed as in Table 1. These variables include 4 dimensions as mentioned above. There are 4 significant variables. Mass Rapid Transit (MRT), park and industrial area with neighbourhood effect, affect specifically estimation model result. The list of variables in Table 1 will export into LDM structure.

Table 1 Description of driving forces estimation model to land cover change with GWR ($R^2=0.4330$)

| Cate. | Variable name                                      | Estimate | Std Err | T      |
|-------|----------------------------------------------------|----------|---------|--------|
|       | Intercept                                          | 0.2619   | 0.1859  | 1.4086 |
|       | SE Population density                              | -6.3148  | 3.1679  | -1.9934* |
|       | NE Whether landside event has occurred at analysis unit | 0.5963 | 0.2539 | 2.3489** |
|       | NE Analysis unit locates at disaster potential area | -0.7422 | 0.4425  | -1.6774 |
|       | LP Distance between analysis unit and interchange  | 0.0001   | 2.057E-05 | 3.3069** |
|       | SC Neighbourhood effect by MRT                     | -0.0634  | 0.0405  | -1.5648 |
|       | SC Neighbourhood effect by park                    | 0.2756   | 0.0089  | 30.8533** |
|       | SC Neighbourhood effect by industrial area         | 0.0798   | 0.0547  | 1.4586 |

** represents significant at 0.01; * represents significant at 0.05.

3.2. Conversion probability of land-cover change and hot spot location
According to the above Table 1, conversion probability can be estimated by applying all parameters and variables. By manipulation spatial information technique, conversion probability of land cover in each analysis unit is illustrated in Figure 3. After comparing location from land cover change and conversion probability distribution, locations of each hot spot are identified. As a whole, the locations for hot spot and conversion probability are around urban centers and some western areas. The result shows that the trend of scenario simulation may be appropriate.
4. Land-Cover Dynamics, Adaptation Policy, and Scenario Comparison

4.1. System settings and assumption
Before formulating LDM modeling, it is necessary to develop conversion rules for land cover types. There are three basic principles to this model. These rules include: (i) no new land use type generates in the next period, (ii) the only conversion mode is abandoned area or vegetation can convert to built-up area but not the reverse and (iii) risk areas with potential hazard, environmental sensitivity, and high mountainous area is restricted to any development.

4.2. Trend analysis and scenario comparison to adaptation policies
To explore the impact of land use from climate change, the model projected various scenarios to survey the possible tendencies. In this part, trend analysis is to model land dynamics without any other specified adjustment. In the other hand, scenario comparison to adaption policies will be helpful to examine the impact under different climate challenges. TCCIP-A1B is converted to specified parameters to control possible land use change. In the meanwhile it considers mitigation and adaptation approaches under land use management. For mitigation approach scenario I volume of land development is controlled in each period for reducing greenhouse gas emission. In adaptation approach scenario II, no development is emphasized close to sensitivity area. In scenario III, it integrates two types of settings. The results of simulation are as below:  
- Baseline  
The trend of development in Taipei Metropolitan Area basically expands from metropolitan center towards peri-urban area in Figure 4. The trend of development in space focuses on western region and toward coastal zone and industrial area. In the end, it spreads toward hillside area. Under the trend, the environment may suffer critical damages and impact. As a result, the volume of built-up area increases rapidly and the extent of vegetation decreases abruptly.  
- Scenario I: mitigation  
It emphasizes influence of raising temperature for affecting the whole system in this scenario. After the control, the increasing rate of built-up area is obviously slower than the state of baseline. The expanding built-up areas obviously are clustered at industrial area in the western part. The trend curve is gentler and the whole environment is toward more safety and healthy.  
- Scenario II: adaptation  
It restricts the development to avoid hazard impact from any climate events. The trend curve is similar to the result in baseline, but the rate of increasing volume of built-up area is slower than the baseline. The expand locations of built-up area are in the western area, the northern area near the coastal zone, and the hillside rate which is far away from flood potential area, such as estuarial and riverside area.  
- Scenario III: mitigation and adaptation
This scenario concerns the two approaches for land management. As a result, the trend curve is similar to scenario II, but the slope of increasing rate of built-up area is higher. It means that in this scenario, the development is toward sustainable and stable. The critical developing areas have moved to the southern peri-urban areas.

5. Conclusion and Discussion

Land use change is a result between interaction of human behavior and natural environment. Human activities accelerate the process of climate change, and create extreme climate. The result causes greater land cover change. People need to change their living pattern to adapt to this influence. In TMA, the development in the future concentrates in the peri-urban areas and high mountainous areas, but the critical areas are near riparian zone and mountainous country. In scenario I, government can mitigate impact from the possibility of disaster producing by limiting the rapid development. In scenario II and scenario III, people may move far away from the risk areas to the peri-urban areas. Through this modeling simulation, it may be helpful to examine land cover change in TMA and to find out the interrelationship between climate change impacts, adaptation polices and dynamics of land cover change.

|      | 2026 | 2046 | 2106 | Trend |
|------|------|------|------|-------|
| Baseline | ![Baseline2026] | ![Baseline2046] | ![Baseline2106] | ![BaselineTrend] |
| S1 | ![S12026] | ![S12046] | ![S12106] | ![S1Trend] |
| SII | ![SII2026] | ![SII2046] | ![SII2106] | ![SII2106] |
| SIII | ![SIII2026] | ![SIII2046] | ![SIII2106] | ![SIII2106] |

Figure 4. Scenario comparison and trend analysis: red color represents trend of built-up area; green color represents vegetation, and light blue color represent abandoned area.

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