Examining the relationship between error due to allocation in land-cover change modeling and non-stationarity of land-cover change

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Abstract: The main purpose of this study is to examine the relationship between error due to allocation in land-cover change modeling and non-stationarity of land-cover change. The GEOMOD model was used to simulate the 2009 land-cover map. Remote sensing-derived land-cover maps for 1988 and 1998 were used to calibrate the model, while the 2009 map was used to validate the simulated 2009 map. A method to assess the relationship between error due to allocation and non-stationarity of land-cover change was introduced. The simulated 2009 land-cover map had an overall accuracy of 85.70% relative to the whole landscape. It also had a 'hits to observed change ratio' (HOC) of 0.585 [with a corresponding 'misses to observed change ratio' (MOC) of 0.415] and a 'false alarms to observed change ratio' (FOC) of 0.381. Results showed evidence of a possible causal relationship between non-stationarity of land-cover change and error due to allocation. Non-stationarity+ had better relationship with misses than with false alarms, while non-stationarity– had stronger relationship with false alarms than with misses.

Keywords: land-cover change, modeling, allocation, non-stationarity, HOC ratio, GEOMOD

1. Introduction

Land-cover change modeling can provide vital information regarding possible causes and consequences of land-cover change (Verburg et al., 2004), and enable better landscape and urban planning for sustainable development.

The suitability of a pixel to undergo change may be influenced by the relationships of the properties of the land-cover changes in the past and/or the properties of the land-cover categories in the beginning time map used in the modeling and the properties of the drivers of change under consideration. However, since there is no guarantee for any existing relationship to continue into the future, the land-cover change process might not be stationary across both calibration and simulation periods. Chen and Pontius (2010) argued that errors of land-cover change modeling are mainly due to the non-stationarity of land-cover change in the study area with respect to the underlying drivers across the calibration and simulation intervals.

The main purpose of this study is to examine the relationship between error due to allocation in land-cover change modeling and non-stationarity of land-cover change in the city of Baguio, the Philippines.

2. Study area, data and methods

2.1 Study area: Baguio city, the Philippines

Baguio city is geographically located on 16° 25' latitude and 120° 35' longitude, approximately 250 km north of Manila (Fig. 1). Baguio is the country's summer capital, thanks to its cool temperatures.

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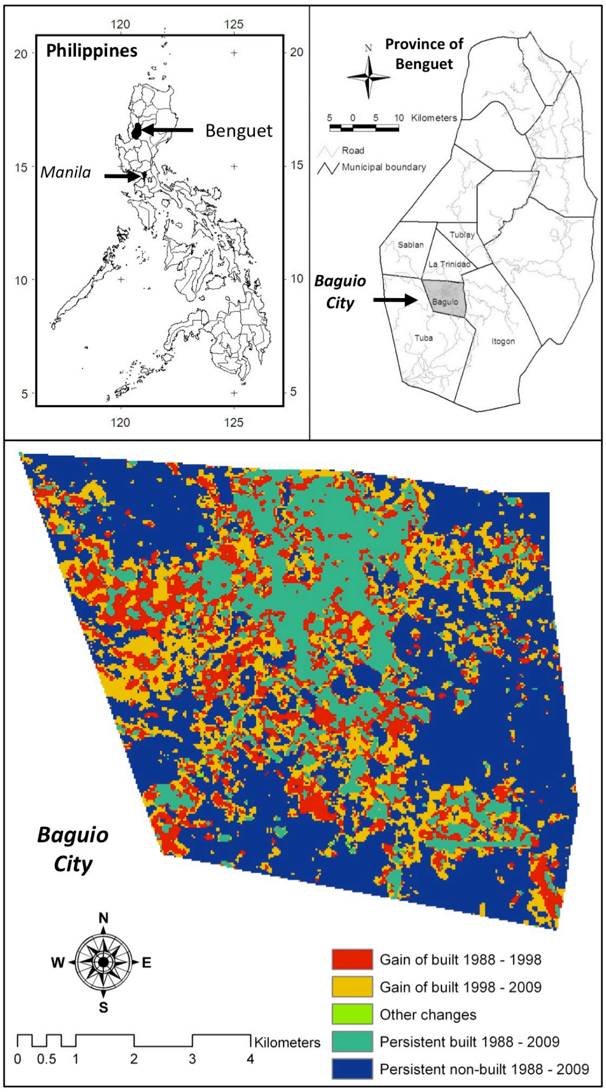

Fig. 1 Location of Baguio city and the land-cover changes across 1988, 1998 and 2009.

2.2 Database preparation

Three remote sensing-derived land-cover maps (1988, 1998 and 2009) of Baguio city, the Philippines (Estoque and Murayama, 2011), were used in this study. These maps were categorized into two: built and non-built. Seven driving factor maps were used, namely distance to city center, distance to growth node, distance to road, distance to tourist spot, elevation, slope and annual population growth rate (APGR). These drivers pre-date the beginning time of the modeling period, i.e. 1998. This is to ensure proper separation of calibration and validation over time. The distance driver maps were categorized using a 100-m bin size, while the elevation and slope driver maps were categorized using a 25-m and a one-degree bin size, respectively. The APGR driver map was categorized using a 2-percent bin size. All the maps were set at a 30m x 30m pixel resolution.

2.3 Methods

During the calibration of the GEOMOD model (Pontius et al., 2001), the total number of new built pixels in 2009 was determined by means of linear extrapolation, based on the trends of urban development during the 1988–1998 period. The relative weights of the drivers were determined using analytic hierarchy process, where 42 experts were consulted. The model was run using the following inputs: 1998 land-cover map (as the beginning time map of the simulation); projected quantity of built in 2009; seven driver maps with their relative weights; and a 3 x 3 neighborhood window.

The simulated 2009 land-cover map was validated using the 2009 reference map cross-tabulated with the 1998 reference map. The validation parameters used include the error due quantity and error due to allocation at the landscape level (Chen and Pontius, 2010), and the HOC, MOC and FOC ratio indices (Estoque and Murayama, in press).

In order to determine the relationship between the error due to allocation and the non-stationarity of land-cover change in this study, the following were calculated: (i) difference in the gains of built between the calibration and simulation periods (DGB_{dk}) (Eq. 1); and (ii) quantity of error due to allocation (misses and false alarms) of the simulated 2009 land-cover map in each of the bins of the categorized drivers. Subsequently, the DGB_{dk} was categorized into non-stationarity+ and non-stationarity–, where the former is characterized by an increase in the gains of built across the calibration and simulation intervals in each of the bins of the drivers, while the latter is characterized by a decrease. Finally, scatter plots were produced and statistical relationships between the quantity of non-stationarity+ and non-stationarity– on the one hand, and the quantity of misses and false alarms on the other, were examined.

$$DGB_{dk} = GB_{dk(sim)} - GB_{dk(cal)} \qquad \text{(Eq. 1)}$$

where d is a particular categorized driver; $GB_{dk(cal)}$ is the gain of built during the calibration period in category k of driver d; $GB_{dk(sim)}$ is the gain of built during the simulation period in category k of driver d.

3. Results

Fig. 2 shows the cross-tabulation of the simulated 2009 land-cover map and the 1998 and 2009 reference maps. The simulated 2009 land-cover map had an error due to quantity and error due to allocation of 0.76% and 13.54%, respectively, with an overall accuracy of 85.70% (null successes + hits) relative to the whole landscape. It also had a ‘hits to observed change ratio’ of 0.585 (with a corresponding ‘misses to observed change ratio’ of 0.415) and a ‘false alarms to observed change ratio’ of 0.381.

Fig. 3 shows the relationships of the difference in the gains of built (non-stationarity+ and non-stationarity–) across the calibration and simulation intervals and the error due to allocation (misses and false alarms).

4. Discussion and conclusions

The ‘better relationship’ of non-stationarity+ with misses indicates that the amount of land-cover change in some of the bins of the drivers was much greater during the simulation period (1998-2009) than during the calibration period (1988-1998). Since the model was calibrated under the much lesser amount of land-cover change in the said bins, the model was not able to accurately allocate the projected changes during the simulation period into these bins (misses). On the other hand, the ‘stronger relationship’ of non-stationarity– with false alarms indicates that the amount of land-cover change in some of the bins of the drivers was much greater during the calibration period (1988-1998) than during the simulation period (1998-2009). As a result, the model had overestimated the amount of changes that were allocated during the simulation period in the said bins (false alarms).

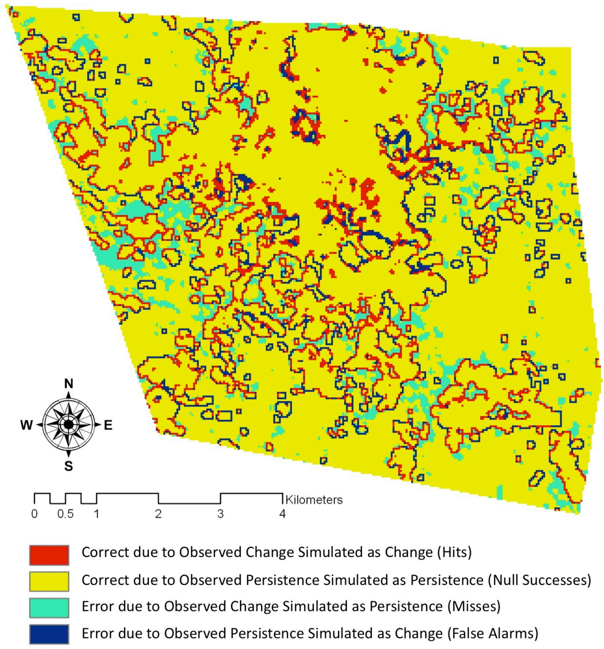

Fig. 2 Cross-tabulation image of the simulated 2009 land-cover map and the 1998 and 2009 reference maps.

Overall, the model would miss and/or simulate false alarms if the actual or observed land-cover changes in the ending time of the modeling period occurred in areas with characteristics not in agreement with the properties of the land-cover changes in the past and/or the properties of the land-cover categories in the beginning time map in relation with the underlying driving factors.

We conclude that, in this study, there was evidence of a possible causal relationship between non-stationarity of land-cover change across the calibration and simulation intervals and error due to allocation. This shows that non-stationarity influenced the accuracy of the modeling output (simulated 2009 land-cover map).

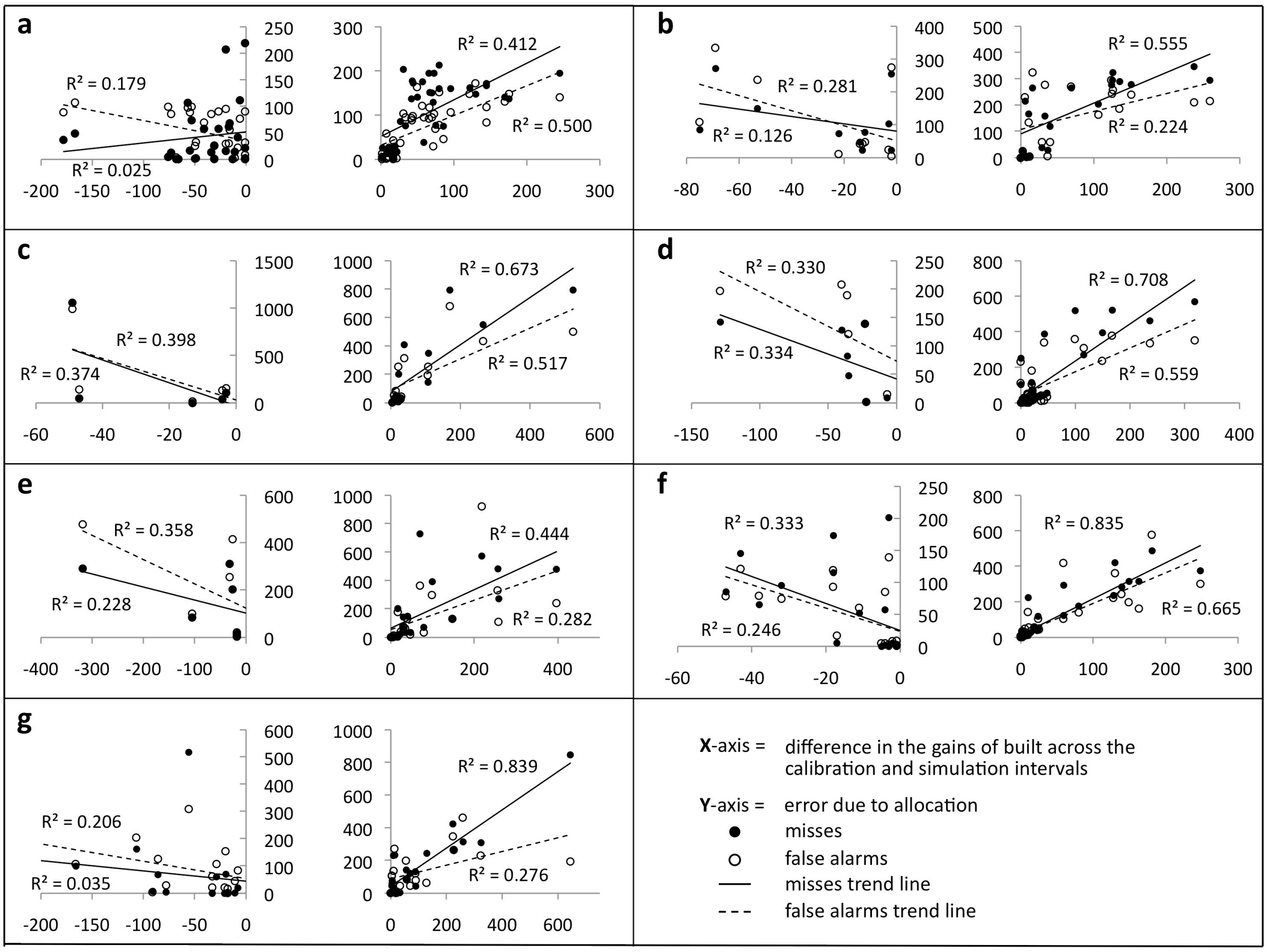

Fig. 3. Relationships of the difference in the gains of built (non-stationarity– and non-stationarity+) across the calibration and simulation intervals and error due to allocation (misses and false alarms) of the simulated 2009 land-cover map relative to each driver (*Unit:* Number of pixels). (a) Distance to city center; (b) Distance to growth node; (c) Distance to road; (d) Distance to tourist spot; (e); Elevation; (f) Slope; and (g) Annual Population Growth Rate (1980-1995).

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