Songklanakarin J. Sci. Technol.
36 (6), 719-725, Nov. - Dec. 2014

SJST SONGKLANAKARIN JOURNAL OF SCIENCE AND TECHNOLOGY
http://www.sjst.psu.ac.th

Original Article

Modeling land development along highway 4 in Southern Thailand

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Received: 19 July 2014; Accepted: 27 October 2014

Abstract

This study aims to investigate the change of developed land in three different locations along Highway 4 Road from Phattalung to HatYai. The method involves creating a digitized grid of geographical coordinates covering the study area. The land-use codes and plot identifiers were recorded in database tables indexed by grid coordinates. Logistic regression of land development adjusted for spatial correlation was used to model its change over a 9-year period using land-use at the previous survey combined with location as a determinant. The results show increasing average percentages of developed land (3% in 2000 and 5% in 2009). Land development occurred mostly in the northern location along the Pattalung to HatYai road.

Keywords: land-use data, grid-digitization, urban growth, land development, logistic regression model

1. Introduction

Modeling of land-use change has attracted substantial attention because it helps to explain the process of land-use change and thus assist relevant public policy-making. Recent publications on modeling the change in land-use include Lambin *et al.* (2000); Veldkamp and Lambin (2001); Verburg and Veldkamp (2001); Weng (2002); Aspinall, (2004); Veldkamp and Verburg (2004); and Heistermann *et al.* (2006). Relevant urban land development studies include those by Allen and Lu (2003); Barredo and Demicheli (2003); Cheng and Masser (2003); Barredo *et al.* (2004); Henriquez *et al.* (2006); Aguayo *et al.* (2007); Hu and Lo (2007); He *et al.* (2008); Luo and Wei (2009); Nong and Du (2011); Al-shalabi *et al.* (2013a); Al-shalabi *et al.* (2013b); and Alsharif and Pradhan (2014). Although developed land usually constitutes only a small proportion of the whole area, it is a catalyst for wider social and environmental changes. Modeling the change of land-use to developed land therefore provides valuable information to planners, developers and policy makers.

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Scientific knowledge of land-use change is well developed in research areas of science, geography, computer science, image processing, and remote sensing, whereas statistical methodologies, in particular time series modeling, have not yet been applied to the same extent. Several studies in recent decades have developed new and improved models of changes in land-use to developed land based on remote sensing (RS) and geographical information systems (GIS) to explain and forecast future development (Sudhira *et al.*, 2004; Liu and Zhou, 2005; Huang *et al.*, 2008; Eyoh *et al.*, 2012).

Modeling approaches used for analysis of land-use change have different purposes. Some dynamic, process-based simulation models (Cassel-Gintz and Petschel-Held, 2000; Stephenne and Lambin, 2001) are useful to predict changes whereas stochastic and optimization methods (Maxwell *et al.*, 2000; Fischer and Sun, 2001) are suitable for describing the decision making for land management. Empirical statistical models identify current land-use changes by applying regression models to relate historical land-use changes and other factors. Logistic regression has been widely used (Allen and Lu, 2003; Cheng and Masser, 2003; Hu and Lo, 2007; Nong and Du, 2011; Eyoh *et al.*, 2012; Alsharif and Pradhan, 2014; Tayyebi *et al.*, 2014). However, spatial correlation, which causes violation of the assumption of independent residuals, is often ignored because the statistical methodology for considering correlation is not well developed for logistic regression models (Hu and Lo, 2007).

Moreover, conventional survey and mapping techniques used in land-use change studies are expensive and time consuming for the expansion of developed land. Such information is not readily available in most developing countries. Analyses of land-use change based on sample data and inferential statistical approaches are needed.

This study uses graphical and statistical methods to display and model the extent of land development. After converting land-use data from polygons to a digitized grid, we use logistic regression with variance inflation factors to obtain confidence intervals for the extent of change in land development.

2. Methods

2.1 Study area

The study area comprises three locations along Highway 4 between Phattalung and HatYai in Southern Thailand (Figure 1). This part of the road is approximately 95 kilometers long and it goes through five districts (Mueang Phatthalung, Khao Chaison, Bang Kaeo, Tamot, and Pa Bon) of Phattaung and four districts (Rattaphum, Khuan Niang, Bang Klam and HatYai) of Songkhla. The area for each region is about 700 km^2 (25 km × 28 km).

2.2 Data

The land-use data for the three locations for 1991, 2000, and 2009 were obtained from the Thailand Department of Land Development, which has records of data from remote sensing and regular surveys in every province. The data are stored as polygonal *shape files* of land-use plots. The files can be restructured into a relational database table. The data structure for statistical analysis is based on an analog-to-digital conversion method, using a grid with dimension 100 m × 100 m, as explained by Thinnukool *et al.* (2014).

2.3 Land-use categories

Land-use was classified into four main categories comprising undeveloped land (UD), paddy field and other agriculture (PF+), rubber plantation (RF), and developed land (Dev). Descriptions of these categories are shown in Table 1.

2.4 Preliminary data analysis and variables

Land-use data can be displayed using thematic maps. These maps represent only the distributions of land-use in different years and locations and thus highlight variations, but they cannot be used directly to compare the areas of land-use categories. Bar charts are appropriate for comparing areas of land use categories by year and location. For detecting association of land-use categories between two periods of time, the percentages of land-use change are depicted using bubble plots with sizes representing magnitudes of change.

The outcome is binary, developed land (Dev) or other. The determinants are location and land-use categories nine years earlier. Since the effects of location and land-use category as determinants of land development might not be additive, there is some advantage in combining them to form a single factor corresponding to all location by land-use group combinations. Locations and land-use categories were thus combined into 12 levels of a categorical variable. These 12 levels comprise combinations of four land-use groups, namely undeveloped land (UD), paddy field and other agriculture (PF+), rubber plantation (RP) and developed land (Dev), and three locations: northern, central and southern locations along the Phattalung to HatYai road.

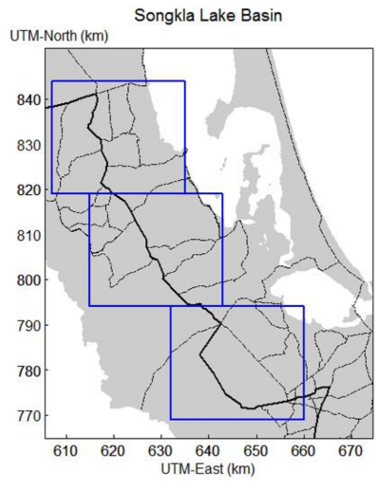

Figure 1. Location of study area.

Table 1. Land-use classification.

Land-use categories	Descriptions
Undeveloped land (UD)	Forest, grassland, water bodies, marsh and swampand miscellaneous land
Paddy field and other agriculture (PF+)	Paddy field, field crop perennial, orchard, horticulture, pasture and aquatic plant
Rubber plantation (RF)	Rubber plantation
Developed land (Dev)	City, town, commercial, village, institutional land, transportation, communication and industrial land

To measure land-use change between two periods of time, two sets of analyses were conducted. First, developed land in 2000 was taken as the outcome and location by land-use group from preceding surveys in 1991 as the determinant. Second, developed land in 2009 was taken as the outcome and location by land-use group in 2000 as a determinant.

2.5 Statistical analysis

Logistic regression was used for modeling the association between developed land (Dev) and location by land-use group. This model was fitted to the digitized grid data. It formulates the logit of the probability p_i of developed land (Dev) outcome in the year of interest and the location by land-use group nine years earlier as a determinant, and thus takes the form

$$\log\left[\frac{p_i}{1-p_i}\right] = \mu + \alpha_i, \quad (1)$$

where μ is a constant and the term α_i refers to the location by land-use group nine years earlier.

Conventional statistical regression modeling assumes that the individual observations are uncorrelated. However, digitized grid land-use data have substantial spatial correlation and thus violate this assumption (Hu and Lo, 2007). Variation inflation factors (Rao and Scott, 1992) were used to account for this spatial correlation and thus obtain valid confidence intervals. The graphical displays and statistical analyses in this study were performed using R (R Development Core Team, 2011).

3. Results

3.1 Land-use change

Figure 2 shows a thematic map that displays the land-use patterns along the Phattalung to HatYai road in 1991, 2000, and 2009 for three locations. Most of the land in the northern part was used for paddy fields and other agriculture (PF+). Rubber plantation (RP) was the largest category of land-use in the central and southern locations.

The bar charts in the Figure 3 show the area (in ha) of undeveloped land (UD), paddy field and other agriculture (PF+), rubber plantation (RP), and developed land (Dev).

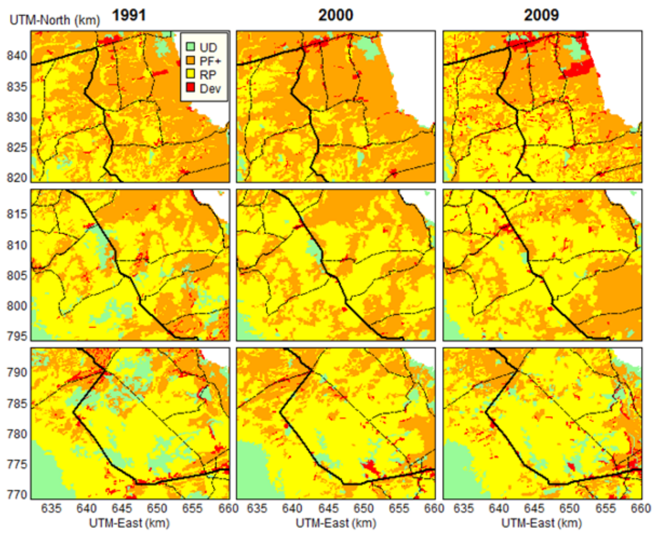

Figure 2. Land-use maps along the Phattalung to HatYai road in 1991, 2000, and 2009 for the three locations shown in Figure 1.

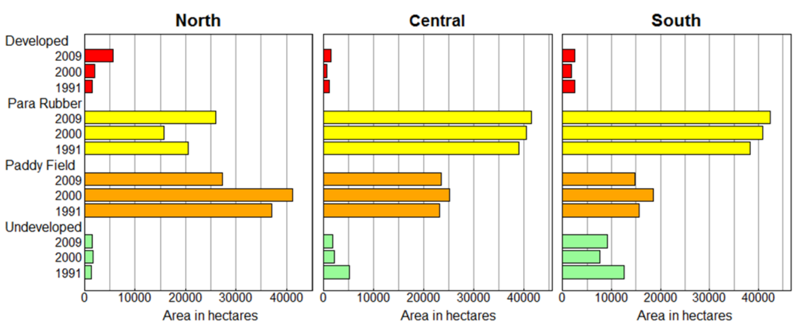

Figure 3. Bar charts of land-use along the Phattalung to HatYai road in 1991, 2000, and 2009 for three locations shown in Figure 1.

Figure 4 shows a bubble plot matrix of percentages of land-use category change in three locations. The top row shows the change of land-use from 1991 to 2000 and the bottom row shows the change from 2000 to 2009. Lighter grey or lighter colors (pink, yellow, orange and green) along the diagonal denote no change in land-use. Darker gray or darker colors (dark green, grey and red) off the diagonal denote land-use changes from one period to the next.

For example, the top right panel shows the change in land-use from 1991- 2000 in the southern location. In 1991, 4.28% of the land was developed land, 55.52% was rubber plantation, 22.70% was paddy field and other agriculture and 17.50% was undeveloped land. In 2000, 2.92% was developed land, 60% was rubber plantation, 27% was paddy field and other agriculture and 10.08% was undeveloped land.

On the diagonal, the pink bubble shows that less than 1% of the land that was developed land in 1991 remained developed in 2000. The yellow bubble shows that 43% of the land that was rubber plantation in 1991 remained so in 2000. The orange bubble shows that 13% of the land that was paddy field and other agricultural land in 1991 remained so in 2000. The light green bubble shows that 7% of the land that was undeveloped in 1991 remained so in 2000.

Off the diagonal line in the first column, the green bubbles, show that out of 4% of the land that was developed in 1991, 2% changed to paddy field and other agriculture and the other 2% changed to rubber plantation in 2000. In the second column, the grey bubbles show that out of the 11% that was rubber plantation in 1991, 2% became undeveloped and the other 9% changed to paddy field and other agriculture in 2000. The red bubble shows that 1% of the land that was rubber plantation in 1991 became developed in 2000. In the third column, the grey bubbles show that out of the 9% of land that was paddy field and other agriculture in 1991, 1% became undeveloped and the other 8% changed to rubber plantation in 2000. The red bubble shows that less than 1% of the land that was paddy field and other agriculture in 1991 became developed in 2000. In the fourth column, the grey bubbles show that the 10% of the land that was undeveloped in 1991, 3% changed to paddy field and other agriculture and the other 7% changed to rubber plantation in 2000. The small red bubble shows that less than 1% of the land that was undeveloped in 1991 became developed in 2000.

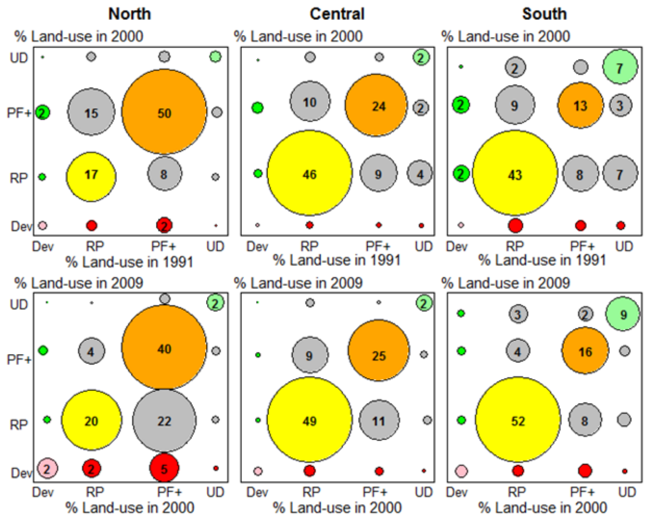

Figure 4. Land-use percentage changes along the Phattalung to Hat Yai road are the periods 1991-2000 and 2000-2009 for the northern, central, and southern locations.

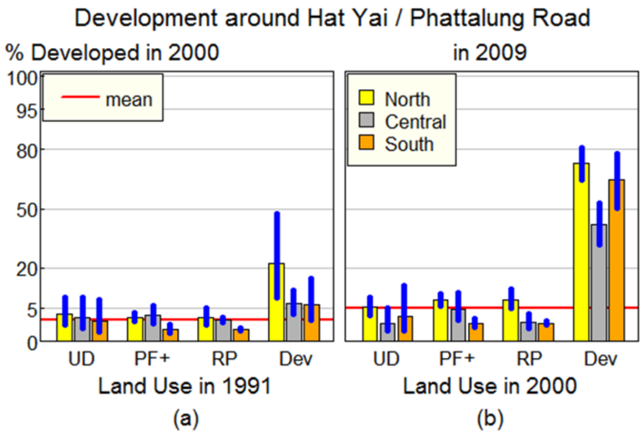

Figure 5. Bar charts of percentages of land that changed to developed land along the Phattalung to HatYai road from (a) 1991-2000 and (b) 2000-2009 by previous land-use and location.

3.2 Modeling results

The logistic regression model gave estimates of the percentages of the change in land-use to developed land and their corresponding standard errors. Standard errors were used to construct 95% confidence intervals for comparing the percentages of change to developed land for each of location by land-use type with their average percentages.

Figure 5 shows bar charts of the crude percentages of the change in land-use to developed land by location and by land-use group with 95% confidence intervals superimposed. The average percentage is shown by the horizontal red line with 3% for 2000 and 5% for 2009. Confidence intervals above the average line reflect the groups that were more likely to become developed land. The percentages of developed land that remained developed were higher in the 2000-2009 period than those in the 1991-2000 period. Greater land development occurred in the north, and the percentage of paddy field and other agriculture (PF+) that became developed was higher in 2000-2009 than in 1991-2000.

In Figure 5a, the developed land in 1991 (22.26% in the northern location, 6.23% in the central location, and 6.09% in the southern location) remained developed in 2000. Less than 4% of undeveloped land, paddy field and other agriculture and rubber plantation became developed. The 95% confidence interval for developed land in the north is substantially above the mean and it is marginally higher than the average in the central location whereas it is not different from the average in the south. Thus, the developed land in the north and the central location were more likely to remain developed land. All of the confidence intervals for the other land-use groups (UD, PF+ and RP) were lower or across the mean. Thus, these groups were less likely to become developed land, especially PF+ and RP in the south.

In Figure 5b, the developed lands in 2000 (73.59% in the northern, 41.86% in the central location and 65.61% in the southern) remained developed in 2009. Less than 8% of undeveloped land, paddy field and other agriculture and rubber plantation became developed. The percentages of developed land in three locations are substantially above the mean for all groups. Thus, they were more likely to remain developed. The results for other land-use groups were similar to the earlier period.

4. Discussion and Conclusions

Land-use change along the Phatthalung to HatYai road from 1991 to 2009 was investigated using statistical methods. The data were converted from polygons to a digitized grid. Thematic maps and bar chart were used to display the data. Bubble plot matrices were used to summarize percentages of land-use change from one period to the next. Logistic regression was used to delineate the association between developed land and location by land-use group nine years earlier.

Our results show increasing average percentages of developed land (3% in 2000 and 5% in 2009). Land development occurred mostly in the north. This may be due to the proximity to Phatthalung City. Moreover, the north is also located at the intersection of two highways (Highway 4 and 41). Road networks can influence the conversion of land to developed land. That developed land occurs closer to road networks was previously reported for Lop Buri Province, Central Thailand (Patarasuk and Binford, 2012). Urban growth and conversion of agricultural land to urban area have been found to occur closer to road networks in disparate locations, including the Kansas City Metropolitan area in the central U.S.A. (Underhill, 2004), Puerto Rico (del Mar Lopez *et al.*, 2001) and in Beijing, PR China (Zhang *et al.*, 2002).

The other land-use categories were less likely to change to developed land, especially PF+ and RP in the south. This can be seen by noting the higher percentage of rubber plantations. Due to a higher expected income from rubber plantations farmers have tended to convert land to rubber plantations rather than develop their land. It is reported that in the Phatthalung watershed, a quarter of the paddy field area has been converted into rubber plantation due to the higher incomes from rubber production (Pensuk and Shrestha, 2008).

The undeveloped land was more likely to change to other categories rather than developed land. This has occurred elsewhere, for example, forest lands were transformed to agricultural land, particularly for shrimp farms in Pak Panang Bay (Prabnarong and Thongkao, 2006) and Ban Don Bay (Muttitanon and Tripathi, 2005). However, various factors affected the extent of land-use change at each location.

Location by land-use group is just one factor that contributes to land-use change. Land-use change is usually the result of a combination of multiple factors including economic, biophysical, social, and political drivers, such as income, rainfall and population dynamics (Geist and Lambin, 2002). This study used locations by land-use group as a determinant of the change to developed land. Further research should include other variables such as ownership, accessibility or proximity to roads and transport hubs, climate, and population density.

Acknowledgements

The authors acknowledge suggestions from Prof D. McNeil. We also would like to thank Thailand's Land Development Department for providing the land use data. Our study was supported by a Prince of Songkla University scholarship.

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