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Original Article

Analyzing land use change using grid-digitized method

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Abstract

This study aims to analyze land-use change by a digitized-grid method, a simple technique that can be used for such analysis. We describe a procedure for restructuring land-use data comprising polygonal “shape files” containing successive (x, y) boundary points of plots for geographic land-use categories as grid-digitized data, and illustrate this method using data from Thailand. The new data comprise a rectangular grid of geographical coordinates with land-use codes and plot identifiers as fields in database tables indexed by the grid coordinates. Having such a database overcomes difficulties land-use researchers face when querying, analyzing and forecasting land-use change.

Keywords: land-use, grid-digitization, geographical information system

1. Introduction

Land-use is defined as human activity carried out on land (Irwin and Geoghegan, 2001, Madureira *et al.*, 2007; Rebelo, 2009; Manonmani and Suganya, 2010). Land-use is influenced by economics, population, culture, politics, and policy. Land-use change is of current scientific interest due to the massive amounts of data available from remote sensing, widespread use of global positioning systems, and the availability of geographic information system (GIS) software. GIS data contain information that needs to be extracted, such as imagery, land properties, land valuation, and geography (Weng, 2001; Strand *et al.*, 2002; Yang and Qiao, 2010). Google Earth provides free access to current views of the whole surface of the Earth (Lammeren *et al.*, 2009; Sadr and Rodier, 2012). GIS software is used to develop land-use data, improve land-use planning (He-bing and Su-xia, 2010; Yang and Qiao, 2010) and to detect land-use change with image processing based on GIS data (Usha *et al.*, 2012). In addition, scientists study ecological systems (Gret-Regamet *et al.*, 2008) and use GIS technology in environmental surveys (Gret-Regamey *et al.*, 2008; Manonmani and Suganya, 2010). Klajnsek and Zalik (2005), Bach *et al.* (2006), and Mizutani (2009) used GIS data to analyze polygonal shaped land-use data. They focused on shape change and use polygon events and status to understand land-use change. Although polygonal data structure can provide thematic maps for displaying patterns for a given year, the data are difficult to analyze because the polygons change. Bach *et al.* (2006), Frazier and Wang (2011), Guo *et al.* (2011), Hun *et al.* (2011), and Stehman and Wickham (2011) described the use of pixels, blocks and polygons to construct accurate maps. Whiteside *et al.* (2011) confirmed that pixel-based construction can accurately show land-use maps.

Using freely available software such as the R program and its special (*sp*) library, data can be restructured as points on a grid, for which land-use change is easily measured because the grid stays put while only the data change. The grid-digitized method provides a data structure that can be used directly for statistical analysis of land-use change. Data were obtained from the Department of Land Development, Thailand.

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2. Methodology

2.1 Grid-digitized method

The grid-digitized method involves converting the polygonal data to grid-point data. We illustrate this method using a simple example as shown in the maps in Figure 1 based on data structures listed in Table 1.

In this example, the region contains four polygonal plots indentified as 126, 131, 134 and 139, with corresponding land uses recorded as upland forest, rubber plantation or coconut plantation. The corresponding data structure is a table with the four fields plotID, pointID, x and y as indicated in the left panel of Table 1. The pointID field determines the order in which the boundary points (x,y) are connected to obtain a closed polygon for each land-use plot. For example the first four and last two values of pointID for plot 134 are indicated in the left-panel of Figure 1.

The computational method for connecting from the polygonal coordinates to those based on the grid involves determining how to assign grid points to polygons. The pseudo code for the program takes the following form:

```
for  each polygon p_i in the specified region
     label all grid points inside p_i as i
end
```

This program can be implemented in any language that accommodates *for…end* loops, provided this language has a function that determines which elements of a specified

Table 1. Data structures used to create the land use maps for Figure 1. The left panel lists polygonal data for creating the left panel of Figure 1, whereas the right panel lists grid-point data within the five rows of the rectangle in the right panel of Figure 2. Note that area outside the specified region has plotID coded as 0 (sea, with land-use code labeled Z0).

plotID	pointID	X	Y
126	1	438.69	891.12
126	2	438.73	891.18
126	3	438.75	891.26
126	4	438.90	891.29
.	.	.	.
.	.	.	.
126	56	438.74	891.09
126	57	438.69	891.12
131	1	439.34	891.07
131	2	439.31	891.04
131	3	439.26	891.01
131	4	439.22	890.99
.	.	.	.
.	.	.	.
131	39	439.31	891.13
131	40	439.34	891.07
134	1	438.69	891.12
134	2	438.74	891.09
134	3	438.76	891.04
134	4	438.80	891.01
.	.	.	.
134	18	438.58	891.05
134	19	438.68	891.10
134	20	438.69	891.12
139	1	439.05	890.85
139	2	439.05	890.84
139	3	439.07	890.81
139	4	439.09	890.81
.	.	.	.
.	.	.	.
139	30	439.01	890.84
139	31	439.05	890.85

x	y	plotID
438.75	891.25	126
438.85	891.25	126
438.95	891.25	126
439.05	891.25	126
439.15	891.25	126
439.25	891.25	126
438.75	891.15	126
438.85	891.15	126
438.95	891.15	126
439.05	891.15	126
439.15	891.15	126
439.25	891.15	131
438.75	891.05	134
438.85	891.05	126
438.95	891.05	126
439.05	891.05	126
439.15	891.05	131
439.25	891.05	131
438.75	890.95	134
438.85	890.95	134
438.95	890.95	126
439.05	890.95	131
439.15	890.95	131
439.25	890.95	0
438.75	890.85	134
438.85	890.85	126
438.95	890.85	126
439.05	890.85	131
439.15	890.85	131
439.25	890.85	139

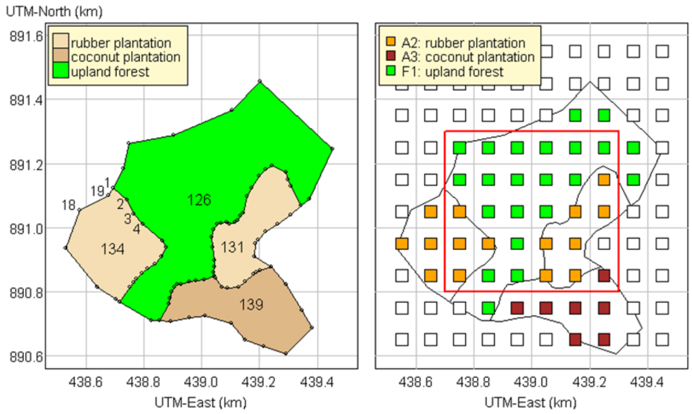

Figure 1. Conversion of polygonal representation (left panel) to digital representation (right panel) for land-use data from Naka-Yai Island in Phuket Province of Thailand in 1985.

set of points are contained within a specified polygon. We use the R program after loading its *sp* library, which contains the function *point.in.polygon*() (R Development Core Team, 2012). We use R because we are not aware of any other freely available software that can perform this.

3. Land-use data analysis

3.1 Land-use change

The grid-digitized method described in the preceding section facilitates measurement of land-use change. However this measurement is complicated by the fact that land-use codes themselves change. For example, the categories A2 (rubber plantation), A3 (coconut plantation), and F1 (upland forest) used in 1985 became A302 (para rubber), A405 (coconut plantation) and F101 (dense evergreen forest) respectively, in 2009. Using the 2009 land-use codes, Figure 2 shows the change in land-use for Naka-Yai Island from 1985 to 2009. Note that the four plots corresponding to the three different land-uses reported in 1985 were reduced to a single land use in 2009, and this land-use corresponds to F101 in 1985.

Note that plots 131 and 134 changed from para rubber in 1985 to other land-use in 2009, and plot 139 also changed completely. An area of plot 126 along its north coast was

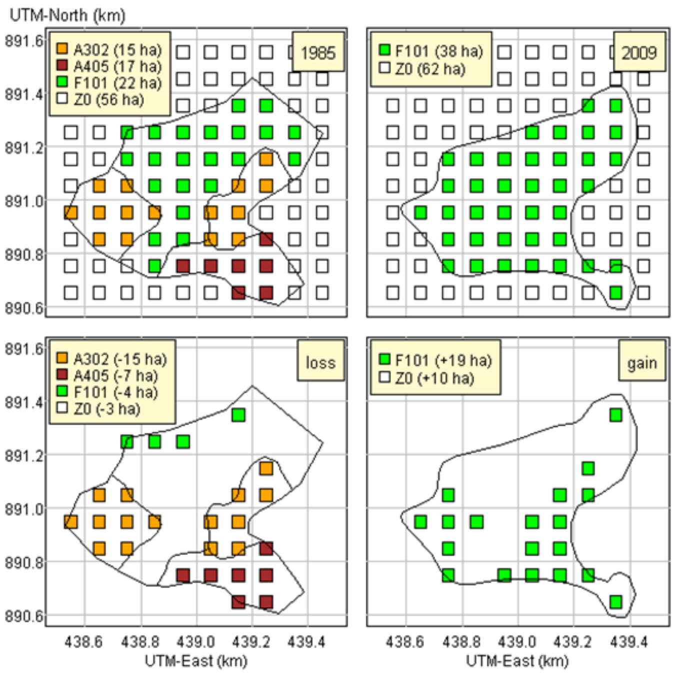

Figure 2. Land-use change in Naka-Yai Island from 1985 to 2009 with losses from 1985 (upper right panel) and gains to 2009 (lower right panel).

also lost but these losses were compensated by gains to plot 126. Note, however, that the apparent loss of the land along the north coast is not a real loss, because the area remained within the island. The explanation of this anomaly is that the coordinates shifted, as described next.

3.2 Coordinate shifts

A complication when comparing land-use over time is that earlier records of UTM coordinates are inaccurate and require correction. Figure 4 shows polygonal maps of small areas in four corners of Phuket province using the original UTM coordinates for 1985 with maps based on corresponding 2011 Google coordinates (http://maps.google.com) superimposed.

The coordinate shifts illustrated in Figure 3 are quite substantial and complicate accurate measurement of land-use change. Assuming that coordinates available from Google Earth maps are correct and that these locations have not changed substantially over recent decades, it is desirable to convert all land-use coordinates to agree with the corresponding Google Earth coordinates. Table 2 shows how the coordinates around Phuket Island shifted from 1985 (x, y) to 2009 (u, v)

The method we use for this conversion is based on a bilinear transformation of the form.

$$u = a_1 + b_1x + c_1y + d_1xy \quad (1)$$

$$v = a_2 + b_2x + c_2y + d_2xy \quad (2)$$

The parameters (a_1, b_1, c_1, d_1, a_2, b_2, c_2, d_2) in Equation (1) and (2) are determined by using the data for the coordinate shifts (dx, dy) at the four locations mapped in

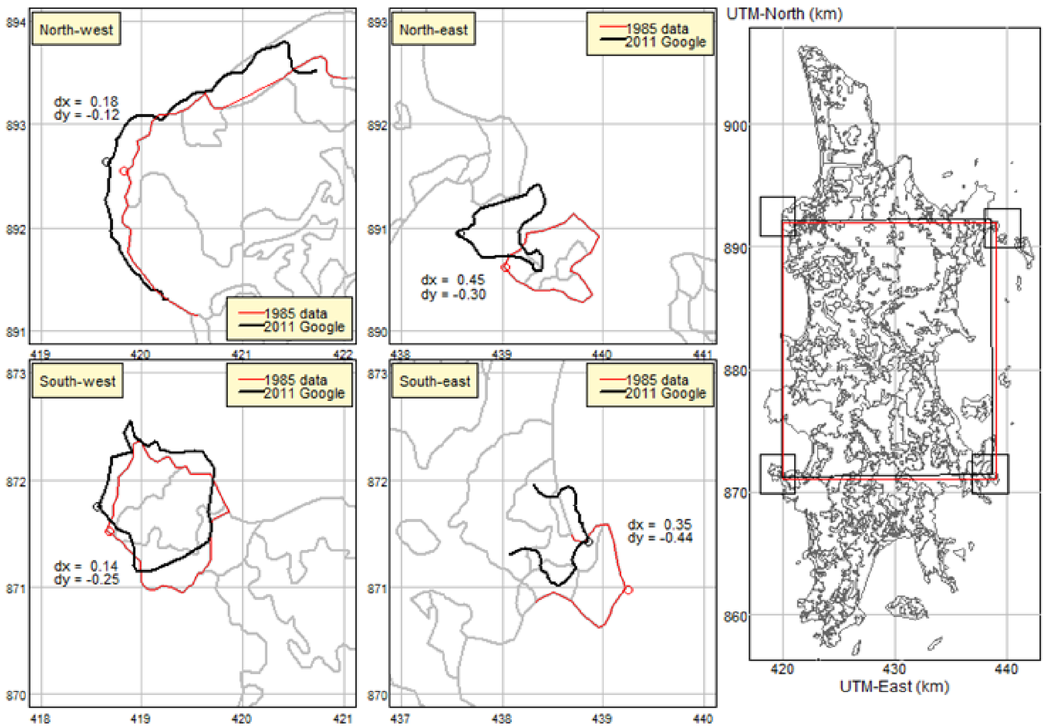

Figure 3. Horizontal (dx) and vertical (dy) shifts (in kilometers) of UTM east and north coordinates, respectively, from 2011 Google map locations in corner regions of Phuket Island, to the corresponding positions based on land-use records recorded by the Department of Land Development, Thailand, in 1985. Table 2 shows (x,y) coordinates of the location of the rectangle (colored red) in the right panels, with corresponding (u,v) coordinates.

Table 2. Coordinate shifts in Phuket Island based on information in Figure 3.

Rectangle Corner	x, y	km	u, v
North east	439.0, 892.0	-0.45, 0.30	438.55, 892.30
North west	420.0,871.0	-0.18, 0.12	420.18, 870.89
South east	439.0, 871.0	-0.35, 0.44	438.65, 871.44
South west	420.0, 871.0	-0.14,0.25	419.86, 871.25

Figure 3. There equations are expressed in matrix form as

$$g = F\,h \qquad (3)$$

In this formulation g is the column vector (u_1, v_1, u_2, v_2, u_3, v_3, u_4, v_4), h is the column vector (a_1, b_1, c_1, d_1, a_2, b_2, c_2, d_2) and F is an 8 × 8 matrix, as follows.

$$\begin{bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \\ u_4 \\ v_4 \end{bmatrix} = \begin{bmatrix} 1 & x_1 & y_1 & x_1 y & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & x_1 & y_1 & x_1 y \\ 1 & x_2 & y_2 & x_2 y & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & x_2 & y_2 & x_2 y \\ 1 & x_3 & y_3 & x_3 y & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & x_3 & y_3 & x_3 y \\ 1 & x_4 & y_4 & x_4 y & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & x_4 & y_4 & x_4 y \end{bmatrix} \times \begin{bmatrix} a_1 \\ b_1 \\ c_2 \\ d_2 \\ a_3 \\ b_3 \\ c_4 \\ d_4 \end{bmatrix}$$

3.3 Analysis method

Using methods described in the preceding section, the grid-digitized method provides a digital map. Change in land-use is then summarized in a cross tabulation giving area (in hectares) or percentages of land-use categories from one period to the next. These numbers can be displayed as a bubble plot matrix as shown in the right panel of Figure 3, with digital maps of changes shown in the middle panels. Note that darker colors show changes and lighter colors denote no change. For example, the changes from agriculture (A) to urban (U) land-use over the period 1985-2000 was 9.9%, and from agriculture to forest (F) during the same period was 10.3%. In summary, from 2000 to 2009, agriculture change to forest was 5.0% and agriculture change to urban was 5.8%.

4. Discussion and Conclusion

This paper presents a method for measuring GIS data using a grid-digitized method based on GIS data. With appropriate choice of colors, bubble plots show how land-use changes between categories, such as natural (forest, grassland, etc.), farm land, and wetland areas. The land-use database is freely available from the Department of Lands, Thailand, and can provide a valuable resource for seeing what happened in the past and for planning the future. Converting shape files comprising polygonal boundaries to more tractable gridded one-hectare units simplifies analysis, enabling straight forward creation of bubble plots and corresponding thematic maps that informatively show changing land-use patterns. The digital grid-based data structure also provides a simple basis for statistical analysis of land-use development over time, because it easily accommodates changes in polygonal plot boundaries and takes account of changing GPS settings.

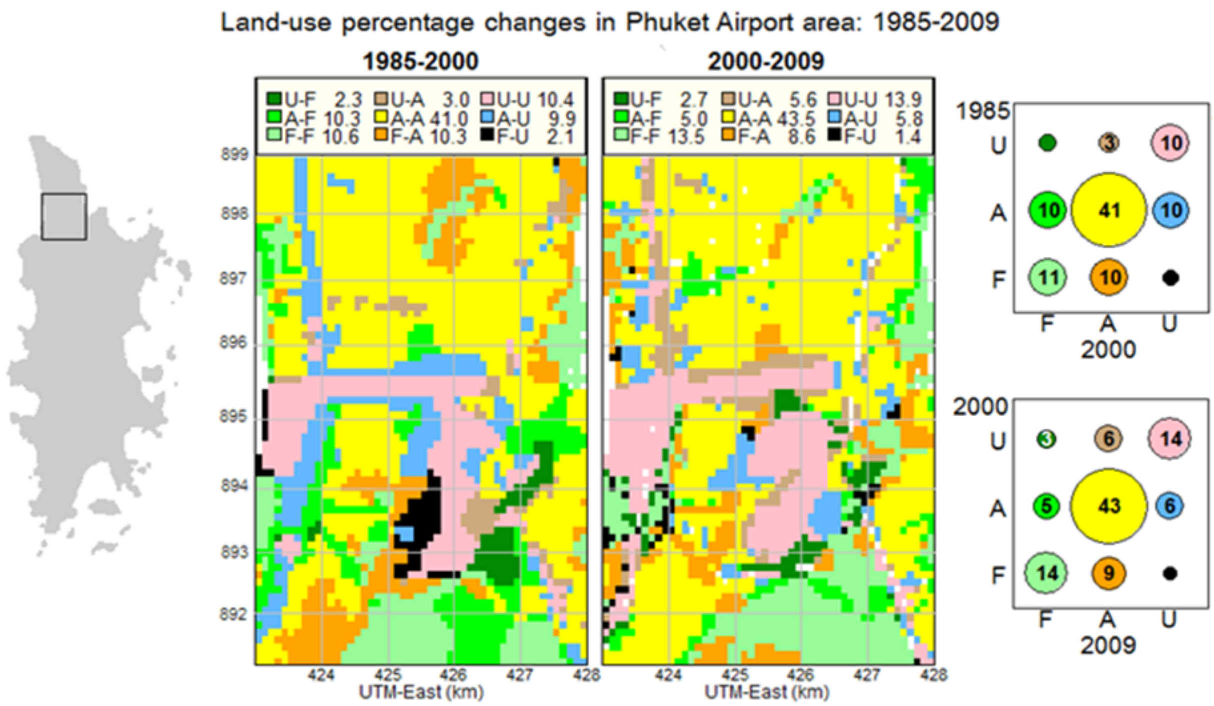

Figure 4. Land-use changes in the region surrounding Phuket airport from 1985 to 2009 based on digitized data structure. The thematic maps use the same colors as these used in the bubble plots.

Moreover, the basic statistical analysis can focus on the percentage of change when the outcome at each grid-point is binary. In this case data can be analyzed by logistic regression, because the specific land-use of interest is binary (e.g., urban or not).Various determinants, such as accessibility or proximity to roads and transport hubs, climate, and population density, may be incorporated into a model based on gridding to predict future land-use at each grid-point.

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References

Bach, M., Breuer, L., Frede, H.G., Huisman, J.A., Ott, A. and Waldardt, R. 2006. Accuracy and congruency of three different digital land-use maps. Landscape and Urban Planning.78, 289-299.

Frazier, A.E. and Wang, L.2011. Characterizing spatial patterns of invasive species using sub-pixel classifications. Remote Sensing of Environment. 115, 1997-2007.

Gret-Regamey, A., Bebi, P., Bishop, I.D. and Schmid, W.A. 2008. Linking GIS-based model to value ecosystem services in an Alpine region. Journal of Environment Management. 89, 197-208.

Guo, L., Du, S., Haining, R. and Zhang, L. 2011. Global and local indicators of spatial association between points and polygons: A study of land use change. International Journal of Applied Earth Observation and Geoinformation. 21, 384-356.

He-bing, Z. and Su-xia, Z. 2010. Development and application of land-use planning management information system based on ArcGIS. Proceedings of 2010 International Forum on Technology and Application, Kunming, China, July 16-18, 2010, 64-67.

Huh, Y., Yu, K., and Heo, J. 2011. Detecting conjugate-point pairs for map alignment between two polygon data sets. Computer Environment and Urban System. 35, 250-262.

Irwin, E.G. and Geoghegan, J. 2001. Theory, data, methods: developing spatially explicit economic models of land use change. Agriculture, Ecosystem and Environment. 85, 7-23.

Klajnsek, G. and Zalik, B. 2005. Merging polygon with uncertain boundaries. Computer and Geosciences. 31, 353-359.

Lammeren, R.V., Houtkamp, J., Colijn, C., Hiferink, M. and Bouwman, A. 2009. Google Earth based visualization of Land Use scenario studies. Proceeding of GSDI 11 World Conference: Spatial Data Infrastructure Convergence: Building SDI Bridges to Address Global Challenges, Rotterdam, The Netherlands. June 15-19, 2009.

Madureira, L., Rambonilaza, T. and Karpinski, I. 2007. Review of methods and evidence for economic valuation of agricultural on-commodity outputs and suggestions to facilitate its application to broader decisional contexts, Agriculture, Ecosystems and Environment. 120, 5-20.

Manonmani, R. and Suganya, M.D. 2010. Remote sensing and GIS application. In Change detection study in urban zone using multi temporal satellite. International Journal of Geomatics and Geosciences.1, 60-65.

Mizutani, C.2009. Land use transition process analysis using polygon events and polygon status: A case study of Tsukuba science city. Proceedings of the 17th International Conference of Geoinformatics, Virginia, U.S.A., August 12-14, 2009, 1-6.

Rebelo, E.M. 2009. Land-economic rent computation for urban planning and fiscal purposes. Land Use Policy. 26, 521-534.

Sadr, K. and Rodier, X. 2012. Google Earth, GIS and stone-walled structures in southern Gauteng, South Africa. Journal of Archaeological Science. 39,1034-1042.

Stehman, S.V. and Wickham, J.D. 2011. Pixels, blocks of pixels, and polygons: Choosing a spatial unit for thematic accuracy assessment. Remote Sensing of Environment. 115, 3044-3055.

Strand, G.H., Dramstad, W. and Engan, G. 2002.The effect of eld experience on the accuracy of identifying land cover types in aerial photographs. International Journal of Applied Earth Observation and Geoinformation. 4, 137-146.

Usha, M., Anitha, K. and Iyappan, L. 2012. Land use change detection through image processing and remote sensing approach: a case study of palladamtalukm, tamilnadu. International Journal of Engineering Research and Application. 2, 289-297.

Venables, W.N. and Smith, D.M. 2008. R Development Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.

Weng, Q. 2001. Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling. Journal of Environmental Management. 64, 273-284.

Whiteside, T.G., Boggs, G.S., and Maier, S.W. 2011. Comparing object-based and pixel-based classications for mapping savannas. International Journal of Applied Earth Observation and Geoinformation.13, 844-893.

Yang, G. and Qiao, G. 2010. Data processing method for current land use using GIS Technology. Proceeding of the Second International Workshop on Education Technology and Computer Science, Wuhan, China, March 6-7, 2010, 511-514.