Transition Probabilities Applied to Land Use Changes in the Northern Metropolitan Areas of Japan

Luis Carlos MANRIQUE Ruiz and Kayoko YAMAMOTO

Abstract: The land use analysis is an important aspect for land use city planning. In order to prevent future issues, and promote specific areas of a territory, the local government has to gather precise information about the cities. In this study, we focus in three different metropolitan areas in the northern part of Japan; also we take into account 3 periods of time to understand the land use changes, and we calculate the transition probabilities by Markov process to predict a future period of time. Later we analyze the transition probabilities through a logit model taking in count geographic, and demographic data also analyzing the anthropogenic impact. The logit model is developed to contrast it with the transition probability matrix of Marvok model. The objective pursued by this study is to give an approach of a compact city for middle and large scale metropolitan areas.

Keywords: Compact city, land use transformation, transition probabilities, logit model, GIS.

1. Introduction

The land use changes are important to planners, scientists, architects among others. These changes affect mainly the natural resources (Aaviksoo, 1995; LaGro and DeGloria, 1992; Lopez E. and Bocco G. et al, 2001). In developed countries such as Japan, there is a serious problem due to depopulation, the elderly people every year is growing while the births are decreasing; also According with Yamamoto, Japan has a lack of green spaces compared with other large cities of advanced nations (Yamamoto, 2007). For this reason it is important to gather the population, preventing the urban sprawling, preventing seemingly random changes in land use, and preserving the natural resources. Models to prevent these situations have been described, such as smart cities, compact cities among others. The term of compact cities has been defined in a first moment by Dantzig and Saaty as places with high population density, less automobile dependence, mixed land use, diversity of life, social fairness and Independency of governance (Dantzig and Saaty, 1974).

University of Electro-Communications,
1-5-1, Chofugaoka, Chofu-shi, Tokyo 182-8585, Japan
Phone: 042-443-5728
E-mail: carlos@si.is.uec.ac.jp

This study analyses large and middle scale cities in the northern and eastern areas, in special case Sapporo and Sendai cities, adopting the compact city model. We present this model to improve the cities' master plan; and we will compare it with Aomori city, because this city is currently working as a compact city. Using Geographic Information Systems (GIS) we study the land use system, population and urbanization areas. Sendai and Sapporo have more than 1 million people each one while Aomori city has almost the 30 percent of them, for that reason it is important to study the land use transformation and population growth using time series. We calculate the transition probabilities to understand and predict a future period of time. We perform two processes, a Markov model process and a logistic regression to predict land use changes. This process will be developed using Geographic Information System (ArcGIS v.10) and R software v.2.15. All the information has been measured in a 100m mesh area.

2. Background

The analysis of land use changes has been developed through different mathematical and stochastic methods. One of the most known methods is the Markov process; this method is time dependent (Logsdon, M. and Bell E., 1996) and analyze the changes in the different classes

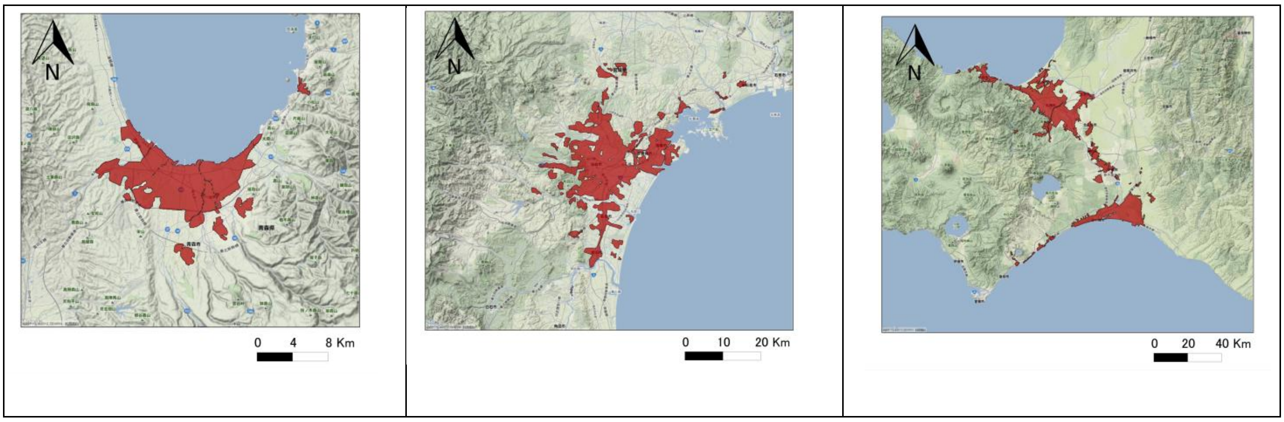

Figure 1. Land Use Promotion area for Aomori, Sendai and Sapporo MA

Table 1. Urbanization Promotion Area (ha)

Met. Area	Year	Paddy Field (1)	Other agric. (2)	Forest (3)	Waste Land (4)	Building (5)	Roads (6)	Other (7)	Rivers (8)	Beach (9)	Ocean (10)	Golf (11)	Total
Aomori	1991	773	194	374	103	3,068	247	662	90	1	519	0	6,031
Sendai	1991	4,174	1,824	7,003	430	10,696	1,191	5,177	834	1	173	215	31,718
Sapporo	1991	615	7,974	12,055	10,789	21,696	2,543	15,020	1,893	83	1,079	276	74,023
Aomori	1997	655	175	309	51	3,327	245	673	90	1	505	0	6,031
Sendai	1997	2,964	1,193	5,231	259	14,802	1,234	4,968	848	264	201	0	31,964
Sapporo	1997	430	6,113	10,534	7,863	28,982	3,017	13,797	1,858	82	1,065	282	74,023
Aomori	2006	345	140	206	45	3,848	305	889	105	2	146	0	6,031
Sendai	2006	1,954	609	3,301	200	18,517	1,160	4,522	996	22	197	240	31,718
Sapporo	2006	291	3,785	7,896	6,925	35,642	2,849	14,003	1,666	156	714	96	74,023

from the period *i* to period *j*.

The analysis of land use transformation and population density has to be done using timelines of historical events, and related information is used to explain the mapped changes (Acevedo 1999).

Nowadays the land use changes have received less attraction in spatially explicit models, because the data is insufficient to describe the anthropogenic impact. An example of a different model was developed by LaGro and DeGloria, They applied a multiple regression to examine the land use dynamics using five classes of land use. Another example also related with environment was developed by Arekhi S. and Jafarzadeh A. published in 2012, they calculate the probabilities of deforestation given some distances to settlements, roads, forest age among other variables. For that reason, this study compares the Markov processes with a logistic model using more variables which are affecting the land use changes.

3. Data description

In Japan all the cities have their own a master plan; it consists in a system for transportation and traffic, community facilities, parks and open space, neighborhoods and housing, economic development and land use. The city planning areas in Japan are divided into different areas, such as: Undivided city planning area such as Urbanization Promotion Area (UPA), Urbanization Control Area (UCA), and Non-undivided city planning area such us Districts, Zoning area. According with the Ministry of Internal Affairs and Communications of Japan, the UPA is designated to Industrial, Commercial and residential area (Kadomatsu, 2006).

In order to proceed with this study, first of all the information related with the master plan for each Metropolitan Area (MtA) was obtained from the Minister of Land, Infrastructure, Transportation and Tourism of Japan (MLIT) through the Land Use Control Back-up (LUCKY) System. This information is obtained as a digital image, for that reason, an automated system for digital image processing was developed in order to reduce the errors extracting the information. The next part was to overlap the information related with the land use also downloaded from the MLIT with the information from LUCKY System.

4. Methodology

The stochastic matrix was calculated, and the probability for each class was defined in the next way:

$$p_{ij} = \frac{n_{ij}}{\sum_k n_{ik}} \qquad (1)$$

Where n's are the number of hectares that experienced the change from *i* to *j*, and *k*. In other words the conditional probability of a change from *i* to *j* is estimated by the number of hectares or mesh units that changed divided by the total number of mesh units that could have changed.

Table 2. Transition probability matrix for Aomori 1991-1997 in UPA

	1	2	3	4	5	6	7	8	9	10
1	0.000	0.076	0.082	0.023	0.579	0.029	0.170	0.023	0.000	0.018
2	0.298	0.000	0.190	0.017	0.322	0.008	0.107	0.033	0.000	0.025
3	0.237	0.169	0.000	0.076	0.263	0.076	0.127	0.008	0.000	0.042
4	0.318	0.068	0.250	0.000	0.182	0.045	0.114	0.000	0.000	0.023
5	0.217	0.071	0.068	0.029	0.000	0.108	0.293	0.043	0.000	0.171
6	0.212	0.011	0.076	0.018	0.450	0.000	0.151	0.007	0.000	0.076
7	0.184	0.041	0.152	0.050	0.364	0.058	0.000	0.018	0.001	0.133
8	0.109	0.020	0.040	0.020	0.545	0.030	0.109	0.000	0.000	0.129
9	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.056	0.000	0.000	0.833	0.056	0.056	0.000	0.000	0.000

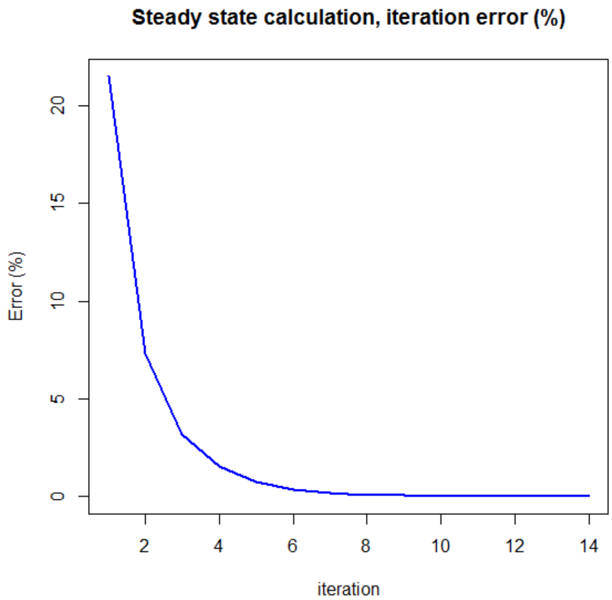

Figure 2. Steady state calculation for Aomori UPA in 1991-1994, iteration error.

As a part of transition matrix, the steady state is calculated, if the Markov chain is ergodic. There is a unique steady-state probability vector $\bar{\pi}$ that is the principal left vector of *p*. It is defined as follows:

$$\lim_{t\to\infty} \frac{\mu(i,j)}{t} = \pi(i) \qquad (2)$$

The second part is to develop a logistic model to calculate the probabilities of land use changes. The logistic model or logit model is defined as follows:

$$\text{logit}[P(y=1)] = \beta_0 + \beta_1 X_1 + \cdots + \beta_n X_n \qquad (3)$$

And the formula for the probability itself is:

$$p(y=1) = \frac{\exp^{(\beta_0+\beta_1X_1+\beta_2X_2+\cdots)}}{1+\exp^{(\beta_0+\beta_1X_1+\beta_2X_2+\cdots)}} \qquad (4)$$

Where β are the coefficients of the model and *X* are the different variables. In further experiments we will calculate the probability of land use changes using variables such as distance to train stations, hospitals, parks, public community services, parks, convenience stores, and we will use related costs with the land use.

In order to evaluate the best Logit model we will use the Akaike Information Criterion (AIC), because it adjusts the residual deviance for the number of predictors, thus favoring parsimonious models.

5. Results

In Figure 1, we show the land use promotion area for Aomori, Sendai and Sapporo Metropolitan areas. We can notice the difference between the size of the areas, while Aomori size is equivalent to 6.031 ha (60.31 km^2), Sendai and Sapporo are 31.718ha (317.18 km^2) and 74.023 ha (740.23 km^2). The size of each polygon on the GIS is same as 1 ha, for that reason the computational time was considerable.

In Table 1 we present the statistics of changes in the Urbanization Promotion Area for the 3 metropolitan areas in 1991, 1997 and 2006. We notice here that the largest changes related with rice fields were in Aomori with a reduction higher than 55%, however the residential area and roads grew in more than 25% and 23% respectively. Although there was a reduction of the agricultural fields, the largest change was in Sendai MtA in more than 67%, and there was a large growth in the residential area in more than 70%. We see here that most of the citizens are leaving the agricultural lands and the residential area is rising.

In Table 2, the transition probability matrix is shown; the data corresponds to Aomori UPA in the year 1991 – 1997. First of all we can see here that there are a few changes to the area next to beach, also there is just a change from next to beach to building or residential area with a probability equal to 1.

We could calculate the steady state with an error of 1.32e-5, before overfitting.

We have highlighted the column related with buildings area (code No.5), because it presents the largest probability among the other variables, and also because the residential area is one of the most important variables to take in count in this study. We can notice here that the probability of change from Rice fields to buildings is more than 57%, also some places related with rivers have changed in more than 54%, while areas dedicated to forest protection is just the 26%, It means that Aomori city is preserving the environment and is encouraging to construct and transform specific areas into residential areas.

6. Discussion

Although the transition probability matrix is useful to understand the behavior of land use changes it does not take in count anthropogenic impact. For that reason, in a first moment the transition probability matrix presents an overview of the performance by different classes. Another way to going further using Markov process is evaluate the probability of changes in the different periods of time using hidden Markov models. This previous model can estimate the phenomenon's data to adequate distributions of observations with the observable and "hidden" variables. The hidden variables will be related with random processes over the time interval.

Arekhi and Jafarzadesh (2012) could calculate the probabilities and construct a scenario to evaluate different variables related with deforestation. They analyzed the relationship between the distances from the roads, settlements, forest edge to the forest area. For this study we will analyze some distances from public services, such as hospitals, parks, schools among others, to residential areas.

It is important to develop the logit model, because we can understand how the land use is changing related with different variables such as distances to public services, parks, hospitals, among others over the time interval. With this model we can understand the most important variables for the decision making process of land use changes in each area.

7. Conclusions

The transition probability matrix is useful to understand how the land use changes from period *i* to period *j*. It gives preliminary results of the city behavior. We found that the steady state is reached with an error less than 1e-4 in the iteration 14. According with results we can understand how Aomori is concerned with maintaining the compact city model, through the performance of the probabilities in the different classes. We can notice that Aomori is encouraging the use of residential areas than other types of land. We can see also that the probability to change to this class are high than the other classes.

Integrating GIS and transition probability matrix we could analyze how the land use is changing in specific areas of the metropolitan cities. According with Arekhi et al, the logit model is suitable to analyze the land use changes. In this study we perform this model with variables related with distance to different kind of public services, also we take in count variables related with land use prices.

In future research we will analyze how is affected a mesh area for their neighbors, and how this one could change its land use class in the time interval related with the neighbors.

References

Aaviksoo, K., 1995. Simulating vegetation dynamics and land-use in a mire landscape using a Markov model. *Landscape and Urban Planning*. **31**, 129–142.

Acevedo, W. 1999. Urban dynamics research program. U.S. *Geological Survey. USGS Fact Sheet*. 188-99.

Arekhi, S., Jafarzadeh, A. 2012. Deforestation modeling using logistic regression and GIS (Case study: Northern Ilam forests, Ilam Province, Iran). *African Journal of Agricultural Research*, **7**, 1727–1741.

Dantzig, G. Saaty, T. 1974. Compact City: Plan for a livable urban environment. Ed. W.H.Freeman and Co. Ltd.

Kadomatsu, N. 2006. Recent development of decentralization, deregulation and citizens' participation in Japanese city planning law. *Kobe University Graduated School of Law and Faculty of Law*. **41**. 1–14.

LaGro, J. DeGloria, S. 1992. Land use dynamics within an urbanizing non-metropolitan county in New York State. *Landscape Ecology*. **7**. 275-289.

Logsdon, M. Bell, E. 1996. Probability mapping of land use change: A GIS interface for visualizing transition probabilities. *Computers, environment and urban*, **20**, 389–398.

Lopez, E. Bocco, G. Mendoza, M. Duhau, E. 2001. Predicting land-cover and land-use change in the urban fringe a case in Morelia city, Mexico. *Landscape and Urban Planning*, **55**, 271–285.

Yamamoto, K. 2007. Evaluation of public green space placement plans as indicator of urban density of Japan's three major metropolitan areas using GIS. *Proceedings of Joint international symposium and exhibition on geoinformation and international symposium on ISG/GNSS 2007*, 15p. (CD-ROM)