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Analysis of Land Use Changes in City Suburbs

—A Case Study on Some Subdistricts of the Bekasi Area of West Java, Indonesia—

Ernan RUSTIADI* and Teitaro KITAMURA**

I. Introduction

The agricultural location theory has played an important role in the evolution of the urban land use theory and in the study of urban fringe. Von Thunen in 1826[1] and Ricardo in 1820[2] drafted the first agricultural location and land rent theories. Only in the twentieth century have location theories been proposed for industry by Weber[3] and for services by Christaller[4] and Losch[5].

Classical spatial analyses have been treated conceptually for about a century, and algebraically for several decades. These classical statistics applied to geo-refereed data have failed to capture location information, however, raising questions of estimation sufficiency, bias, efficiency, and consistency[6]. Only recently have the analyses of spatial data become a major preoccupation of numerous statisticians

Spatial interaction is a broad term encompassing any movement over space that results from a human process. Gravity models, as groups of spatial interaction models, are the most widely used type of interaction model. They are mathematical formulations used to analyze and forecast spatial interaction patterns. Gravity models appear to capture and interrelate at least two basic elements[7] : (1) scale impact (mass factor), for example, cities with large populations tend to generate and attract more activities than cities with small populations, and (2) distance impact, for example, the farther places, people or activities are apart, the less they interact. Potential models have close conceptual, empirical, and historical associations with gravity models. These potential models have used frequently as indices of the intensity of possible between social and economic groups at different locations. Potential models are concerned with the opportunity for interaction between groups, created by their size and location, rather than with the interaction itself, whereas gravity models are more concerned with analyzing or predicting observed patterns of spatial flows.

Cities of Developing Countries in Asia, especially megacities are now experiencing a phenomenon that no other cities have experienced before. In this new era of urbanization in developing country which posses only limited resources, planners and city managers must generate new ideas. The experiences from most developing countries show that land use and development controls in rapidly growing cities have failed to appreciably influence development pattern. Knowledge of urbanization rates and how they are related to their determinants will define how the land use planner can make plans and policies more accurately.

This study introduces a new approach to modeling the land use change process. In an effort to describe urban land use distribution in city suburbs, spatial statistic parameters are proposed to analyze changes in land use patterns, and then a mathematical equation applied to an analogy of a potential model function and a statistical approach as an empirical test is adopted. The study focuses on (1) analyzing the spatial pattern of the distribution of urban land use in city suburbs, and (2) finding the best model for analyzing the dynamics of the urban land ratio and its growth rate with changing distances.

II. Model formulation

1. Spatial land use pattern analysis

Spatial statistics are better able to aid in making maps of pattern changes than to make

*Graduate School of Agriculture, Kyoto University
**Tokyo University of Agriculture
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comparisons of time series conventional land use maps. In urban geography, spatial statistics have been used mostly for population-related distributions, especially for the analysis of population distribution changes, the location of urban activities, and urban internal migration[8]. In this study, some spatial statistical parameters are proposed for analyzing changes in land use patterns.

(1) Spatial mean is obtained as an ordered pair that takes into account the position of the centroid of each region and the weight associated with the centroid[9]. Spatial mean, as noted, represents an average location, not an average of the characteristics of the phenomena found at the location. This measurement is useful for comparing several series on a temporal (changes in the same area over time) or inter-regional (by comparing two or more regions) basis[8]. On describing the spatial mean of an urbanized area of a certain region, the following formulations are proposed :

$$\overline{X}=\frac{\sum_{i=1}^{n} Au_i X_i}{\sum_{i=1}^{n} Au_i} \quad (1), \quad \text{and} \quad \overline{Y}=\frac{\sum_{i=1}^{n} Au_i Y_i}{\sum_{i=1}^{n} Au_i} \quad (2)$$

where $(X_i,\ Y_j)$ is the geographical position of the center (centroid) of village i, Au_i is the total urbanized area of desa i, and $(\overline{X}, \overline{Y})$ is the spatial mean of the urbanized area.

(2) The second parameter is the *dispersion index of the urbanized area*. The statistical standard deviation measurement has been used almost always together with the concentration measurements (median, mean, modes, etc.). These measurements can be used to describe the dispersion index from the center. In spatial geographical analyses, the dispersion index measures the average distances from all weighted points (centroids) to the center (spatial mean). In the case of suburbanization analyses, where the real center is located outside the suburb (in the center of the city), a modification of the classic formulation should be adopted. When the suburbanization process is assumed to expand in all directions with similar potential for growth, it is possible to adopt a common standard deviation equation using the real spatial mean in the center of the city. When the suburbanization expansion is thought to vary, as with changes in direction, a modification should be adopted.

Suburbanization in the study area is considered to have a relatively simple direction pattern. The general pattern of expansion grows continuously along the main road, which is relatively parallel to the X-axis direction (east-west direction). To accommodate this phenomenon, the following formulations are proposed :

$$S_X=\frac{\sum_{i=1}^{n} Au_i X_i^2}{\sum_{i=1}^{n} Au_i} \quad (3), \quad \text{and} \quad S_y=\frac{\sum_{i=1}^{n} Au_i (Y_i-\overline{Y})^2}{\sum_{i=1}^{n} Au_i} \quad (4)$$

where S_X and S_Y are the dispersion indices for the X-axis and the Y-axis directions, respectively. Dispersion along the X-axis is determined as the average quadrate distance from all weighted X-axis coordinates to the line of $X=0$, where the center of the city is located. Dispersion along the Y-axis is determined as the average weighted-quadrate-variation of all Y-axis coordinates to $\overline{Y}$. The higher the S_Y, the more disperse the urban area is from the spatial mean, while S_X describes how far the suburbanization expands from the center of the city. Small values for S_X and S_Y indicate a stronger agglomeration process than deglomeration process.

(3) The third parameter is the *spatial direction of suburbanization*. For conditions where only one direction of suburbanization is assumed, the direction is determined by a simple straight-line $y=a+bx$. The conventional least squares method cannot be used ; therefore, the best fit should be found by using a modification of the conventional least squares method, where weight is associated for each point of observation. To find the minimum value for F, the following formulation is proposed :

$$min\ F_i=\sum_{i=1}^{n} Au_i \{ Y_i-(a+bX_i)\}^2 \quad (5)$$

If two derivatives of equation (5) are set equal at 0, then

$$\frac{\partial F}{\partial a}=-2\sum_{i=1}^{n} Au_i (Y_i-a-bX_i)=0, \quad \text{or} \quad \sum_{i=1}^{n} Au_i (Y_i-a-bX_i)=0 \quad (6)$$

and $$\frac{\partial F}{\partial b}=-2\sum_{i=1}^{n}Au_iX_i(Y_i-a-bX_i)=0, \quad \text{or} \quad \sum_{i=1}^{n}Au_iX_i(Y_i-a-bX_i)=0 \tag{7}$$

By considering equations (1), (2), (6), and (7), a and b can be formulated as

$$a=\frac{\overline{Y}\sum Au_iX_i^2-\overline{X}\sum Au_iX_iY_i}{\sum Au_iX_i^2-\overline{X}\sum Au_iX_i} \quad (8), \quad \text{and} \quad b=\frac{\sum Au_iX_iY_i-\overline{Y}\sum AuX_i}{\sum Au_iX_i^2-\overline{X}\sum AuX_i} \tag{9}$$

The values of spatial parameters $\overline{X}$, $\overline{Y}$, S_X, S_Y, a, and b will vary and depend on the choice of axes, but the use of the standard geographical coordinates (UTM coordinates) for determining X and Y is considered to be more practical.

2. Suburbanization Model

The most famous achievement of "physics-social science analogies" has been the attempt to develop social physics by applying Newton's law of gravity to spatial interactions[7]. Stewart proposed replacing the physicist's "masses" with demographic masses[10]. Haynes and Fotheringham[7] indicated three basic modifications of the original formulation ; they are : (1) the exponent of distance b, (2) the exponent of mass variables α, λ, and (3) constant or parameter k. A basic modification of the gravity model is shown by equation (10), namely,

$$T_{12}=k\frac{P_1^{a}P_2^{\lambda}}{r_{12}^{b}} \tag{10}$$

The potential model is an opportunity index of the intensity of interactions between social and economic groups at different locations. It has been interpreted variously as[11] (1) a measure of the 'influence' of one place or group on another, (2) a generalized measure of concentration or density, (3) an index of the nearness of groups to a point, and, the most common definition, (4) an indicator of the geographical position or accessibility of groups in different places relative to each other.

In this study, the technical term urban land ratio is proposed for describing the proportion of urban land use in one area, mathematically formulated as Au/A or σ. Considering that the urban land ratio has an analogy and is non-linearly correlated with population potentials, Gong and Kitamura[12] described the urban land ratio for a case study in Nagahama City, Japan. They employed a model for analyzing the urban land ratios for four distinct years in Nagahama City. Despite the fact that time t was considered to be a variable in the formulation, they examined distance r in their study as the only independent variable ; and population P was constant.

The statistical test performance of the model in their study was considered low, and the highest regression coefficient of determination R^2 was only 55.1%. The application of their equation to the data sets in this study area is also considered very low (in the range of 5.9% to 65.8%). Possible reasons for this inability are : (1) Distance measurement r can be determined by many procedures. Due to their variety, road distances might be considered as several variables rather than a single variable, (2) Suburbanization is a complex phenomenon, therefore, a complex model is more appropriate than a bivariate model. Accordingly, more determinants should be included in the model, and (3) In a more complex formulation, a logarithmic transformation approach is not effective for parameter identification of the model, therefore, a non-linear optimization technique should be applied to solve the formulation.

For the above reasons, a new suburbanization model will be introduced in this study using new hypothetical interpretation and methodological approaches. In classical gravity and potential models, spatial interaction is the main concern of the models. The suburbanization model in this study deals with a model of the urban land ratio in the city's suburbs. The basic hypothesis is that urbanization growth rates in a city's suburbs (suburbanization) are affected by a push factor from the city core, pull factors from the attractiveness of the suburbs[13,14,15], and also by their accessibility to the city. Accordingly, the center's magnitudes (population, socio-economic activity size, etc.) are thought of as push factors of the urbanization process in the suburbs (suburbanization). The common theories of urbanization consider a city as a pull factor. In the case of a megacity such as Jakarta, however, where the city center has been saturated, the frontier of urbanization areas is not the city's center anymore, but the suburbs. The development of the city has become a push factor for the development of its suburbs.

To obtain an appropriate model from the methodological side, the first attempt is to find an appropriate distance measurement. Ideally, the proposed measurements of road distances should be consistent for any number of years, but empirically, road conditions do vary and change every year. For simplicity, the road types in the study area can be grouped into three classes, namely, local roads, main roads, and toll roads. Main roads, also called jalan negara in Indonesian, mean National Roads. They are constructed and financed by the central government, and they connect provincial capitals. The local roads, which are financed by local governments, are varied and connect the local towns. Toll roads are roads or highways on which a toll (a payment) is exacted. The condition of the main roads has been the most stable and homogeneous. Accordingly, it is possible to use these main roads as the standard measurement of road distances. In the study area, toll roads have gradually been extended since 1984. Currently, they have become the major access for long-distance transportation and are the chosen routes for daily travel. To accommodate the variation in distances, a standardized distance formulation is proposed, namely,

$$r_{it} = c_{1t} r_{1it} + r_{2it} + c_{3t} r_{3it} \tag{11}$$

where r_{it}, r_{1it}, r_{2it} and r_{it} are standardized, toll road, main road, and local road distances from desa i of year t, respectively, and c_1 and c_3 are coefficients for r_{1it} and r_{3it}, respectively. This new distance formulation was proposed on the assumption that road distances are standardized with a linear unit conversion for local and toll roads, denominated as c_{1t} and c_{3t}, respectively.

The second attempt is to propose some more determinants in the model. Since suburbanization is not homogenous, some regions outpaced others and became new hub local centers. These local centers with better facilities and conditions have become more attractive to people from Jakarta and other areas looking for housing. The new settlers, the majority of whom came from urban areas, would prefer easy accessibility to jobs or commercial centers such as markets, shopping malls, etc. Naturally, the preferable places are often agglomerated places in the new centers. Accordingly, the agglomerating factors should also be considered as an attraction or pull factor of the desa affecting its urban land ratio. Every desa in the suburb has the potential to become a center. Accordingly, a measurement of this potential (agglomeration index) is proposed.

Thus, the new model could be formulated by equation (12), namely,

$$\sigma_{it} = \frac{Au_{it}}{A_i} = G\frac{M_t^c \,.\, F_{it}^d}{(c_1 r_{1it} + r_{2it} + c_3 r_{3it})^b}, \quad \text{where } F_{it} = \frac{Au_{it} + \sum_{j=1}^{n_i} Au_{jt}}{A_i + \sum_{j=1}^{n_i} A_j} \text{ and } b_t > 0\,, \tag{12}$$

where σ_{it} is the urban land ratio of *desa* (village, see Section Ⅲ) i in year t, Au_{it} is the urban area of desa i in year t, A_i is the total area of desa i, F_{it} is an agglomeration index of desa i in year t, j is the desa which directly borders desa i, n_i is the total number of desas surrounding desa i, and A_j is the total area of desa j. The models formulated above still have unique parameters for each year. M_t is a mass variable describing Jakarta's magnitude of year t. Population, GDP, and GDP per capita of Jakarta City (P, D, and I) will be examined as push factors (M). Since Jakarta's mass is the only source of its push factor, statistically the impact of the push factor can be examined when using a time series data set. In the case of a single year's analysis, mass variable M_t is included in constant G ($k_m M^{c_m} = k_p P^{c_p} = k_D D^{c_D} = k_I I^{c_I}$, where k_m, k_P, k_D, and k_I are constants, and C_m, C_P, C_D, and C_I are exponents of M, P, D, and I). To examine the push factor parameter, a time series data set will be used.

In this non-linear formulation, a logarithmic-transformation approach cannot be utilized for parameter identification, therefore, a non-linear optimization technique is employed. In this study, *Quasi-Newton's* non-linear optimization method technique, which is well known as one of the most effective non-linear optimization techniques, is applied.

On formulating models, it is important to be able to measure the accuracy of the model, since inaccuracy suggests an incomplete understanding of the process. The most commonly used goodness-of-fit statistics for a model with normally distributed errors is the coefficient of determination, R^2 [16,17,18,19]. R^2 can be interpreted as the proportion of the variance of the dependent variables explained by the model. In this study, goodness-of-fit statistic R^2 is employed to measure the accuracy of the proposed model.

3. The sensitivity of the urban land ratio to distance

Based on the urbanization model, the urban land ratio decreases as the distance increases with a different level of sensitivity for every change in distance. This sensitivity can be measured by a derivation procedure. The derivation is useful for describing the impact of changes in distance or the improvement of the accessibility of land use conversion from non-urban use to urban use. Based on the results of equation (12), partial derivatives of σ with respect to standardized road distances are

$$\frac{\partial}{\partial r}\sigma = -bG\frac{M.F^{a}}{r^{b+1}} \tag{13}$$

where $(\partial/\partial r)\sigma$ is the sensitivity of the urban land ratio to standardized distance r.

Ⅲ. Data collection

Jabotabek is the acronym for JAkarta, BOgor, TAngerang, and BEKasi, where Bogor, Tangerang, and Bekasi administratively belong to the Province of West Java, located within the immediate vicinity of Jakarta (the hinterland of Jakarta)*). Jakarta has been associated with an urban spatial development pattern that fits a metropolitan city. Kenneth A. Watts formulated an Outline for Jakarta that anticipated the city becoming a metropolis[20]. Accordingly, the growth of Jakarta has always been integrated with that of its hinterland (Botabek).

As a result of the suburbanization process, regional administrative units (*desa*, *kecamatan*, and municipality or *kabupaten*) in the study area have changed considerably. Many desas or kecamatans have been divided into two or more desas or kecamatans. And some desas, in part or in full, have merged with surrounding desas. These changes were necessary to deal with the increasing population, which was especially evident in some new settlement areas. For comparing land use data during three different years, equal and comparable regional units must be analyzed. This study used the 1993 year administrative unit as the reference regional unit for the analysis. Land use data and other data from eight kecamatans in Kabupaten Bekasi for three years (1969/70, 1981/82, and 1993) was collected. The eight kecamatans were chosen due to data availability and to match the purpose of the analysis. These kecamatans are located along the main roads which connect Jakarta City with its eastern regions (Figure 1). These eight kecamatans consist of 100 desas, but due to the lack of data, only 88 desas were selected for this case study. As shown in Table 1, the land use category "*emplasment*" failed to be useful because of a lack of clear and consistent information about its definition. Some areas have very scattered urban land use, implicating like areas without urban activities on the maps. Scattered settlements, especially in upland areas (the southern part of the study area), contrast with areas dominated by rice fields where settlements tend to be clustered, making map delineation easy.

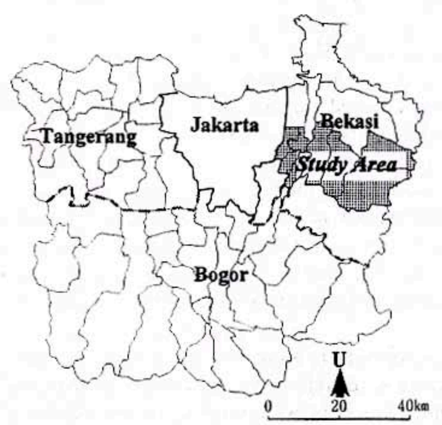

Figure 1 Location of study area

The land use types in the study area can be categorized into three major groups, namely, urban use, agricultural use, and others, as described in Table 1. The land use maps for the three years were produced by different agencies. The 1969/70 and the 1993 land use maps were produced by the National Land Agency (BPN), while the 1981/82 ones were created by the National Coordination Agency for Mapping and Surveys (*Bakosurtanal*). These two national agencies have different processes for land use

*) Indonesia is administratively divided into 27 provinces. A province is subdivided into several districts. There are three types of districts : *kabupaten* (regency), *kodya* (municipality), and *kota administratif* (administrative municipality). A district is subdivided into several *kecamatans* (subdistrict), and a kecamatan consists of several *desas* (villages)

classification systems and survey methods. The land use maps for 1969/70 are 1 : 50,000 scale maps and consist of fourteen land use categories. The 1981/82 land use maps are 1 : 25,000 scale maps with nine land use categories ; more correction and information were added. The 1993 land use maps are 1 : 25,000 scale maps and consist of nine land use categories.

Distance r is measured as the physical distance between each desa's centroid to the center of Jakarta City, the National Monument (*Monas*). A desa's centroid is the location of it's administrative offices. Generally, it is located in the most populous and urbanized section of the desa. The reasons for using Monas as Jakarta's center in this study are as follows : (a) In the first Jakarta Master Plan created in 1965, the Jakarta Development Strategy took Monas as the central point from where several urban development plans were designed within 15 kilometers ; (b) Based on an empirical survey determining the most frequently visited area by Botabek Commuters, from 12 identified main destinations, three main destinations were located near and around Monas ; and (c) The biggest station in Indonesia, *Stasiun Gambir,* is located in Monas.

Ⅳ. Results

1. Spatial land use pattern changes

Figure 2 shows briefly the distribution of the urbanized area for each year, indicating a moderate change between 1969/70 and 1981/82, and contrasts between 1981/82 and 1993. From the maps, it is clear that the fast-growing regions are concentrated in certain areas close to Jakarta City (western areas) and close to the main roads. Table 2 shows some parameters describing the land use pattern in the study area. In the intervening periods from 1969/70 to 1980/81 and 1980/81 to 1993, the position of the spatial mean of the urbanized area (Figure 3) moved toward Jakarta City and the dispersion index of the urbanization on the X-axis (east-west direction) $\overline{S_X}$ also became consistently smaller. These results show that, despite a suburbanization process in most of Jakarta's suburbs, the agglomeration process in the study area was stronger than the deglomeration process.

Considering the relative position of the spatial mean of the urbanized area to the main roads and toll roads, the results of the analysis show that suburbanization has been relatively concentrated

Table 1 Classification of land uses

Land Use Map	Land Use Group		
	Urban Uses	Agricultural Uses	Others
1969/70's map	1. *kampung* 2. cemetery	1. rice field 2. *tegalan* 3. shift cultivation (*ladang*) 4. estates 5. vegetables farm 6. mixed plantation 7. forest 8. pond	1. swamp 2. idle land 3. *alang-alang* 4. dike
	emplasment		
1981/82's map	1. housing 2. building	1. rice fields 2. tree crops/estates 3. forest 4. upland/food crops 5. fish ponds	1. water areas (swamp, lake, dike, reservoirs, etc.) 2. bush/shrub
1993's map	1. *kampung* 2. settlement/housing 3. cemetery, industry, storage	1. rice fields 2. mixed farm (*kebun campuran*) 3. upland/food crops	1. idle land 2. swamp

Note:

kampung: in Indonesian means village; it is broadly used in reference to any unregulated or popular settlement. In the BPN's land use classification it refers to urban uses, excluding developers-built new/modern type houses

ladang: upland crops; it refers to food crops land uses, such corn, vegetables, etc.

tegalan: upland permanent

kabun campuran: (cultivation mixed plantation), mixed traditional plantation, normally tree crops

alang-alang: specific homogeneous grasses growth on dry-non productive cultivated land

emplasment: there is no clear or consistent explanation on this land category, two desas with this land use category have been excluded in analysis. It is considered that the remaining data is sufficient and quite repersentative.

Table 2 Land use pattern parameters

		1996/1970	1980/1981	1993
Spatial mean of urbanized area	$\bar{X}$	15.4	13.8	13.0
	$\bar{Y}$	12.7	12.7	12.5
Dispersion index of suburbanization	S_X	329.5	269.8	243.5
	S_Y	14.3	11.5	13.9
direction of suburbanization		$y=9.5+0.203x$	$y=5.7+0.507x$	$y=12.6-0.007x$
spatial mean of main road		$y=14.3-0.146x$		
spatial mean of toll road		—	—	$y=14.4-0.433x$

note: x and y measured on km unit, the location of Monas (0,0) is located at 06° 10'30"S and 06° 49'32"E or 9317088mU and 702163mT.

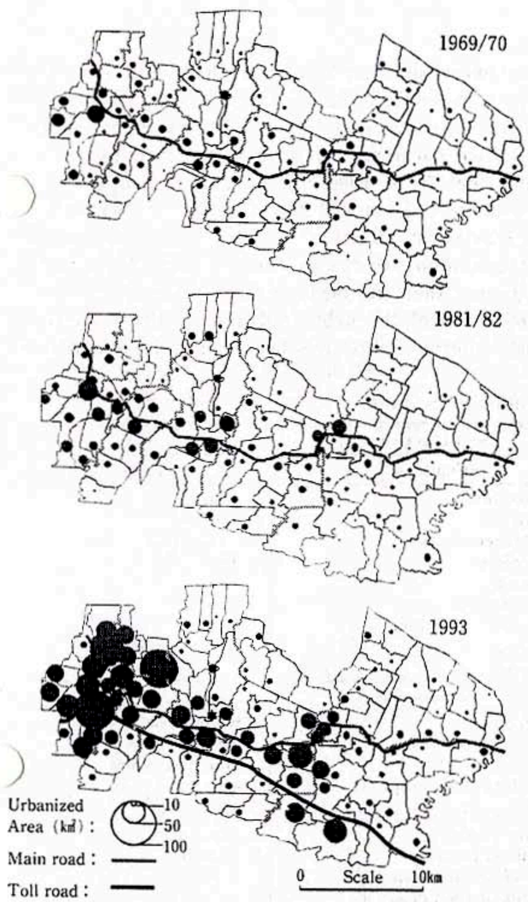

Figure 2 The location of desa's centroids weighted by urbanized area

along the main roads (Figure 3). The trend of the spatial means' movement during two periods (1969/70 to 1980/81 and 1980/81 to 1993), however, shows that movement was directed more toward the main roads in the first period, but the existence of toll roads pulled the suburbanization process toward the south, during the later period, bringing it closer to the toll roads.

The changing of the suburbanization direction could also be explained by $\overline{S_Y}$, the dispersion index on the Y-axis. Changes in $\overline{S_Y}$ are not significant and there was not a consistent trend. This indicates that there was no significant improvement in the local road conditions. The direction line shows more detail concerning the direction. The direction line of suburbanization has moved from the northeast toward the southeast. This analysis gives evidence that the existence of toll roads during the last period encouraged suburbanization in the southern areas.

2. Determining the most appropriate urban land ratio model

The urban land ratios of all desas in the study area are influenced by many factors. Figure 4 describes the spatial distributions of the urban land ratio. As shown in Figure 4, the urban land ratios of all the desas in the study area were low and almost homogeneous in 1969/70, but have become more heterogeneous since that time.

If equation (12) is employed for each year of study area data sets (M_i is constant), the most suitable equation is :

$$\sigma_{69/70}=70.61\ F^{0.458}(r_2+2.57\,r_3)^{-0.361} \quad R^2=99.6\%$$
$$\sigma_{81/82}=88.28\ F^{0.460}(r_2+2.29\,r_3)^{-0.360} \quad R^2=99.8\% \qquad (14)$$
$$\sigma_{93}=72.76\ F^{0.727}(0.054\,r_1+r_2+1.50\,r_3)^{-0.127} \quad R^2=74.8\%$$

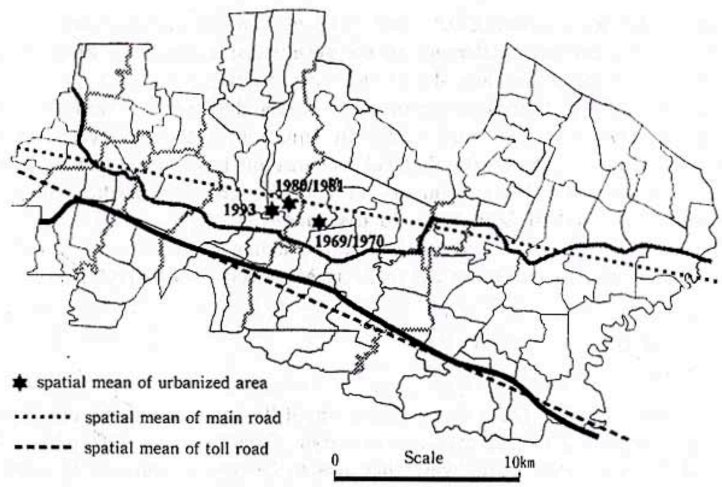

Figure 3 Spatial mean of urbanized area, main road and toll road.

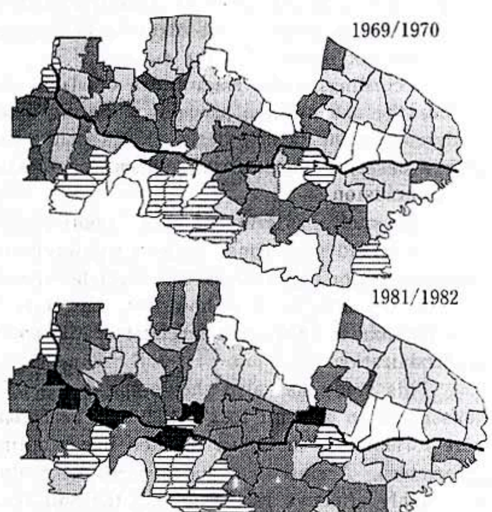

Figure 4 Spatial distribution of urban land ratio

The models for the first two years (1969/70 and 1981/82) were able to cover more than 99% of the total variation of σ. A modification of the distance formulation, the addition of variable F, and the application of the Quasi-Newton non-linear optimization technique have increased the statistical performance. Considering the results shown by equation (14), the coefficient of local road c_3 has consistently decreased over time, meaning that its contribution to standardized distance r has decreased. The exponent of standard distance b has also become smaller, meaning a decrease in the distance's contribution to the urban land ratio. On the other hand, the contribution of pull factor F_i has been become higher as its exponent d has increased. In each yearly data set's analysis, the push factor from Jakarta M has become constant, and its value is included in each constant (G_i) in the equations. Equation (15) shows the most suitable equations if three alternative mass factors for suburbanization (population, GDP, and GDP per capita) and the three years of data are used as one data set (time series data set). The results, respectively, are

$$\begin{aligned}
\sigma &= 0.354\ P^{0.335}\ F^{0.663}(0.139 r_1 + r_2 + 1.655 r_3)^{-0.1672} && R^2 = 83.7\% \\
\sigma &= 12.307\ D^{0.109}\ F^{0.662}(0.143 r_1 + r_2 + 1.659 r_3)^{-0.1669} && R^2 = 83.6\% \\
\sigma &= 68.041\ I^{0.160}\ F^{0.662}(0.144 r_1 + r_2 + 1.661 r_3)^{-0.1667} && R^2 = 83.6\%
\end{aligned} \tag{15}$$

where P, D, and I, are population, GDP, and GDP per capita (income per capita) of Jakarta, respectively. There is no significant difference in the results using the three kinds of mass variables, and the coefficients of determinations are almost the same (between 83.6-83.7%).

Normally, the R^2 of formulations using the time series data set is lower than that using each yearly data set of formulations. The 1993's best-fit equation is the only equation in which R^2 is lower than in equation (15). This indicates that suburbanization has tended to become a more complex process and it needs a more complex explanatory or complex model to predict the phenomena.

3. The sensitivity of the urban land ratio to distance

According to equation (15), the derivative of the urban land ratio with respect to standard distance r, or, using three alternatives to Jakarta's mass proxy, respectively, are:

$$\begin{aligned}(\partial/\partial r)\sigma &= -0.0592\ P^{0.35}\ F^{0.663}\ r^{-1.1672}\\ (\partial/\partial r)\sigma &= -2.0540\ D^{0.109}\ F^{0.662}\ r^{-1.1669}\\ (\partial/\partial r)\sigma &= -11.4039\ I^{0.160}\ F^{0.662}\ r^{-1.1667}\end{aligned} \tag{16}$$

As shown in equation (16), there is no significant difference among the other parameters using three kinds of mass variables, except for the constants. The equation (16) shows that the closer the desas are to Jakarta City, the more likely they are to become urbanized. In other words, closer desas are more prone to land use conversion from non-urban to urban uses, due to their easy accessibility to Jakarta City. Distribution of the sensitivity of the urban land ratio in 1993 was significantly different from the patterns of the previous two years, meaning that the sensitivity of the urban land ratio to the distance has become more complex due to some unexplainable factors which are not included in the model.

According to the magnitudes of Au/A and its derivations, it is clear that during the study period, the urbanization process in the city suburbs caused a wide gap to appear between the nearer desas and the farther desas. Rates in the urbanization process varied between the nearer and the farther desas, being fast and dynamic in the former, and slow and stagnant in the later.

V. Conclusion

This study has given us a new approach for describing land use pattern changes in city suburbs. The three land use change pattern measurements (spatial mean, dispersion, and spatial direction of suburbanization) quantitatively describe spatial changes in land use patterns. These quantitative analyses are able to show how fast, how far, and in which direction the changes have taken place. It is possible to apply this practical spatial analysis to other regions where it is necessary to evaluate suburbanization.

This study has also shown the model of suburbanization in one of Jakarta's suburban areas, Bekasi. In an attempt to get the best performance, many variables and measurement combinations were formulated, and then the non-linear optimization technique was applied to identify the model's parameters. A statistical goodness-of-fit evaluation showed that the model proposed in this study was highly effective for examining the suburbanization process in the study area during the period 1969/70-1993. Therefore, it is very useful for further studies on suburbanization and land use conversion. Considering statistical test performances, these results show that the model proposed for explaining the determinants' effects on urban land ratio will be higher when we consider this process more of a complex formulation than bivariate functions. It indicates that the suburbanization process in the study area has a wider dimension of determinant relations. As the suburbanization process has expanded, the urbanization phenomena have become more complex, and it seems that in turn more complex formulations will also be needed in the future studies.

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都市近郊の土地利用変化に関する実証的研究

—インドネシア西ジャワ州ブカシ地域を事例として—

エルナン　ルスチアディ，北村貞太郎

I　緒論

都市的土地利用の研究には，19世紀の農業立地論に始まり，より洗練された形の立地論や空間的相互作用モデルの展開が大きく貢献してきた。近年，様々な空間データが身近に利用できることとなり，その分析および新たなモデル提示が多くの研究者の主要な関心事になってきた。土地利用パターンの研究分野では，実際の土地利用データセットを用いて新たな空間統計学的手法を開発・改良し，従来の統計分析手法との基本的な相違およびその有用性について明らかにされつつある。

本研究は，インドネシア西ジャワ州ブカシ地域

key words : 1)都市近郊地域の都市化，2)都市的土地利用率，3)土地利用変化，4)都市近郊地域の都市化指標

を事例として，土地利用変化過程の分析およびモデル化に新しいアプローチを導くものである。まず，土地利用パターン変化分析のための新たな空間統計量を提示し，都市近郊における都市的土地利用分布について分析を行う。次いで，ポテンシャルモデル理論に基づく新たな土地利用モデルを展開し，都市的土地利用率変化の分析・推定について考察する。

Ⅱ　手法およびモデルの定式化

1　土地利用パターンの分析

以下の三つのパラメータにより，土地利用パターンの変化を分析する。

(1)空間的重心（$\bar{X}$, $\bar{Y}$）：ある地域の都市化区域の空間的重心を表し，本文(1)式および(2)式（以下，式については本文を参照のこと）で定義される。

(2)都市化区域の分散指数（S_x, S_y）：都市化が中心地からX軸方向（東西）およびY軸方向（南北）にどのくらいの広がりをもって進んでいるかを表す指数である。中心地の原点として，X方向についてはジャカルタ市中心（X＝0），Y方向については$\bar{Y}$を採用する。S_xとS_yが大きいほど，都市化の分散度が高く，集落が散らばっていることを表す((3), (4)式)。

(3)郊外への都市化進展の空間的方向性（a, b）：郊外都市化が1方向に進むと仮定し，集落面積による重み付き最小二乗法を用いて単純な直線$y=a+bx$で決定される。a, b値は(8), (9)式で与えられる。

以上の空間的パラメータ$\bar{X}$, $\bar{Y}$, S_x, S_y, aおよびb値は軸の取り方によって変化する。一般的にはX_iとY_iの座標として地理学的標準座標（UTM座標）を用いるのが実際的である。

2　都市化展開のモデル

一つの集落における都市的土地利用率をA_u/Aで定義し，σで表す。ここに，A_uは集落内の都市的土地利用面積，Aは集落面積である。

Gong・北村は，ポテンシャルモデルとのアナロジーから，都市的土地利用率が中心地のみについての人口ポテンシャルに比例するとした。この関係式を本対象地域に適用した結果，モデルの適合度を表す決定係数（R^2）は総じて小さく，このモデルのブカシ地域への適合性は低かった。そこで，モデルの改良を図り，都市的土地利用に関わる他の説明変数を取り上げてみた。本地域における都市化はジャカルタ市から均一に進んできているわけではなく，都市化の過程で本地域内部に新しく核となる地区ができ，こうした地区によりよい施設が整えられ，居住条件が改善されていった。その結果，このような新たな核となる地区が周辺地域に対して求心力をもつようになり，一つの中心地のみを吸収源として展開されたGong・北村による関係式には限界があったものと考えられる。したがって，中心地（ジャカルタ市）の人口ポテンシャルのみではなく，集落の全人口ポテンシャルをとればよいが，本調査地域では行政界の変更のため集落単位の人口データが利用できず，この方法をとることができなかった。

一般に，都市近郊における都市化成長率は都市中心部からの拡大力（放出性），郊外地域の魅力からの吸引力（吸収性），および都市へのアクセシビリティ（分離性）に影響されると考えられる。そこで，視点を転換し，ジャカルタ市中心から周辺地域へ向かう何らかの社会経済的力を想定し，これに比例して周辺地域の都市的土地利用率が定まると仮定する。そして，この力は一般化した重力モデルで表され，放出性には任意の社会経済的質量M（ジャカルタ市の人口，GDP，1人当たりGDPなど，表2参照）を，また吸収性には一つの集落とそれに隣接するすべての集落についての都市的土地利用率を採用する。

さらに，分離性の指標としての道路距離には，道路の種類（高速道路，幹線道路，支線道路）の相違を考慮して，(11)式によって基準化したものを用いる。

以上によって，最終的に都市的利用率σ_{it}を表すモデルが(12)式に示される。

なお，モデルパラメータの同定には準ニュートン法を使用し，決定係数（R^2）でモデルの精度を検討する。

3　都市的土地利用率に対する距離の感度

(12)式を距離で偏微分して得られる(13)式は，都市的土地利用率に対する距離の感度を表し，集落が

中心地から離れるに連れ都市的土地利用率にどの程度影響を与えるか，あるいは道路改良によって中心地との相対的距離が短縮された場合の効果などを知ることができる。

Ⅲ　対象地域とデータ

インドネシア共和国ブカシ県の8郡（kecamatan），88集落（desa）について，3時点（1969/70年，1980/81年，および1993年）の土地利用データとその他のデータを収集した。ブカシ地域はジャカルタ市と東部地域を結ぶ幹線道路沿いに位置している（図1）。近年，急激に都市化が進展している地域であり，無秩序な土地利用の展開が危惧されているところである。

対象地域の土地利用は都市的利用，農業的利用およびその他の三つに類型化した。3時点の土地利用図は異なる機関によって作成されたことから採用された土地利用種が異なっており，対象地域の土地利用種を表1のように再分類した。

距離（r）には，各集落の中心とジャカルタ市の中心間の物理的距離（直線距離と道路距離）を用いた。

Ⅳ　結果と考察

1　土地利用パターンの変化

都市化地域の空間的重心の幹線道路や高速道路との相対的位置を考えると，都市化が幹線道路沿いに進行していることが示された（表3，図2，3）。しかし，2期間（1969/70年～1980/81年および1980/81年～1993年）の空間的重心の移動傾向については，前者の期間は移動方向が幹線道路に向いていたが，後者の期間は高速道路の完成によって都市化進行が高速道路に引きずられて南側に移動した。

Y軸方向の分散指数はS_Yには大きな変化はないが，X軸方向の分散指数S_Xは前後半の期間とも減少している。このことは，都市化がブカシ地域一体に広がりながらも，ジャカルタ市寄り（西側）に都市の集積が進んでいることを示す。都市化の方向線は北東から南東へ移動しており，1980年代後半に完成した高速道路の影響が表れている。

2　都市的土地利用率のモデル

まず，年度毎に各集落の都市的土地利用率を表すモデルが⒁式のように決定された。各年度について導出されたモデルの決定係数（R^2）はいずれの場合も高く，統計学的有意性が確認された。

つぎに，すべての年度について統一的に都市的土地利用率を表すモデルとして⒂式が得られ，この場合についてもいずれも決定係数は高く，モデルの有用性が検証された。

3　道路距離に対する都市的土地利用率の感度

⒂式を距離で偏微分して得られる⒃式では，社会経済的質量（M）の取り方による差がないことが読みとれる。Mとして人口をとった感度分析の例を図6に示したが，各年度ともジャカルタ市に近いほど道路距離の感度が高くなり，都市化への影響が大きいことが分かる。一方で，1993年に対する結果は他の2年度と異なり，都市化の過程により複雑な要素が絡んできていることをうかがわせる。

Ⅴ　結論

本研究では，大都市郊外における土地利用転換の分析に新しいアプローチを試みた。提案した土地利用変化パターン分析の三つの測度は土地利用パターン変化の定量的記述に有用であることが実証された。このような定量的分析により，土地利用変化の速度，大きさ，方向について比較検討することが可能となる。

また，各集落の都市的土地利用率を表すモデルによって，ジャカルタ市周辺地域の都市化進行の過程をより詳細に分析することができた。道路距離が大都市周辺の都市化の主要な変数であることは明らかであるが，都市化が進行するに連れ都市化現象そのものが複雑化し，これを解明するモデルもますます洗練されたものが必要となると考えられる。

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