H-3.2 Analysis on Land-use Change at Lower Yangtze River Basin due to Industrialization and Urbanization

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Total Budget for FY 1998-FY2000: 5,289,000Yen (FY2000: 1,093,000Yen)

Abstract We have analyzed land-use change in the Lower Yangtze River Basin by means of remote sensing and GIS, and developed a model to estimate the amount and position of arable land to be converted into urban area in the basin with100-m grid resolution. We found that urban expansion was closely related to population growth in urban area. We assumed that the population growth could be dealt as diffusion process and have developed a two dimensional diffusion model for city expansion, assuming that the diffusion coefficient depends on geographical conditions and socio-economic factors of each county. Using the simulation result for a given total future population each county, we produced a 2-km grid map of arable land to be extinguishedand those of food production and consumption.

Key words: China, Lower Yangtze River Basin, Urban Expansion, Diffusion Model

1. Introduction

We are considering the following potential negative impact in rapid economic growth areas, such as the Lower Yangtze River Basin:

(1) Decrease in productive cropland areas due to industrialization and urbanization at coastal regions in China;
(2) Decrease in grain production in the biggest grain belt;
(3) Increase in demand for food due to population increase and adoption of western life styles;
(4) National polices of forest conservation and self–sufficiency infood supply; and
(5) Need to produce more crops in other areas, such as northern and northeastern China.

The amount of arable land to be newly cultivated in northern and northeastern China depends on the amount of decrease of food production in other areas, such as the Lower Yangtze River Basin, where much arable land has been converted into urban area. It is very important to estimate how much and which arable land will be converted into urban area in such areas owing to economic growth in the future.

2. Research Objectives

The research objectives of this study are to analyze land-use change in the Lower Yangtze River Basin by means of remote sensing and GIS, and to develop a model for projecting how much and which arable land will be extinguished in the basin in the future with 100-m grid resolution. Our targeting outputs are 2-km grid maps of food production and consumption and that of arable land to be extinguished

3. Research Method

As for modeling urban dynamics, a lot of related researches have been done. However, only a part of researches are application oriented (such as, Clarke *et. al*[1], Wu and Webster[2], Ward *et. al*[3], Li and Yeh[4]). Most of current urban growth models have been designed in a micro-view and applied locally. Those local models require developers to know the mechanism or behavior of land-use changes and need very detailed data. When we apply such models to a region, we may meet a lot of difficulties. Firstly, in most cases, we only know general category of the driving factors and cannot know concrete factors of land use changes there. Secondly, land use decision-making is a kind of human activity and the decision is made not only by determinative factors, but also with some stochastic features. It is very difficult to simulate such a dynamic and stochastic process. Thirdly, even if we knew the concrete factors, still, it is not easy to quantify them consistently. It would be more difficult to describe quantitatively the relationship between those factors and range of land use change.

1) Appearance of urban growth

If the development or growth of a city is projected on a two-dimensional space, the spatial extent of the city will usually increase. If we abstract the surface on the ground into two land types: urban land and non-urban land, we may find the changesbetween urban land and non-urban land are mostly in one way, namely from non-urban land to urban land. In a view of changes of city size, urban area grows in continuous form in space, which looks like a flow on a space. Carefully examining the expansion of urban area in the case study area, we have noticed that the urban growth is similar to a two-dimensional diffusion process in following aspects:

(1) flowing in single way: non-urban to urban,
(2) urban area becomes bigger and bigger,
(3) expansion happens on edges of urban land, and
(4) expansion characters continuity in terms of year.

Thus, abstractly viewing morphological changes of urban expansion,we can point out that there is an obvious analogy between urban expansion and flow process. Clearly urban expansion is based on a kind of diffusion that leads to cities growing at their edges (Batty, Longley 1994[5]). Accordingly, we posit that the process of urban expansion is similar to a diffusion process and urban expansion iscaused by the differences of density between urban area and non-urban area.

2) Basic Theory

A basic diffusion is described as:the rate of transfer of substance through unit length of a section is proportional to the density gradient measured normal to the section, i.e.

$$f_e = -\rho \times \partial m / \partial e \qquad (1)$$

where f_e is the rate of transfer per unit length of section, m is the density of diffusing "substance", e is the space coordinate measured normal to the section, and ρ is called the diffusion coefficient or parameter and its domain is [0,1]. This equation in a two-dimension space becomes

$$\partial m/\partial t = \partial/\partial x(\rho\times\partial m/\partial x)+ \partial/\partial y(\rho\times\partial m/\partial y) \qquad (2)$$

In practice, we often use an approximate numerical solution to calculate the amount of substance at a given place based on a discrete space grid system. Commonly, we chose square grids to be embedded in a plane and set the grid to be a unit area so that $\Delta x=\Delta y=1$. The numerical solution or diffusion formula is

$$m_{ij}(t+\Delta t)= m_{ij}(t)+\rho\times\Delta^2 m_{ij}(t) \qquad (3)$$

where i and j are the row and column number respectively at a given grid (i,j), $\Delta^2 m$ is double difference on the space.

In a diffusion equation, density m is the main element to describe a diffusion process. Therefore, population density is adopted as demographic data in such a diffusion model. In general, larger density occupies smaller space and density decline leads to occupy larger space. The degree of density decline can be associated to the extent of urban growth in some way. In addition, socio-economical factors also act as key exogenous forces to drive urban area to extend. It is the exogenous forces that lead to density decline so that urban area extends. If we limit population density only in urban area (means buildup areas), a region can be divided into two areas according to density value: buildup area Ω_1 and non-build-up area Ω_0 where density is 0. At the time t_0, the total population (sum of density) is $\sum_{\Omega_1(t_0)} m_{ij}(t_0)$; at time t_1 ($>t_0$), the total population will become $\sum_{\Omega_1(t_1)} m_{ij}(t_1)$. Urban area $\Omega_1(t_1)$ consists of two parts: the old urban area and newly increased area, namely $\Omega_1(t_1)= \Omega_1(t_0)\cup\Delta\Omega_1$ ($\Delta\Omega_1$--newly increased urban area)

$$\sum_{\Omega_1(t_1)} m_{ij}(t_1) = \tau \sum_{\Omega_1(t_0)} m_{ij}(t_0) + \sum_{\Delta\Omega_1} m_{ij}(t_1) \qquad (3)$$

In this way, parameter τ refers to the integrated influence of socio-economic factors--the exogenous force--on urban growth. Since transformation of land use is usually in single direction: non-urban land to urban land, the value of τ should be larger that 0.

4. Results and Discussions

1) Case study areas

The case study area is located in the southern part of Jiangsu province (China) by Yangtze River. Economy in Jiangsu province ranks to the top list among provincial economy in China. The area is characterized by three features, such as, high dense population, quick urbanization, and agricultural production base. The total area of the case study area is about 25000km^2 and 24 county-level spatial units. We examine urban growth in the period of 1990 to 1995.

2) Applicable model

Due to policy on population and constitutional system, development of cities in this case study area (actually in the mainland of China) was restricted before about 1980 and population density was comparatively high. After the policy of openig and reforming was put in practice, urban area increased greatly and people's living condition improved both in cities and the countryside. Population density in urban areas tended to decline. Therefore, urban growth from time t_0 can be simulated by the following series formulae based on formula (3).

$$m_{ij}(0) = \tau \times m_{ij}(t_0) \tag{4.1}$$

$$m_{ij}(t+1) = m_{ij}(t) + \gamma_{ij} \Delta^2 m_{ij}(t) \tag{4.2}$$

Equation (4.1) is actually to initialize the density in a simulation process and $m_{ij}(t_0)$ is supposed to be static population density at that time t_0. Parameter γ represents environmental impacts on the expansion; parameter τ represents the integrated influence of socio-economic factors on the expansion, and is determined by these factors.

3) Deriving the value of τ from land cover change

Since we have data (remotely sensed images) for land cover change between 1990 and 1995, we can simulate urban growth in each spatial units in 1995 from 1990 by finding a proper value for τ so that the simulated results are approximate to those in the actual growth in 1995. According to formula (3), change of values of τ is ordered, the binary searching strategy is adopted for finding the best value of τ for each unit (county).

τ represents an integrated influence of socio-economic factors on urban growth. There might be a lot of factors related to the values of τ. Since we have 24 spatial units, we analyzed variation of the values of those factors with τ. We finally found the patterns of variation of output value of township/village industry and that of average land resource are more correlated to the parameter τ than the others based on their diagrams. The relationship can be approximately described by the following function.

$$\tau' = 1-\tau = v(i,l) = k \times i \times l + c \quad \text{(k,c—constants).}$$

where i denotes the output values of township/village industry and l the average land area per person.

4) Calculation of diffusion coefficient γ

According to the features of the diffusion process, the diffusion coefficient ρ can be regarded as external influences on a flow on surfaces and represents a measure of friction to the flowing substance. Here γ is contributed by two factors: road and past expansion trend.

$$\gamma = w_d \times d + w_p \times p \tag{5}$$

where d is an index of road impact, p is an index of past expansion trend, w_d and w_p are weights correspondingly. If $\gamma=0$, this land cannot be turned to urban land (such as water bodies).

5) Simulating process

This is the main procedure for simulations. Value of population plays a key role in the recursive process in which once the initial state is set, the process will keep going until the aggregated people over a certain area is no less than a given population for the area (Fig -1).

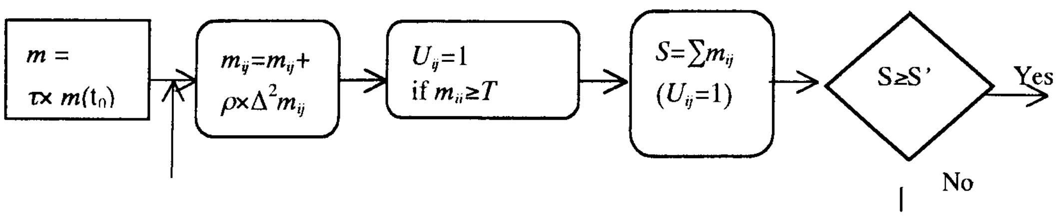

Fig. -1 Simulation procedure

In this diagram, U_{ij} represents state of pixels, 1 - urban, 0 - non-urban, T is the threshold value of population density for turning non-urban into urban, which is determined by minimal density in a unit (county or city). S' is the total population in a given year.

6) Simulation of future growth

Once we find the driving factors for urban growth, it would be natural to simulate urban growth based on those factors. We first estimate change trend of the factors, then use their values as input for simulation process and simulate growth by this process. Fig.-2 shows an example of simulation in 2020.

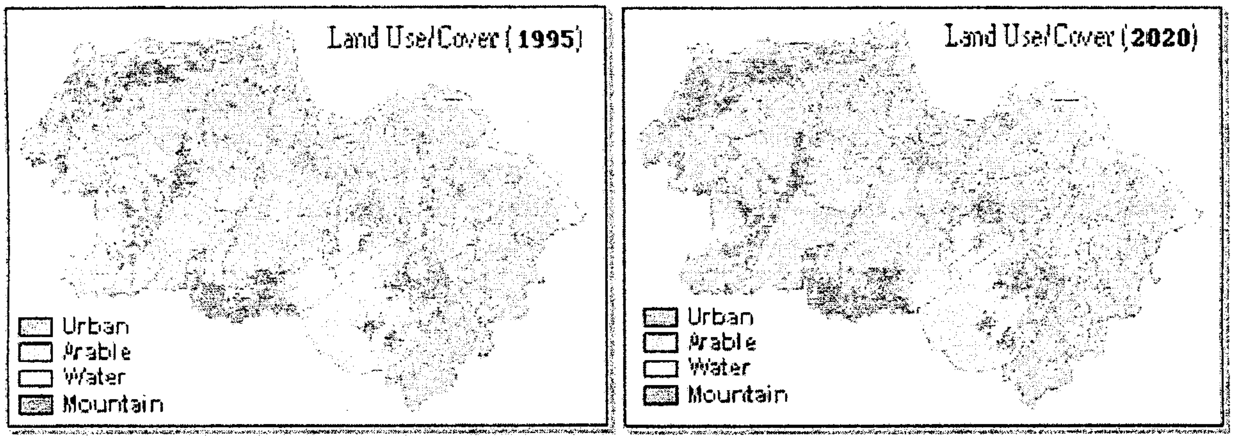

Fig.-2 Simulation results of future urban growth

5. Conclusion

Through the experiments and analyses, we found that driving factors for urban expansion in the southern part of Jiangsu province were population and township/village industry in that period. According to the results of the case study, it was also found that urban expansion could be evaluated by RS images with the help of GIS, and our diffusion-based model could be applied for urban growth on a regional scale with sketchy data on land cover changes rather than details of land uses.

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