H-3.2.1 Development of the land use/change dataset of China

Contact Person Jianxin Gong
Research Associate
National Institute for Environmental Study
Environment Agency of Japan
Onogawa 16-2, Tsukuba, Ibaraki, 305, JAPAN
Tel: +81-298-50-2417 Fax: +81-298-50-2576
E-mail: gongjian@nies.go.jp

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Abstract In this research, the author has developed a historical database on land use/cover change of change at various administrative units and introduced a simple model simulating year variations of fractions of five land use/cove categories; forest, agricultural land, grassland, urban and non-agricultural land, and others. This model is named GKSIM (Generalized Kane's Simulation Model) is introduced. First, we describe the background of the development of GKSIM. GKSIM has been developed to be applicable to developing countries where land use/cover data and related socio-economic data are very much limited in spatial and temporal resolutions. Secondly, we will induce GKSIM mathematically and will show the concept of influential matrices, and will discuss the advantages of GKSIM. GKSIM succeeds to the advantages of both regression models and system dynamics models. Finally, we will show an example of GKSIM application to China, in which the projection of year variations of five land use fractions in China up to 2050 is carried out.

Key Words: land use/cove change, projection, simulation model, GKSIM

1. Introduction

In 1996 we developed a model GKSIM for simulating land use change in long-term. The model satisfies the following four conditions that has been understood to be essential to models of this kind.

(1) Each predicted area of land use does not exceed its marginal value that is determined by natural conditions such as slope and weather, or by socio-economic factors such as population and GDP (Gross Domestic Products).

(2) The sum of all land use area coincides with the total area of the targeted region always.

(3) Statistical test can be carried out. This will ensure that the calibration result simulates well the trend of land use change in the past. Otherwise the projected result could not be reliable.

(4) The influence resulting from policy change on land use change can be reflected quantitatively.

GKSIM has the following main structure.

(1) $$x_{i,t} = 1 - q_i \left\{1 - x_{i,t}\right\}^{s_i w_{i,t}},$$

(2) $$w_{i,t} = \frac{1 + \sum_{j=1}^{n} \left\{ c_{ij,t} \right| + c_{ij,t} \}}{1 + \sum_{j=1}^{n} \left\{ c_{ij,t} \right| - c_{ij,t} \}}.$$

where,

$x_{i,t} \in [0,1]$: standardized land use area of ith category at time t, $i = 1,2,\cdots,n$. Here 0 and 1 are related to the maximum and minimum values that x_i is able to take, respectively.

n: number of all land use categories studied

$0 < q_i \le 1$, $s_i > 0$: parameters being determined statistically

$c_{ij,t} = Ia_{ij} Se_{ij,t} P_{ij,t}$, Ia_{ij} is the quantified interaction between x_i and x_j, $Se_{ij,t}$ and $P_{ij,t}$ are respectively quantified influences of socio-economic factors and concerned policies on Ia_{ij} at time t, $i, j = 1,2,\cdots,n$.

In order to have GKSIM be more applicable in practice and be stricter mathematically, we have modified GKSIM in some aspects. The modified GKSIM will be applied to project the land use change in long-term in China again. This time, however, the visions on cultivated area and forest changes made by Chinese government will be regarded as two given scenarios. Some discussion based on the results will be made then in this paper.

2. Structure of Modified GKSIM

The modified GKSIM has the following structure.

$$x_{i,t+1} = b_i - \Delta_i q_i \left(\frac{b_i - x_{i,t}}{\Delta_i} \right)^{s_i w_{i,t} d_t} \tag{3}$$

$$\sum_{i=1}^{n} x_{i,t+1} = A \tag{4}$$

$$w_{i,t} = \frac{v_i + \sum_{\substack{j=1 \\ j \neq i}}^{n} \{ | c_{ij,t} | + c_{ij,t} \}}{v_i + \sum_{\substack{j=1 \\ j \neq i}}^{n} \{ | c_{ij,t} | - c_{ij,t} \}} \tag{5}$$

Where,

n: number of the all categories studied

$x_{i,t}$: land use area of ith category at time t, $i = 1,2,\cdots,n$

b_i: maximum value of land use area of ith category

a_i: minimum value of land use area of ith category

$\Delta_i = b_i - a_i$

$0 < q_i \le 1$, $s_i > 0$: parameters determined statistically

A=*constant* : total area of studied region

$d_t > 0$: coefficient used to hold Eq.(4)

$c_{ij,t} = Ia_{ij} x_{j,t} Se_{ij,t}$, Ia_{ij} is the quantified interaction between x_i and x_j, $Se_{ij,t}$ is the quantified influences of driving forces on Ia_{ij} at time t, $i, j = 1,2,\cdots,n$.

$v_i > 0$: any positive real number mainly used to ensure Eq.(5) meaningful, usually being 1

Because $0 \le (b_i - x_{i,t})/\Delta_i \le 1$, $s_i w_{i,t} d_t > 0$ and $q_i \le 1$, we have $a_i \le x_{i,t+1} \le b_i$. In addition,

if rewriting Eq.(3) as

$$\ln\frac{b_i - x_{i,t+1}}{\Delta_i} = \ln q_i + (w_{i,t} d_t \ln\frac{b_i - x_{i,t}}{\Delta_i}) s_i \tag{6}$$

parameters q_i and s_i can be determined by means of method of least-squares, and the model can, therefore, be tested statistically. Thus the above-mentioned conditions (1) and (3) are still satisfied. Note when $0 < q_i \leq 1$, and $s_i > 0$ are not held, different v_i will be necessary. It is obvious that condition (2) is held by Eq.(2). The condition (4) will be held by the structure of $c_{ij,t} = Ia_{ij} x_{j,t} Se_{ij,t}$ discussed as follows.

Ia_{ij} is as same as the one in Eq.(1). $Se_{ij,t}$, being shown in Eq.(7), is mainly composed of two parts, $f_{ij}(p_{t-1}, p_t)$ and $g_{ij}(e_{t-1}, e_t)$, which show how the change of population and that of GDP influence current interaction, $Ia_{ij,t}$. Population and GDP are recognized as the two most important influential driving forces on land use change of all socio-economic factors in China. $h_{ij,t}$ is coefficient determined by experience. $h_{ij,t}$ may change as time passes*.

$$Se_{ij,t} = h_{ij,t} f_{ij}(p_{t-1}, p_t) g_{ij}(e_{t-1}, e_t) \quad i, j = 1, 2, \cdots, n \tag{7}$$

$$f_{ij}(p_{t-1}, p_t)_{(p_{t-1} < p_t, Ia_{ij} \geq 0)} = \begin{cases} 0, & i = j \\ \dfrac{p_{t-1}}{p_t}, & \textit{if the policy will be made to weaken the interaction, } Ia_{ij} \\ 1, & \textit{if the current interaction, } Ia_{ij}\textit{, is favorable} \\ \dfrac{p_t}{p_{t-1}}, & \textit{if the policy will be made to strngthen the interaction, } Ia_{ij} \end{cases} \quad i \neq j. \tag{8}$$

Where, p_{t-1}, p_t and e_{t-1}, e_t are population and GDP at time (t-1) and the next time t, respectively. Note when $p_{t-1} > p_t$ or $Ia_{ij} < 0$, $f_{ij}(p_{t-1}, p_t)$ can be determined in similar way as Eq.(8), so can be $g_{ij}(e_{t-1}, e_t)$.

3. Land Use Change in China

3.1 Result of Projection of Land Use Change

A master plan of land use in China (1985-2000) has been made by Chinese government. A long-term vision on land use in China by the end of 2020 and 2050 has been made, too. By the end of 2050, according to the vision, the ratio of forest area to total area of the country will get to 30%, and cultivated area of about 1,700 million mu (1mu=15ha) is necessary if all food for about 1,600 million population is self-supported. In this section, we regard the visions on forest and cultivated area as two given scenarios, and project the changes of grassland, non-agricultural land and other by means of modified GKSIM. The projected result of land use is shown in Fig.1.

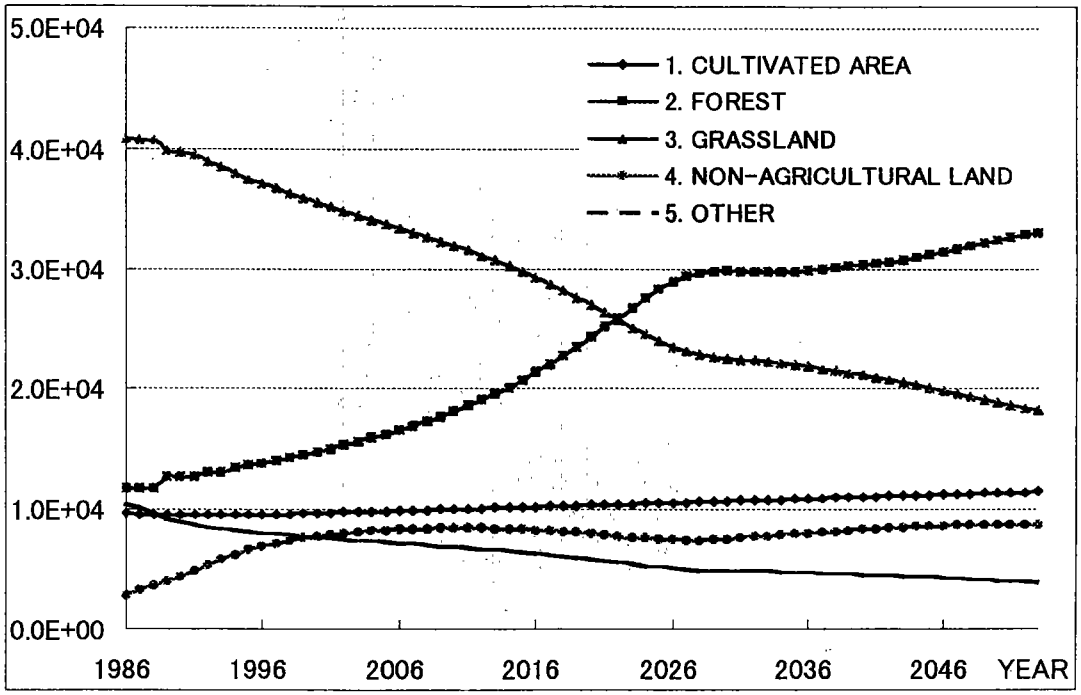
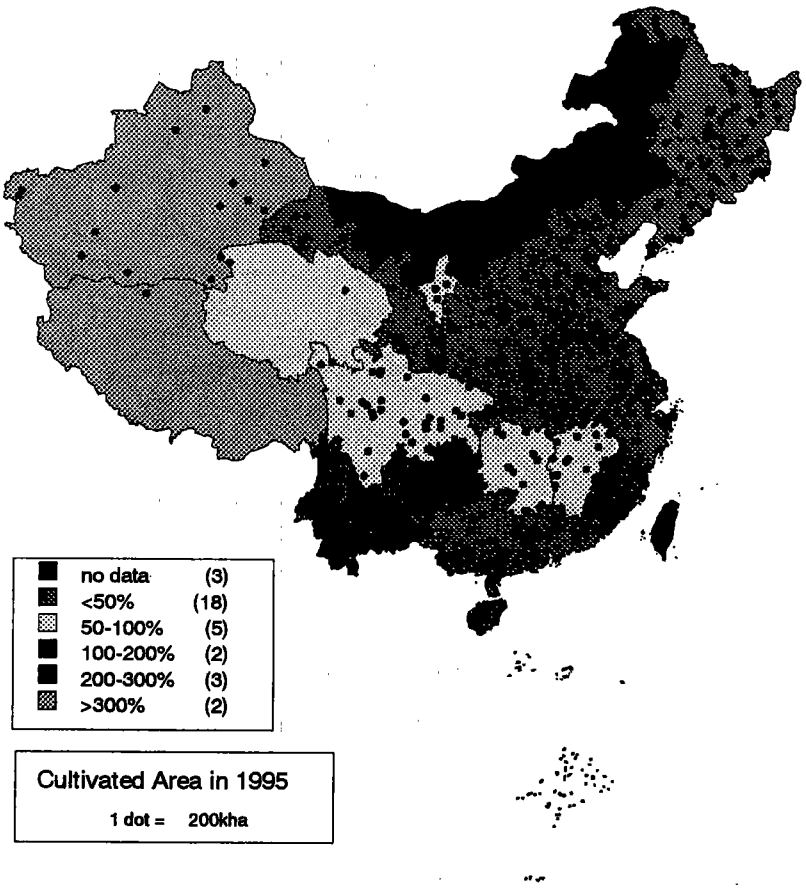


Fig.1 Land Use Change up to 2050 in China (unit: 10,000ha)

3.2 General Pattern of Land Use Change

Fig.1 shows that if the ratio of forest area increases to 30%, the area of grassland has to decrease much. This will be the general pattern of land use change up to 2050 in China. In China the wasteland suitable to be converted to cultivated area is limited as shown in Map 1, which shows the percentage of the wasteland to the cultivated area in 1995. The dots there represent the amount of cultivated area. A little increasing in cultivated area, therefore, will not change the above-mentioned general pattern of land use in China. So will not non-agricultural land.

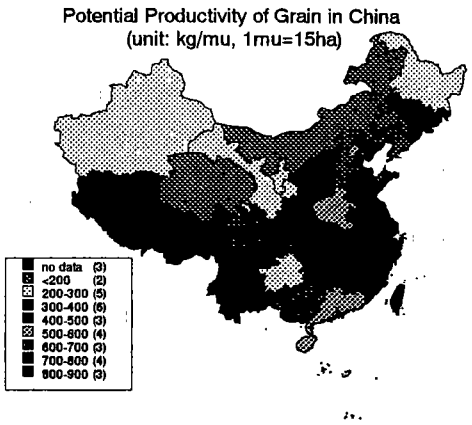


Map 1 Wasteland Percentage and cultivated area in 1995

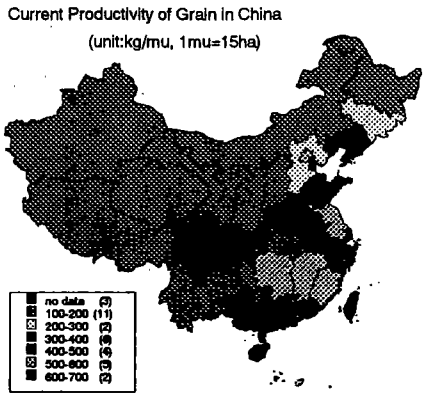
3.3 Problem of Grain Productivity

If cultivated area does not increase much, grain productivity has to be kept increasing to supply food to all people in China, whose population will reach 1600 million around 2050. Map 2 and Map 3 show the potential grain productivity and the current productivity (1996) for each province. It is obvious that there exists a big difference between them. The vision mentioned above was made under some ideal political, economic and natural conditions. The conditions in recent years matched those ideal ones. But it does not mean these conditions will continue till 2050. Map 4 shows the distribution of population and GDP in China in 1996. It shows that high grain productivity coincides with high GDP and high population density. Cultivated area there may be converted into urbanized area with high possibility.

There are two problems in China, therefore, in food supply in the future. One is how to maintain enough amount of cultivated area, especially the one with high quality. Another is how to increase grain productivity steadily, especially in the region where productivity is very low.



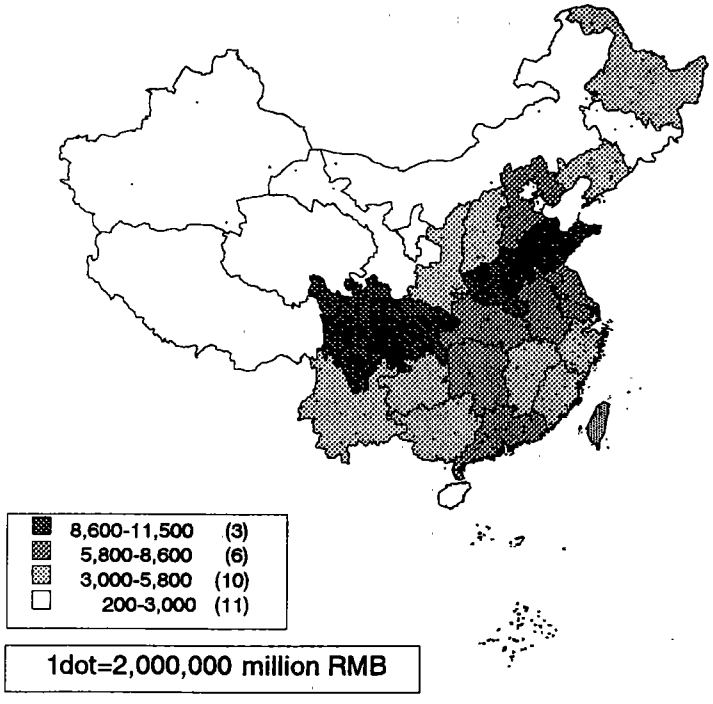
Map 2 Potential Grain Productivity



Map 3 Current Grain Productivity (1996)

3.4 Balance of Development among Regions

To solve the problems just being mentioned earlier, one way is to disperse development area properly among regions. As Fig.1 shows, along with the increasing of population and GDP, non-agricultural land will keep increasing. If west part of China is suitably developed, much population will stay there. The cultivated area with high quality in east part of China may then be maintained.



Map 4 Distribution of Population and GDP in 1996

4. Conclusion

The land use change simulation model GKSIM developed in 1996 has been modified to be more applicable and stricter. Modified GKSIM is then applied to China. We found that if the long-term vision made by Chinese government on forest area and food supplying came true by the end of 2050, land use change in long-term would appear as the following pattern. That is, forest will have a good increasing, while grassland will decrease a lot. Non-agricultural land will increase, and cultivated area may increase a little. However, there are two problems in China in food self-supply in the future. One is how to maintain enough amount of cultivated area. Another is how to increase grain productivity steadily. To solve these problems, one way is to disperse development area properly among regions.

Notation

*: Eq.(7) can also be written as

$$Se_{ij,t} = \{f_{ij}(p_{t-1}, p_t) g_{ij}(e_{t-1}, e_t)\}^{h_{ij,t}},$$

and $h_{ij,t}$ can, for example, take the following form.

$$h_{ij,t} = k1_{ij}[1 \pm \{\frac{t - t_0}{t_{d_{ij}} - t_0}\}^{k2_{ij}}],$$

where, t_0 is the initial time when concerned data is used. $k1_{ij} > 0$ is the initial value $h_{ij,t}$ gets at initial time, t_0, that is, $h_{ij,t} = k1_{ij}$ when $t = t_0$. $k2_{ij} > 0$ as well as the sign $\pm$ determine the way $h_{ij,t}$ changes after the initial time. If sign - is used, $h_{ij,t}$ becomes a monotonous decreasing function of t, and $t_{d_{ij}}$ is the time when interaction, Ia_{ij}, is considered to become zero, that is, when $t = t_{d_{ij}}$, $h_{ij,t} = 0$. If sign + is used, on the other hand, $h_{ij,t}$ becomes a monotonous increasing function of t, and $t_{d_{ij}}$ is the time when $h_{ij,t}$ is considered to become two times of its initial value, that is, when $t = t_{d_{ij}}$, $h_{ij,t} = 2k1_{ij}$. Note when $t_{d_{ij}} = \infty$, to any t, $h_{ij,t} \equiv 1$.

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