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Article *in* Journal of Geographical Sciences · July 2002

DOI: 10.1007/BF02837545

Journal of Geographical Sciences 12, 3 (2002) 275–282 ISSN: 1009–637X

The land use and land cover change database and its relative studies in China

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Abstract: In the mid-1990s, we established the national operative dynamic information serving systems on natural resources and environment. During building the land-use/land-cover change (LUCC) database for the mid-1990s, 520 scenes of remotely sensed images of Landsat Thematic Mapper (TM) were interpreted into land-use/land-cover categories at scale of 1:100,000 under overall digital software environment after being geo-referenced and ortho-rectified. The vector map of land-use/land-cover in China at the scale of 1:100,000 was recently converted into a 1-km raster database that captures all of the high-resolution land-use information by calculating area percentage for each kind of land use category within every cell. Being designed as an operative dynamic information serving system, monitoring the change in land-use/land-cover at national level was executed. We have completed the updating of LUCC database by comparing the TM data in the mid-1990s with new data sources received during 1999-2000 and 1989-1990. The LUCC database has supported greatly the national LUCC research program in China and some relative studies are incompletely reviewed in this paper.

Key words: land-use/land-cover change database

CLC number: F301.24; P208

1 Introduction

Recent development of spatial technology has introduced an improvement to the LUCC research program. Integrated spatial technologies including satellite technology, sensor technology and representing and retrieving technologies of temporo-spatial datasets have played an indispensable role in resources surveying, environmental monitoring and yield estimation (Liu, 1996). Study on the physical characteristics of earth's surface and modern process has entered the quantification stage with the whole data acquirement by the spatial technology. Existing site data and survey data can be transformed into coverage in ARC/INFO platform by certain interpolation methods. Then a spatial information system integrated by social, economic, environmental and land-use/land-cover change data can be built up to reconstruct the modern process to support the further quantificational research on the human-environment interaction process (Liu, 2000).

In addition, remote sensing and GIS technologies have been employed widely in China. A majority of scientific staff were trained and cultivated and the relative systematic theory and methodology are consequently developed. In the mid-1990s, we implemented a key project entitled "Remote Sensing Investigation and Dynamic Study on Resources and Environment in China", employing remote sensing technology characterized by macro-scale, rapidness and high accuracy. It proves that we have the capability and foundations to establish our national "operational land use and land cover dynamic monitoring system" based on remote sensing and GIS technology (Liu, 1996).

Land-use and land-cover change and the environment are always in dynamic process (Johnson *et al.*, 1998). Surveying on land-use and land-cover change across China and providing

Received date: 2002-03-10; **Accepted date:** 2002-06-10

Foundation item: The Knowledge Innovation Project of CAS, No.KZCX1-Y-02; No. KZCX02-308

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the dynamic information in certain period and updating the data in time are of importance for the government. The established LUCC database would meet the needs for continuous information to macro decision-making and management of relevant authorities.

Additionally, more and more people have realized the indisputable economic, social and cultural development in the past few years in China. Apart from that, both the local government and common people have a high expectation on sustainable development. In the past ten years, however, due to the excessive emphases placed on economic development, many environmental problems occurred.

In recent years, studies on global land-use and land-cover change have become the core research project for IGBP, HDP and WCRP. Its objective lies in carrying out the studies on global land-use and land-cover change to establish quantificational model of LUCC depending on the terrestrial surface tempo-spatial dataset, and to identify the biophysical and social driving forces for LUCC and then, employing dynamic theory, to predict scenarios development so as to provide a decision-making support for relevant authorities in charge of land-use management (Turner *et al.*, 1990; Turner II, 1994; Vitousek *et al.*, 1997; IGBP-IHDP, 1999).

2 Establishment of LUCC database of China

2.1 Existing data

Since the 1970s, the Chinese government and the Chinese Academy of Sciences (CAS) have organized many survey programs on land use, integrated survey of soil and other special topics across China and carried out series of researches on regional environmental situation. As a result, many LUCC and environment datasets have been accumulated. However, due to the difference in programs' objectives and the resultant shortage of a metadata standard, it is difficult to employ such kind of data to analyze the land-use and land-cover in China. A necessary procedure, herewith, was put forward to design a methodology to integrate the existing data based on GIS technology (Liu, 2001).

2.2 Objectives

The general objective to establish LUCC database of China is to promote the establishment of the State Operational Land-use and Land Cover Dynamic Monitoring Information System and improve its integrated serving function benefiting partly from its timely data updating based on remote sensing technologies (Liu *et al.*, 1998; Zhuang *et al.*, 2001). The main objectives cover the following aspects: 1) to obtain and provide the dynamic information for land use categories such as farmland and built-up areas each year; 2) to obtain and provide the basic information on resources and environment across China, especially on those of agricultural resources every five years; 3) to obtain and provide the dynamic information on LUCC and environment of some typical areas; 4) to investigate the relationship between the LUCC and the driving forces including both geophysical and socio-economic factors, and assess the process of LUCC affecting the potential agricultural environment and consequentially forecast the scenarios in the future; 5) to establish national decision-making support system on sustainable land-use management, environmental protection and sustainable agricultural development; 6) to establish state operational land-use and land-cover dynamic information serving system; 7) to provide the Internet service for national high-level decision making authorities and the departments concerned on assessment of the existing policies and measures, suggestions of improving the policies and measures for environmental emergency responses; and 8) to support the relative environment research in China.

2.3 Technical frame and implementation

Supported by some key projects of the state and CAS, we have established the LUCC databases during 1990-2000 at scale of 1:100,000 in China, which mainly cover three-phase datasets, i.e., LUCC datasets of 1990, 1995 and 2000 and other datasets for environmental change, social and economic conditions, etc.

During Landsat TM image interpretation, a man-machine interactive method was employed to guarantee the classification accuracy. The overall digital working flow (Figure 1) designed and experienced furthermore, decreased the accumulated errors and amounts of labors' work. Supported by the abundant data accumulation, we designed a technical frame (Figure 2) to organize the LUCC database to be established, which was implemented on the Client/Server structure, with Arc/Info as its kernel management kits. It was developed based on Arc/Info Macro Language (AML) and AVENUE (programming language and development environment of ArcView GIS).

Under the above-mentioned technical frame, all the data then have been integrated into a dynamic information system with a flexible interface, which can realize the synchronous management on image data and the vector data. User, including those who can just operate computer primarily, can use the dynamic information system efficiently.

In addition, the technical system we designed and employed makes the information extraction and data updating at real time much easier and more effectively, e.g. based on the open structural features, the remote sensing data during 1999-2000 (Figure 3) were integrated into the dynamic system with high efficiency.

3 Land cover classfication based on LUCC database

Over last two decades, numerous studies have used remotely sensed data from the Advanced Very High Resolution Radiometer (AVHRR) sensors to map land use and land cover at large spatial scales, but achieved only limited success. Supported by the dynamic information system on LUCC, we

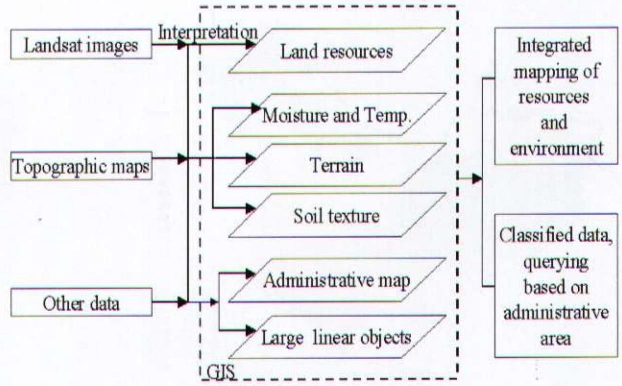

Figure 1 Overall digital working flow for interpreting remote sensing images

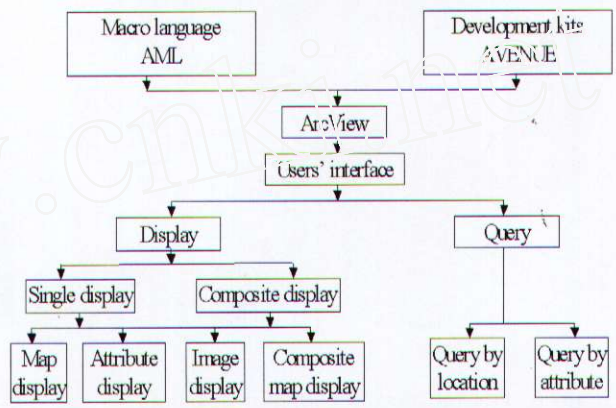

Figure 2 Technical frame to design dynamic information system on LUCC in China

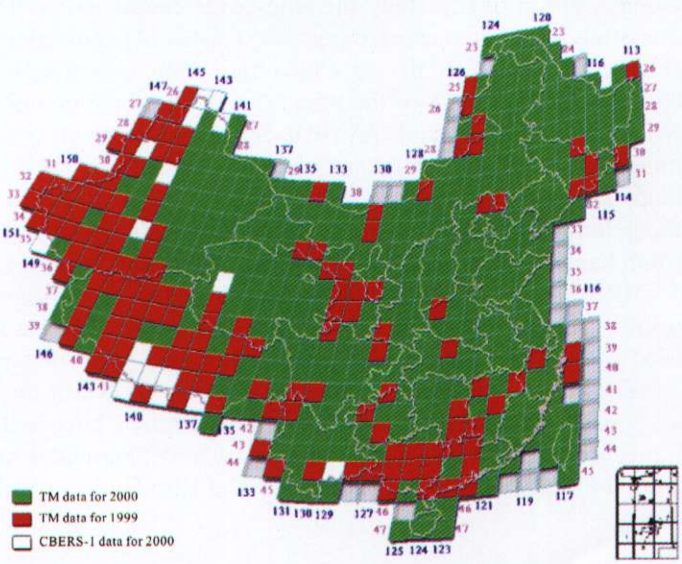

Figure 3 Data sources for updating the LUCC database in 1999-2000

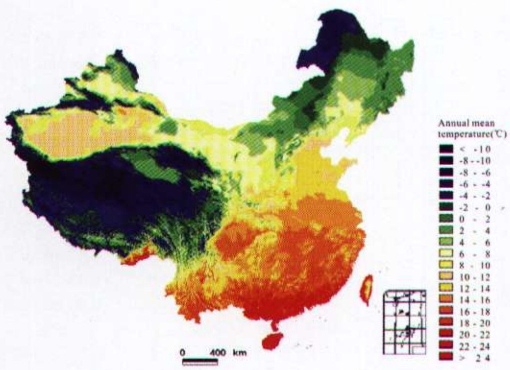

Figure 4 Annual mean temperature of China

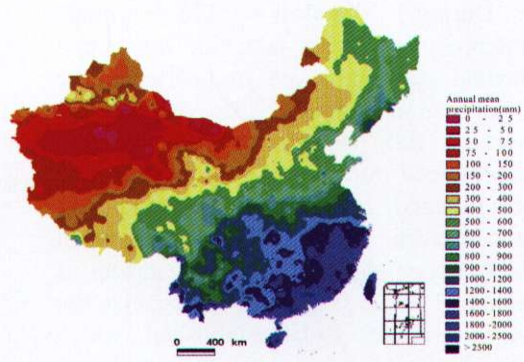

Figure 5 Annual mean precipitation of China

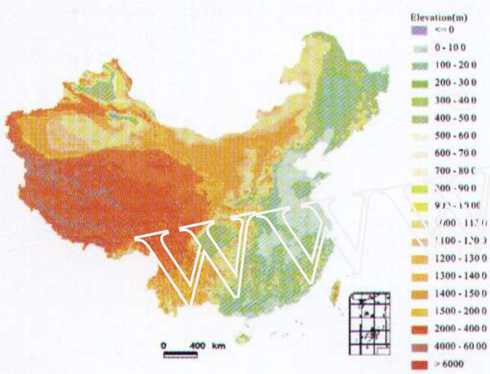

Figure 6 Digital elevation model of China

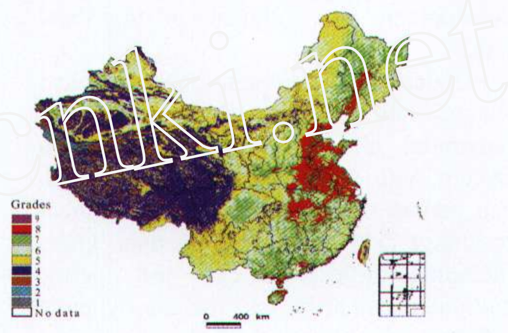

Figure 7 Grades distribution of physical environment on LUCC in China

employed an approach that combines both AVHRR images and geo-physical datasets (e.g., climate, elevation) to study the land-cover classification. Three geo-physical datasets are used in this study: annual mean temperature (Figure 4), annual precipitation (Figure 5), and elevation (Figure 6). We first divide China into nine bio-climatic regions, using the long-term mean climate data. For each of the nine regions, the three geo-physical data layers are stacked together with AVHRR data and AVHRR-derived vegetation index (normalized difference vegetation index) data, and the resultant multi-source datasets were then analyzed to generate land cover maps for individual regions, using supervised classification algorithms. The nine land-cover maps for individual regions were assembled together for China. The existing land cover dataset derived from Landsat TM images was used to assess the accuracy of the classification that is based on AVHRR and geophysical data. Accuracy of individual regions varies from 73% to 89%, with an overall accuracy of 81% for the whole country. The results showed that the methodology we used is, in general, feasible for large-scale land-cover mapping in China.

The basic vegetation distribution in China shown in the classification result could be summed as Forests in northeastern China, southeastern China and parts of Tibet region; Grassland in Inner Mongolia region, and Southwest China; Farmland in the eastern part of the country; and large areas of sparsely vegetated land and bare land in Northwest China (Table 1).

4 Study on land–use change

Supported by the dynamic information system on LUCC, the land-use change during 1996-2000 was implemented, as in some sense, an indispensable try for the feasibility of the methodology we designed. As we all know, supported by the 1 km grid global database, IGBP, IHDP and other international research organizations have implemented a series of researches including land cover dynamics, mechanism and global and regional models. We also think that the 1 km grid is a kind of effective data integration methods, which can promote the regional land-use change monitoring, predication and driving forces analyses. The methods to generate 1 km grid data are not so complicated as we have expected. Firstly, comparing the two-period land-use maps and drafting the changing patches of land-use, then intersecting the changing patches map and the former period land-use map at grid scale of 1 km and getting the changing areas and conversion areas in each 1 km grids, and then carrying out the statistical analyses and displaying the land-use dynamics based on a vector map with 1 km grid scale. The design of working flow insists on "zero-loss" of information. Due to ignorance of the thin objects existing in different land-use categories, the summary of land-use categories only can represent the remote sensing

Table 1 Description of land cover classification system for China from supervised classification of AVHRR and geo-physical datasets

Land Cover Types	Description	Area (km²)
Evergreen coniferous forest	Lands dominated by coniferous trees remain green all the year around.	379,258
Deciduous coniferous forest	Lands dominated by seasonal coniferous tree communities with an annual cycle of leaf-on and leaf-off periods.	128,864
Evergreen board-leaved forest	Lands dominated by broadleaved trees remain green all the year around.	145,254
Deciduous board-leaved forest	Lands dominated by seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.	232,845
Mixed forest	Lands dominated by trees communities with interspersed mixtures or mosaics of the four kinds of forest cover type above. None of the forest types exceeds 50%.	58,029
Shrub	Lands with woody vegetation less than 2 meters.	1,080,855
Dense grassland	Lands with herbaceous types. The canopy cover is over 60%	928,933
Moderate dense grassland	Lands with herbaceous types. The canopy cover is 20-60%	508,940
Sparse grassland	Lands with herbaceous types. The canopy cover is 5-20%	958,085
Farmland	Lands covered with temporary crops followed by harvest and a bare soil period (e.g. single and multiple cropping systems).	2,077,498
Wetland	Lands with a permanent mixture of water and herbaceous or woody vegetation that cover extensive areas.	56,809
City	Land covered by buildings and other man-made structures.	36,915
Water body	Oceans, seas, lakes, reservoirs, and rivers.	124,235
Ice and snow	Lands under snow and/or snow and never has more than 5% vegetated cover during a decade.	79,397
Harsh desert	Lands expose soil and stone and never have more than 5% vegetated cover.	1,232,057
Sandy desert	Lands expose sand and never have more than 5% vegetated cover.	548,045
Bare rock	Lands expose rock and never have more than 5% vegetated cover.	485,507
Forest in Tibet	Lands in Tibet were dominated by coniferous, broad-leaved and shrubby forests.	436,129

investigation areas, which, in some sense, can be named "gross areas". Figure 8 is the illustration of net change for each kind of land use category drawn based on the above-mentioned methods.

Main features of land-use and land-cover change during 1995-2000 can be generalized as follows: 1) newly expanded farmland, built-up areas, rural housing areas are evident while shrinking of natural forest is obvious at the same time; 2) newly increased 1,690,000 ha of farmland were mainly converted from natural land-cover types such as forest land and grassland; 3) paddy field increased more significantly than dry land; and the increased areas are mainly distributed in Northeast China; 4) the average of grassland density becomes lower influenced by the change of geophysical conditions as well as human activities, and some of them, especially sparse grassland, were converted into other kinds of land-use categories; 5) in relation to the forest land, natural forest decreased obviously with the increase of artificial forest; 6) change of water area is obvious, most of them have been converted into other categories of water bodies due to the annual and seasonal fluctuations of precipitation, together with and natural evolvement of riverbed, e.g., about 11.07% of shrunk lake was reclaimed into paddy field based on the interpretation information of Landsat TM images; 7) built-up areas expanded clearly, but most of the newly expanded built-up areas are converted from cropland, e.g., 18.46% of newly formed urban areas came from rural housing areas; and 8) unused land decreased slightly, among which, the noticeable wetland decrease and the increase of salinized land had important implication that physical environment had trended to deterioration in some areas (e.g. Northwest China).

5 Integrated analyses for environmental conditions on LUCC

Based on the LUCC database, we analyzed the areal differentiation of environmental conditions influencing LUCC. In order to comprehensively understand the relative factors affected regional environment, we established the hierarchical frame of index system to analyze comprehensively the impact of each factor on the regional environment. We struggled to learn about the integrated environmental conditions to analyze their periodic variation and understand the areal differentiation of environmental conditions and their main influencing factors so as to offer the decision-making support for the rational exploitation and protection of resources and environment and guarantee the regional sustainable development.

The integrated models can comprehensively analyze the whole situation and areal differentiation of multi-thematic environmental factors and indicate and identify their characteristics quantitatively. Three models have been used during the analyses: (1) GRID spatial analyses model, (2) Analytical Hierarchy Process (AHP) and (3) factor analysis models (Gao, 2000).

Based on the principle of AHP, we designed the index system of integrated physical environment and applied the GRID spatial models to implement the physical environment analyses, using the following models to calculate the integrated physical environment index.

$$I_p = \sum_{i=1}^{n} X_i W_i \quad (1)$$

where I_p is the integrated physical environment index, X_i is the index value, W is the relative weight of each index, i is the index numbers of a certain sub-hierarchy.

Based on the above formulae, we calculated the index values of climate (B_1), topography (B_2), soil (B_3), vegetation and land productivity (B_4). According to the four values, considered weights (W_1, W_2, W_3 and W_4) of the four index groups, we got the integrated physical environment index value (T_P):

$$T_P = B_1 * W_1 + B_2 * W_2 + B_3 * W_3 + B_4 * W_4 \quad (2)$$

On the basis of thematic analyses covering climate, topography, soil, vegetation and land productivity, we analyzed and assessed the physical environment of China using GRID spatial models, and obtained the grades system of physical environment on LUCC in China (Figure 7).

Areas of grades 8 and 9 own the best physical environmental conditions of China, mainly distributed in the Three River Plain, Huang-Huai-Hai River Plain, middle and lower reaches of Changjiang River plain, Zhujiang Delta, Changjiang Delta, etc. They belong to plains, alluvial fans or river deltas in topography, humid and sub-humid areas with abundant precipitation. They are part of subtropical and temperate zones and their temperature conditions can guarantee one or more harvests of crops in a year. Agricultural soil types are widely distributed there. Except the Three River Plain, where the accumulated temperature cannot meet the requirement of crops to grow, these areas own no restrict factors for agricultural development. They own the highest grades of land use in China with densely distributed population and developed industry and agriculture. Land use categories of agriculture and urbanization are predominant. The total areas occupy 6.81% of the whole territory of China.

Areas of grades 6 and 7 own a little worse (still own high quality) physical environmental conditions that those areas for grades 8 and 9, mainly distributed in the three provinces of Northeast China, Jiangnan hills, Shandong hills, Sichuan Basin, Hanzhong Basin and oases at the foot of Tianshan mountains. Their elevation ranges from 200 m to 1000 m. They belong to hills, basins, and low mountains in topography. Forestland and grassland soil types are predominant there. There are some restrictive factors (such as topographical features, moisture and accumulated temperature) affecting land use there. Agriculture, forestry and livestock husbandry dominates there. Their areas account for 35.61% of the total land resources of China with higher population density.

Areas of grade 5 lie in the Second Step of Topography in China with comparatively poor physical environmental conditions. They belong to plateaus and mid-high mountains with elevations ranging from 1,000 m to 2,000 m. Land use categories of forest and grassland are predominant there. The topographical, moisture and accumulated temperature conditions have somewhat impeded the exploitation of land resources. It is difficult for human beings to live there, so the population density is very low. Land use categories of forestland, grassland, as well as unused land dominate there. Areas of grade 5 occupy 26.8% of the whole territory of China.

Areas with below 5 grades mainly lie in the First Step of Topography of China with worse physical environmental conditions than those of grade 5. Their average elevation is above 2,000 m. They belong to plateau, basin and high mountains in topography. Mountainous soil and desert are distributed widely. Most of land resources are underdeveloped, so there exists the lowest land use grades of China there. Their areas occupy 30.78% of the whole territory of China.

6 Conclusions

Supported by the abundant data accumulation, we established the LUCC database of China as well as the updating mechanism of the database. A series of studies have been implemented based on the LUCC database. That is, the LUCC database has not only supported the national LUCC research program in China but also exerted great impact on the relative environmental studies in China. Furthermore, on the basis of the LUCC database, a temporal and spatial database will be established to support the earth science researches of China. The project of creating national resources and environment database and data sharing mechanism, a knowledge-innovation project of CAS, will integrate the accumulated data covering physical field of terrestrial surface environment with regional social and economic data and set up a data center involved in the terrestrial temporal and spatial process database, human and nature relationship database and its corresponding spatial database of social and economic fields. The implementation of the project will not only meet the information requirement of national decision-making in exploitation of land resources and construction of ecological environment but also support the development of Earth systematic sciences and Earth spatial information sciences as well as the knowledge-innovation of CAS.

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