Study on spatial pattern of land-use change in China during 1995—2000

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Abstract It is more and more acknowledged that land-use/cover dynamic change has become a key subject urgently to be dealt with in the study of global environmental change. Supported by the Landsat TM digital images, spatial patterns and temporal variation of land-use change during 1995—2000 are studied in the paper. According to the land-use dynamic degree model, supported by the 1km GRID data of land-use change and the comprehensive characters of physical, economic and social features, a dynamic regionalization of land-use change is designed to disclose the spatial pattern of land-use change processes. Generally speaking, in the traditional agricultural zones, e.g., Huang-Huai-Hai Plains, Yangtze River Delta and Sichuan Basin, the built-up and residential areas occupy a great proportion of arable land, and in the interlock area of farming and pasturing of northern China and the oases agricultural zones, the reclamation of arable land is conspicuously driven by changes of production conditions, economic benefits and climatic conditions. The implementation of "returning arable land into woodland or grassland" policies has won initial success in some areas, but it is too early to say that the trend of deforestation has been effectively reversed across China. In this paper, the division of dynamic regionalization of land-use change is designed, for the sake of revealing the temporal and spatial features of land-use change and laying the foundation for the study of regional scale land-use changes. Moreover, an integrated study, including studies of spatial pattern and temporal process of land-use change, is carried out in this paper, which is an interesting try on the comparative studies of spatial pattern on change process and the change process of spatial pattern of land-use change.

Keywords: land-use change, China, spatial pattern, regionalization.

Land-use/cover change has become an event being of paramount importance to the study of global environmental change[1,2]. Land-cover change is closely related to the terrestrial surface material cycles and life-support processes[3], i.e., the interaction between biosphere and atmosphere, biodiversity, biogeochemical cycle and sustainable exploitation of resources[4,5]. The series of scientific study programs, issued and promoted by IGBP and IHDP in 1995, make the study of land-use and land-cover change (LUCC)[6] become one of the hot topics in the global environmental change study.

Case study at regional scale, especially the comparison study on the process of land-use change, the pattern of land-use change and land-use dynamics, became the key components in

LUCC study[7] for the first time, and a series of regional studies on LUCC have been conducted in China[8]. As a developing but booming country, China has formulated a series of policies exerting great influence on the land-use change. In addition, due to varied physical environments and vast land areas, its land-use changes not only influence the social and economic development but also impact the global change accordingly. In order to simulate the modern process of land-use change, and more accurately predict its trend, the Chinese Academy of Sciences (CAS) has planned to build a temporal and spatial data platform supported by the National Resources and Environment Database (NRED), with remote sensing data as its main data sources[9–11] while laying the emphases on the study of the land-use change in the 1990s.

It is essentially fundamental to study the regional differentiation of land-use dynamics for the regional land-use monitoring, driving forces analyses and the prediction of land-use change. In the study, the 1km GRID data of land-use change, reflecting area proportion for each kind of land-use category and its net change were generated to eliminate the scale effect of different data sources during data fusion and guarantee the data accuracy[12].

1 Data sources and handling

There are two kinds of methods to extract land-use change information from remote sensing data[13], (i) by comparison of classified data at two periods, i.e. classifying based on the radiation data at first and then comparing the classification maps to get the dynamic information, and (ii) information extracted directly by temporal variation characteristics of surface radiation. The former needs much more accurate classification standards, higher data accuracy and more labour efforts, whereas the latter has the rigorous requirement for the selections of remote sensing data sources and accurate data handling.

In the process of building the National Resources and Environments Database, an efficient classification system is drafted and an effective research team is organized to work on remote sensed data through human-machine interactive interpretation to guarantee classification consistency and accuracy. Land-use maps at scale of 1∶100000, classified into 6 first levels and 25 second levels of land-use categories in total, are drawn based on the Landsat TM (Thematic Mapper) data. The outline of land-use change is delimited by comparison of TM data in 1995 and 2000, with the references from land-use background in 1995. The work flow of this integration is displayed in fig. 1.

The main data sources are Landsat TM digital images(520 scenes in 1995/1996 and 508 scenes in 1999/2000).Apart from that,the CBERS-1(China-Brazil Earth Resources Satellite 1)data were also used to acquire land-use information for 1999/2000.After image being geometrically corrected and geo-referenced, the average location errors are less than 50 m (about 2 pixels). The out-door survey and random sample check (covering line survey of 70000 km and 13300 patches) testified that the average interpretation accuracy for land-use/land-cover is 92.9% and 97.6%for land-use change interpretation.The maps for linear features and ecological and environmental

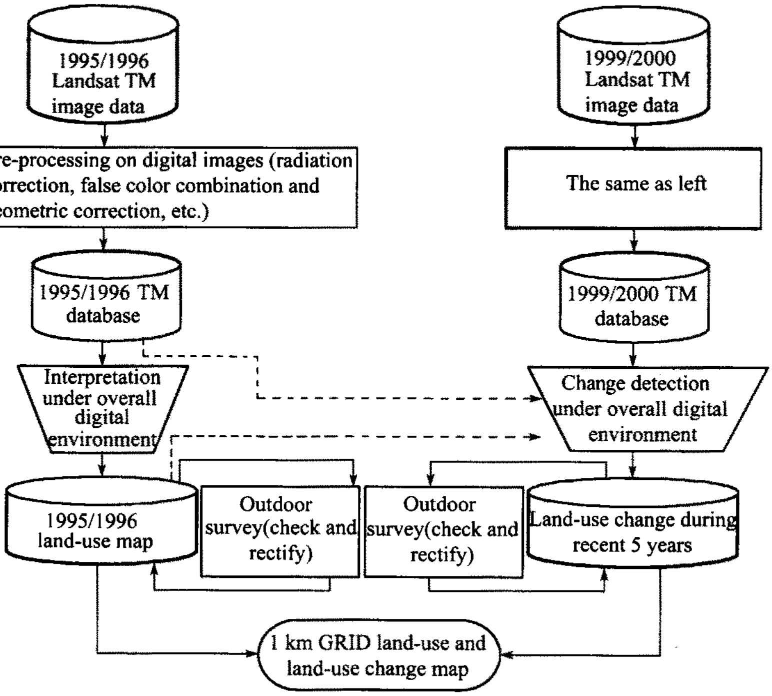

Fig. 1. Work flow of land-use change monitoring work.

factors in our NRED are used during the driving forces analyses.

As we all know, supported by the 1km GRID global database, IGBP, IHDP and other international research organizations have done a series of researches including land-cover dynamics, mechanism and global and regional models[6]. We also think that the 1km GRID data are an efficient kind of data fusion methods, which can promote the regional land-use change monitoring, prediction and driving forces studies[1)]. On one hand, it is more effective and efficient to handle GRID data than vector data, which facilitates the data integration and fusion for multi-source data, on the other hand, its data accuracy partly determined by its data structure meets the need for studies on LUCC at regional or national scales while the well-known application of 0.5° of latitude ×0.5° of longitude cells to global research is too coarse to extract the phenomena for national and local domain. Generation of the 1 km GRID percentage data is processed in ESRI Arc/Info 8.02 software environments and could be described as follows: firstly, combining the land-use change patches (178 173 in total) with one coverage; secondly, intersecting the changing patches map with 1km vector data; thirdly, under TABLE model, taking statistical process on each kind of land-use change area grouped by 1km vector cell ID (fig. 2); lastly, changing the vector data into grid format data with area percentage information of all land-use change types in which

1) Tang Xianming, Studies on geo-spatial data fusion and its applications, Ph. D Thesis, Institute of Remote Sensing Applications, CAS, Beijing, 2000.

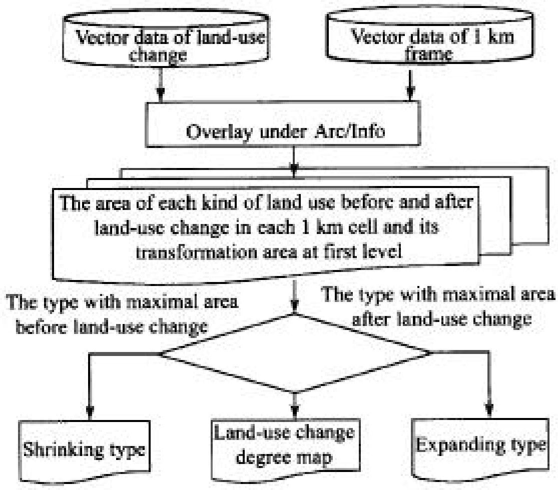

Fig. 2. Workflow of constructing 1km GRID land-use change map.

we are interested. The 1km GRID data have been further aggregated to 10 km GRID data frame to realize the dynamic regionalization of land-use change. The design of working flow insists on "zero-loss" of area information. Without special notification, the statistical farmland area according to the GRID data is survey area by satellite remote sensed data, which can be called "gross area".

Census data (1995, at county level) for dynamic regionalization of land-use change have been spatialized based on the distribution features of built-up areas1), while the data of railway and road (length) are derived from the line feature map at scale of 100000.

2 Characteristics and measures on land-use change

The regional differentiation of land-use change rate can be represented by the dynamic degree model of land use[9], i.e.

$$S=\left\{\sum_{ij}^{n}(\Delta S_{i-j}/S_i)\right\}\times(1/t)\times W_i\times 100\%,\quad n=1, 2, 3, \cdots, \tag{1}$$

where S is the land-use change rate, S_i represents the total areas of i (land-use category) at the former stage while W_i is the weight of areas proportion of i, and ΔS_{i-j} represents the net change of area from i to j (land-use category) at the time scale of t. This model can also be used to measure the dynamic degree for a single land-usce category.

The basic unit to employ the dynamic degree model is 1km GRID, and the statistical result serves as basis to draw the land-use change and land-use conversion maps classified by land-use categories.

The code system of land-use change patches, theoretically, includes 600 kinds determined by land-use change types at the second level (25×24). On the basis of the land-use change patches of 1995/1996 and 1999/2000 at the GRID scale of 10 km, together with the working flow of fig. 2, the distribution maps for expanding and shrinking types of land-use change are generated based on maximal change type in each cell according to area summary (Plate I). In order to lay the emphases on the analyses of the main conversion direction, a main transform matrix for land use is

1) Zhuang Dafang, Research on spatial information of remote sensing and GIS on land-use/land-cover change, Ph. D Thesis, Institute of Remote Sensing Applications, Chinese Academy of Sciences, Beijing, 2001

generalized, which includes 9 kinds (C1 to C9) (table 1). C1 (cropland-cropland) refers to the conversion between paddy field and dry land; C2 is the result from returning arable land into woodland or grassland; C3 represents water body expansion (including river, lake, reservoir, glacier, seabeach and bottomland.); C4 refers to the other land-use categories being converted into built-up areas; C5 is the result from deforestation and reclamation; C6 discloses forests being destroyed into grassland; C7 is grassland or unused land being reclaimed; C8 mainly refers to the afforestation in grassland or unused land; and C9 represents the conversion from water body to other kinds of land use (except built-up area). The transition type is determined by the conversion direction with the maximal conversion rate for each GRID (at the GRID scale of 10 km), but to evaluate certain land-use conversion area for those GRIDS with "no change" under the conditions, their maximal conversion rate has to be less than 0.05%, then the land-use dynamic map was generated (plate II).

Table 1 Classification and coding system for land-use conversion[a)]

Forward \ Backward	AL	WL	GL and UL	WB	BuA
AL	C1	C2			
WL	C5	–	C6	C3	C4
GL and UL	C7	C8	–		
WB		C9		–	

a) AL, WL, GL, UL, WB and BuA represent arable land, woodland, grassland, unused land, water body and built-up areas respectively.

According to the spatial pattern of land-use change, a dynamic regionalization of land-use change was designed, supported by the 10 km GRID data, so as to disclose the regional differentiation during 1995—2000. Referencing to physical regionalization[14] and agricultural division [15] and comprehensively considering the man-environments related factors, the main principle for dynamic regionalization of land-use change is designed: (i) taking the land-use change type within each cell as primary considered factor to determine the zone and guarantee the consistency of main land-use change type in each zone as a whole; (ii) differentiating the land-use change zones with the same change type at different regions by the name of geographical units when considering the principle of zonation continuity in geographical location. This principle is to ensure the consistency of regional geomorphology and macro economic environments; and (iii) comprehensively considering the physical environments and land-use characteristics to try to make them consistent in each zone. The spatial generalization and experience always lay the foundation for carrying out the dynamic regionalization of land-use change. Using the land-use change map at scale of 10 km (Plates I and II), the geomorphological map, land-use background map for 1995/1996 and climatic resources map as references, the outline of land-use dynamic regionalization, free from the limitation of administrative boundaries, is drafted under the overall digital environments. Then a land-use dynamic regionalization of land-use change, including 12 zones, is completed and their names, titles, main land-use features, land-use change characteristics and population distribution are shown in table 2.

Table 2 Zones of land-use change and population distribution in China

Code	Name	Land-use features	Features of land-use change	Population (million)
1	Northeast Da and Xiao Hinggan Mts—— woodland/ grassland to arable land conversion zone	woodland (70%)[a)] and grassland (14%) as main land-use types; dry land (10%) dominating the arable land	large area of woodland and grassland converted into farmland, totaling 260 khm^2	6
2	eastern part of Northeast China —— woodland/ grassland to arable land conversion zone	woodland (67%) and arable land (23%) as the main land-use categories, dry land dominating the arable land	the same as zone 1, woodland and grassland converted to arable land totaling 400 khm^2	18
3	Northeast China Plain ——dry land and paddy field bi-directional conversion zone	arable land (63%) densely distributed and woodland occupying 20% of land area. Relatively most of arable land in northeast of China distributes in this zone.	bi-directional conversion of dry land and paddy field totals 75 million ha, dry land decreasing by 450 khm^2 while paddy field increasing by 580 khm^2	41
4	Huang-Huai-Hai Plain, Yangtze River Delta —— arable land to built-up areas conversion zone	important agricultural area, 31% of national arable land and 51% of the built-up area distribute here. In this zone 9% of land is covered by town and other built-up areas.	The expansion of built-up areas is conspicuous. The arable land is decreased by 238 khm^2 while the increase of built-up areas totals 268 khm^2	460
5	Sichuan Basin—— arable land to built-up areas conversion zone	arable land (80%) densely distributed, among which 40% is covered by paddy field and 60% by dry land.	The same as zone 4, the expansion of built-up areas company is mainly due to encroachment of the arable land.	79
6	North China Plain and Loess Plateau—— grassland to arable land conversion zone	typical interlock area of farming and pasturing. In this zone, arable land (33%) and grasslands (42%) are densely distributed. It is the second largest arable land area in China.	Arable land reclamation and abandonment coexist, grassland converted to arable land totals 760 khm^2, arable land returned into forest land or grassland totals 440 khm^2, and net increase of arable land totals 437 khm^2.	74
7	northwest China —— reclamation and abandonment of arable lands coexisting zone	oases agriculture, grasslands and desert region, unused land (54%) account for 61% of the total unused land in China, 30% of grassland distributed here	Reclamation and abandonment of the arable land are interlacedly distributed, and the increase of arable land at large scale totals 436 khm^2.	23
8	Central China Plain ——water body fluctuation and built-up areas expansion coexisting zone	water body (12%) and paddy field (37%) densely distributed	The fluctuation in areas of water body is obvious, the shrinking and expanding areas total 480 khm^2 and 430 khm^2 respectively.	67
9	southeast hilly areas ——woodland to arable land conversion zone	woodland (70%) densely distributed, woodland with canopy density greater than 30% accounts for 15% of those in China, arable land (20%) densely distributed, among which paddy field and arable land coexist with an area ratio of 2:1	Woodland converted to arable land at large scale totals 450 khm^2.	91
10	coastal Southeast China—— grassland to man-made forest bi-directional conversion zone	national important paddy field and forest land distributing area account for 18% and 20% of those in China respectively. And economic forest and newly planted woodland account for 44% of those in China, and built-up areas account for 11%.	The bi-directional conversions between grassland and man-made forests are obvious, the economic forests and newly planted forests conspicuously increased, and the increase of built-up areas totals almost 550 khm^2.	169 (excluding Taiwan)

(*To be continued on the next page*)

(*Continued*)

Code	Name	Land-use features	Features of land-use change	Population (million)
11	southwest China —— woodland to grassland, woodland/grassland to arable land conversion zone	woodland densely distributed, accounting for 21% of those in China, shrub and sparse woodland easy to be seen, and arable land (19%) and grassland (25%) are also densely distributed	Woodland converted to grassland together with grassland converted to arable land at large scale are conspicuous, and the decrease of woodland totals 320 khm^2 while the increase of arable land totals 50 khm^2.	92
12	Qinghai-Tibet—— no change or little change zone	the less disturbed region by human activities, grassland (57%) and unused land (31%) densely distributed	No conspicuous land-use change happened	3

a) Values in the parentheses represent the percentage that this land-use type covers the overall land area in the zone.

3 Spatial pattern of comprehensive land-use change in China during 1995—2000

The main features of land-use change during 1995—2000 can be generalized in the following (table 3): (i) The expansion of arable land at large scale is conspicuous, and increases of paddy field and dry land total 597 khm^2 and 1170 khm^2 respectively, or 585 khm^2 and 1001 khm^2 after the thin objects were discounted in arable land[16]; (ii) The expansion of built-up and residential areas, 533 khm^2 in total, is obvious, among which most of them are converted from arable land; (iii) The decreasing trend of woodland and grassland still exists, with decreasing areas totaling 1300 khm^2 among which a large majority of land is converted from woodland with canopy density greater than 30% and high dense grassland (canopy density greater than 50%); and (iv) areas of water body and unused land are increased with a small scale.

Table 3 Net change of land-use change for each dynamic zone (Unit: hm^2)

Zones	Paddy field	Dry land	Woodland	Grassland	Unused land	Water body	Built-up areas
1	14714	607826	–443796	–78277	7845	–108827	536
2	103073	247567	–323828	–5013	1286	–28396	5797
3	580264	–454643	–56278	–26400	16307	–47174	3420
4	–129519	–108414	–29195	–26043	8568	–27783	267818
5	–23099	–17074	–5605	1658	1636	0	42486
6	123144	313600	–35227	–500960	–10337	88523	21269
7	12851	423894	28164	–931964	138647	242720	85699
8	–6615	–6149	–5377	816	–5621	8578	14368
9	–13426	41586	–49430	–3423	10995	–28	13729
10	–50081	45465	–71075	28553	29771	–8636	54553
11	–14100	64584	–321384	235020	15134	–63	20814
12	0	11761	–6292	–38827	17109	13996	2253
Total	597206	1170002	–1319323	–1344861	231341	132908	532742

There exists conspicuous regional differentiation of land-use change in China (Plates I—III), which lays the foundation to draw the dynamic zones. The rapid change of land-use change during 1995—2000 happened in North China, Loess Plateau—agricultural and pasturing interlaced area, Northeast China, southeast coastal region, middle and lower reaches of Yangtze River, eastern coastal region, the land-use change with a moderate scale happened in Sichuan Basin, North China Plain, southwest mountainous region, and slow change (or no change) has happened in the Qinghai-Tibet Plateau and other undeveloped regions in China.

The spatial pattern of land-use change features is identified as follows: Large areas of arable land have been reclaimed in Northeast China, North China and Xinjiang oases while conspicuous decrease still exits in Huang-Huai-Hai Plain, Yangtze River Delta, Huanghe River band in the vicinity of Baotou and Datong section and Sichuan Basin (Plate III-1); the serious trend of wood land destroy still exists in Northeast China, Southwest China and southeast coastal regions (Plate III-2); the decrease of grassland, happening mainly in Central China and northwest China (Plate III-3), is conspicuous; there also exists a common phenomenon of built-up and residential expansion, which mainly happened in Huang-Huai-Hai Plain, Beijing-Tianjin-Tangshan, central part of Gansu, southeast coastal region, Sichun Basin and Xinjiang oases (Plate III-4).

4 Characteristics of land-use conversion

Just as mentioned above, land-use change during recent five years has outstanding regional differentiations. In this paper, we mainly discuss the land-use transformation in types (Plate II) without considering the change in land-use intensity.

In Northeast China——woodland/grassland to arable land conversion zone (zones 1 and 2) characterized by the interlaced distribution of agriculture and woodland (or grassland), about 728 khm^2 of woodland with a low elevation and 350 khm^2 of grassland and unused land are converted to arable land (table 4). Northeast China Plain——dry land and paddy field bi-directional conver sion zone (zone 3) is characterized by the dry land to paddy field, and the net increase of paddy field is about 580 Khm^2, which results from the driving of comparative profit of rice planting (much higher than that of crop planting) and the regional temperature increasing which further

Table 4 Conversion matrix for land-use dynamic zones[a)] (Units: hm^2)

Zones	Conversions								
	1	2	3	4	5	6	7	8	9
	AL-AL	AL-WL/GL	OL-WB	OL-BuA	WL-AL	WL-GL	GL-AL	GL-WL	WB-OL
1	17244	57417	8291	544	428066	61570	252061	4595	447
2	150333	43362	5974	5317	300291	46156	99289	992	4365
3	753177	47369	13319	3420	66276	1757	107302	370	12504
4	14183	12355	111598	269591	13935	16443	25394	3712	58639
5	2444	1100	1830	42490	3025	2007	135	63	112
6	175405	441016	46367	21627	121419	59206	764667	66484	56337
7	10288	147027	188647	86497	15843	29702	622802	60285	49234
8	137	1833	43259	14375	3092	1970	515	989	48422
9	100	4739	14513	13833	45156	17221	4634	15547	3285
10	16307	15894	20013	55260	45568	190531	6901	163712	4300
11	599	8382	15857	21059	69744	334957	14648	81486	692
12	0	210	44798	2255	1096	14178	11551	7751	27689
Total	1140218	780705	514465	536269	1113510	775695	1909899	405986	266027

a) The explanation of each kind of land-use transformation can be seen in table 1 except that OL represents other land-use category.

affects the change of crop planting routine and demarcation line with the climatic change[17].

Huang-Huai-Hai Plain, Yangtze River Delta (zone 4) and Sichuan Basin (zone 5)——arable land to built-up areas are conversion areas, and the traditional agricultural regions with densely distributed population, which have the trends to expand built-up areas. The increase of built-up areas totals 310 khm^2, covering more than 50% of the total increased built-up areas in China during 1995—2000, among which 88% are converted from the arable land. The bi-directional conversions among reservoirs, ponds and bottomlands occurred significantly. It can be seen that some of the paddy fields have been converted to reservoirs or ponds in Jiangsu Province (Plate II)

North China Plain and Loess Plateau——grassland to arable land conversion zone (zone 6) feature the conversion from grassland to arable land at large scale, accompanying arable land returned into woodland and grassland occurring in some areas. Almost 760 khm^2 of grassland and unused land are reclaimed to arable land (table 4), among which more than two thirds converted from high dense grassland (with canopy density greater than 30%); in contrast, areas of arable land returned into woodland or grassland total 400 khm^2, herewith, the arable expansion and grassland shrinkage coexist in zone 6.

Northwest China——reclamation and abandonment of arable land interlaced zone (zone 7) distributes in arid and sub-arid areas. Areas of arable land and grassland have been decreased by 436 khm^2 and 931 khm^2 respectively (table 3). One half of the decreased grassland is converted to arable land, the other half to desert. The built-up areas total 85 Khm^2, accounting for a large proportion of area.

Central China (zone 8), covering dense lakes, features chiefly the bi-directional conversion among paddy field, reservoirs, ponds, bottomland and lakes and the urban and residence expansion. The bi-directional conversion between water body and paddy field nearly keeps balance, totaling more than 40 khm^2. Southeast hilly area——woodland to arable land conversion zone (zone 9) is arable land and woodland interlaced distribution region which has arable land converted from woodland (table 4) totaling 45 khm^2. Southeast coastal zone (zone 10) is characterized by the conversions from grassland to woodland and open woodland to other woodland, the former totals 160 khm^2 while the latter 190 khm^2 (table 4), among which the conversions from open woodland to man-made economic or newly planted forests are conspicuous, further showing the general characteristics of the coexistence of deforestation and afforestation.

In southwest China——woodland to grassland and woodland/grassland to arable land conversion zone (zone 11), the deforestation and grassland reclamation (to arable land) coexist. The reclamation from woodland nearly totals 70 khm^2, and the conversion from woodland to grassland totals 335 khm^2, leading to the significant decrease of woodland (320 khm^2 in total) and the increments of arable land and grassland totaling 50 khm^2 and 237 khm^2 respectively. Southwest Qinghai and Tibet——no (or less) change region in land use, are characterized by a slow change in land use, showing fewer disturbances of human activities for physical land cover.

5 Human driving forces for the typical modern process of land-use change

Land-use change, in one sense, results from the human activities influencing natural resources and environments, on the premise that (i) The conversion possibility of land-use categories or using modes is affected directly by the regional physical geophysical background (including climate, landform, soil, land cover types, etc.) and (ii) The disturbance from human activities are mainly characterized by the possibility, frequency and land-use mode which are further determined by the population distribution, transportation, society requirement and economic industrial structure. For the regional land-use change, policies about land use are always the key factors.

Urbanization is a necessary stage in social and economic development. As a developing country, the urban expansion has increasingly become the dominant features in land-use change. The typical characteristics can be concluded as follows: (i) In Huang-Huai-Hai Plain (traditional agricultural zone) and Yangtze River Delta zone, the expansion of built-up areas has increased significantly, accounting for 50% of the total increased built-up areas of China, which partly resulted from the dense population distribution, being more infrastructure than other places and even landform. (ii) Sichuan Basin with the highest increasing rate of built-up area, accounting for 18.8% of the increased built-up areas of China, resulting from rapid agricultural development, has not only supported the development of urbanization but also impacted directly the development of township and village industries which acts as the driving force for the regional urbanization. (iii) The expansion of west China (including northwest and southwest China), with a high increasing rate of urban expansion, accounting for 11.7% of the increased built-up areas, results chiefly from the relatively low level of infrastructure there and the implementation of western China development. (iv) The most conspicuous urban expansion of China in the 1990s is located in Zhujiang Delta and Fujian coastal areas. During 1995—2000, conversion from arable land to built-up areas is held back, which is partly affected by land management law of China that is put in force. In a word, the urban expansion is centralized in plain cities and economic development zones and expanded outside; the main development zones involved include Beijing-Tianjin-Tangshan areas, Shanghai, Nanjing and Hangzhou-Suzhou, Wuxi and Changzhou, coastal and inland areas of Shandong, Xi'an – Xianyang, Chengdu and Chongqing peripheral areas, Turpan-Urumqi-Shihezi and the development axes of Baotou-Lanzhou (Plate III-4).

With large population and the large share of agricultural industries in the gross domestic product, the arable land protection is of most importance for agricultural production to guarantee grain security. Even though there are relative items to protect arable land in the Land Management Law of China, there also exist the conspicuous conflicts between arable land protection and urban expansion, as showed in the irrational conversion from arable land to built-up areas. In the interlaced area of agriculture and/or grassland/woodland, there are also exist conflicts between human activities and environmental protection. On one hand, benefited from the agricultural techniques and the regional climatic change suitable for agriculture, large area of woodland and grassland transformed into arable land; on the other hand, policies of "returning arable land into woodland or grassland" result in the conversion from arable land to woodland and grassland and the abandonment of arable land resulting from the environmental deterioration. In the end of 1990s, wild wood protection project is issued together with the implementation of "reusing arable land as woodland or grassland" policies. Afterwards, an afforestation trend began to appear in some local areas such as coastal southeast areas and central part of China. Because the investigation by remote sensed data is ended in 1999/2000, and more land-use change affected by the policies has not been extracted, which can be disclosed in the coming years by most resent data sources.

The macro adjustment and management of land-use change direction at regional scale have also been embodied by the alteration of water body areas in Central China. In this area water system is well developed and rivers and lakes interlace in most places and there exist large areas of reservoirs, ponds and paddy fields surrounding the natural lakes as before. As natural processes, there exists inter-annual fluctuation in boundary of paddy land and bottomland due to climate and agricultural productive condition. However, after flooding disasters happened in Yangtze River in 1998, a series of projects about "returning arable lands to lakes" are implemented, leading to the enlargement of lakes, and the land-use structure and ecological environments began to convert rationally and optimally.

6 Result and discussion

(1) According to current research work, it becomes clear that integrated study on "spatial pattern" and "temporal process" feature of geographical objects and phenomena through spatial-temporal analysis tools to find out the "pattern of dynamic process" and the "dynamic process of pattern" of the research objects should be taken not only as fundamental scientific issue, but also as an approach in LUCC research. In this paper, a dynamic regionalization scheme is designed to reveal the modern temporal and spatial land-use change characteristics of China, which serves as a basis to study land-use dynamics at regional scale and strengthens the temporal and spatial feature-oriented analyses on land-use dynamics. The paper exerts an effective effort on the integrated studies of "spatial pattern" and "temporal process" for land-use change reveal the regional land-use change characteristics on pattern of dynamic process and dynamic process of pattern.

(2) There exists conspicuous regional differentiation on land-use change during 1995—2000, e.g., obvious expansion of built-up areas and decrease of arable land in the traditional agricultural zone of eastern and central parts of China, the reclamation of arable land in agricultural and pasturing ectone of northern China. All these are controlled by physical environments and affected by human activities.

(3) Systematical land-use change study should include the following aspects: change detect, driving forces analysis, global change impact on land-use change, modeling and simulation on the land-use change, and biogeochemical process influenced by land-use change, etc. Up to now, we

have constructed a systematic monitoring system on land-use change for long-term and continuous observation. In the future, we need to study thoroughly the impact of human's social and economic activities on land-use change at regional scales, and further, study the effect of land-use change on global environments by joining together researches on life material's physical, chemical and biological processes in land surfaces.

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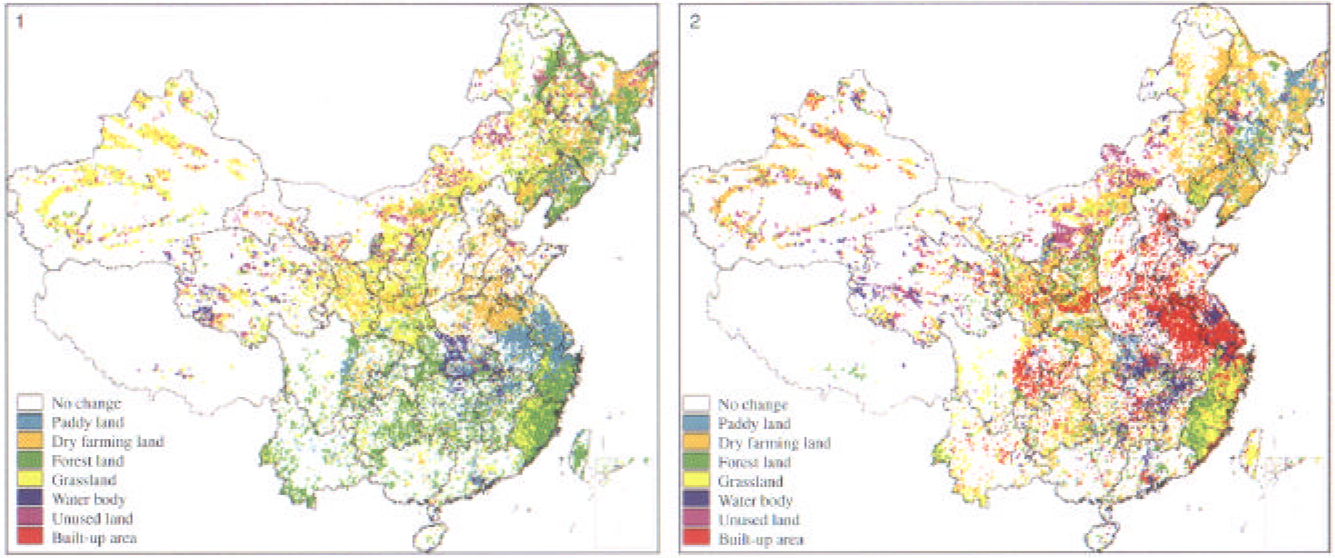
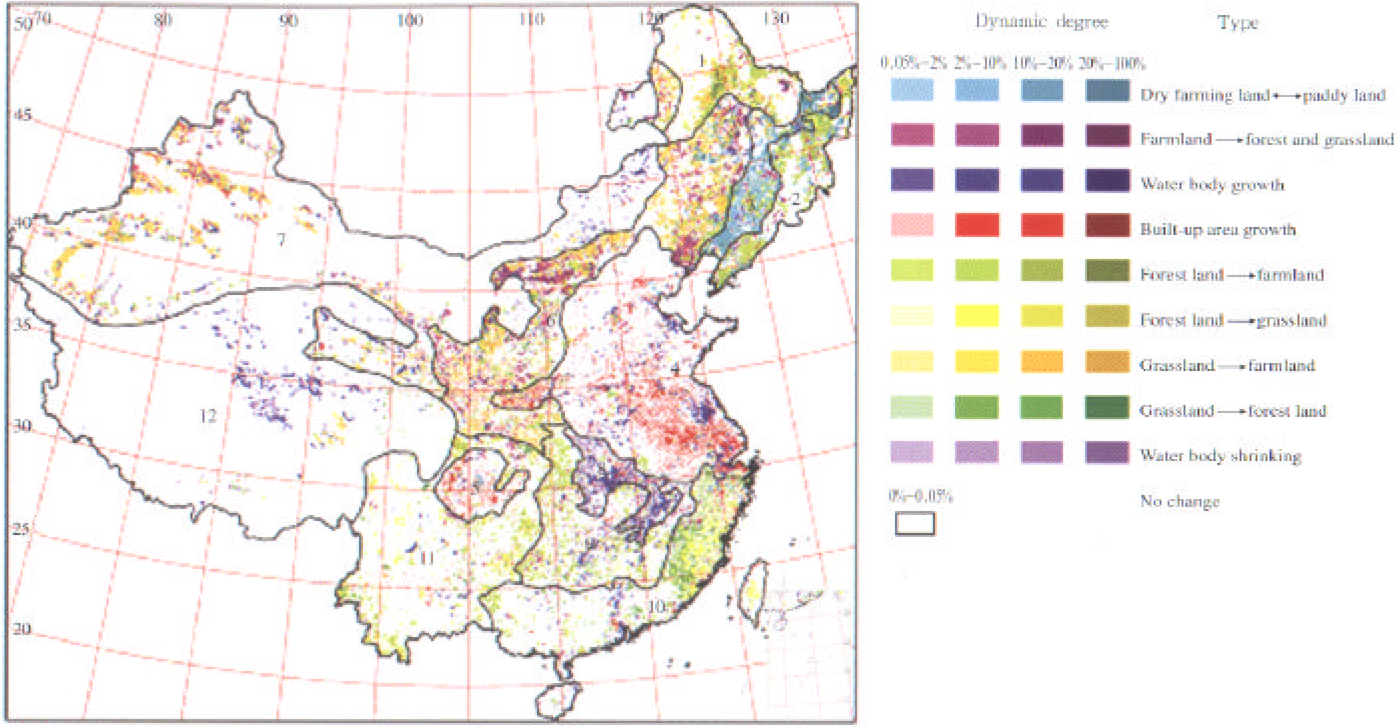
References

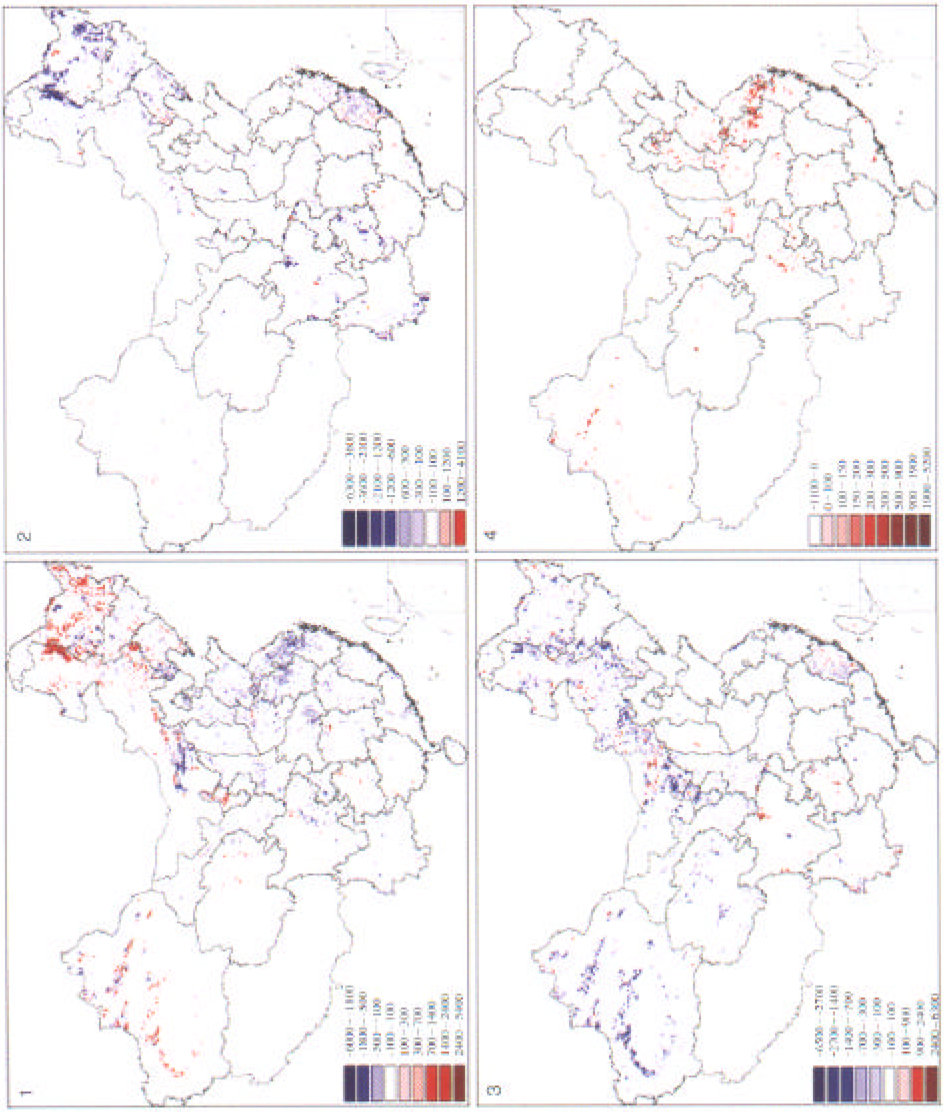
1. Geist, H. J., Lambin, E. F., What drives tropical deforestation? LUCC Report Series; 2001, (4): 116.
2. Turner, B. L. II., Clark, W. C., Kates, R. W. et al., The earth as transformed by human action, in Global and Regional Changes in the Biosphere over the Past 300 Years, Cambridge: Cambridge University Press (with Clark University), 1990.
3. Lambin, E. F., Ehrlich, D., Land-cover changes in sub-Saharan Africa (1982—1991): Application of a change index based on remotely sensed surface temperature and vegetation indices at a continental scale, Remote Sens. Environ., 1997, 61: 181—200.
4. Robert, T., Watson, I. R., Noble, B. B. et al., Land Use, Land-Use Change, and Forestry, Special Report of the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press, 2000.
5. Meyer, W. B., Turner, B. L., Changes in Land-Use and Land Cover: A Global Perspective, Cambridge: Cambridge University Press, 1994.
6. Turner, B. L. II., Skole, D., Sanderson, S. et al, Land-use and land-cover change, in Science/Research Plan. HDP Report 7/IGBP Report 35, Stockholm and Geneva, 1995.
7. Turner, B. L., Moss, R. H., Skole, D. L., Relating Land Use and Global Land-cover Change: A Proposal for an IGBP-HDP core Project, Report from the IGBP-HDP Working Group on Land-Use/Land-Cover Change (=IGBP Report 24/HDP Report 5), Stockholm: Royal Swedish Academy of Sciences, 1993.
8. Lambin, E. F., Baulies, X., Bockstael, N. et al., Land-Use and Land-Cover Change (LUCC) Implementation Strategy (=IGBP Report48/IHDP Report10), Stockholm: Royal Swedish Academy of Sciences, 1999.
9. Liu Jiyuan, Buheaosier, Study on spatial-temporal feature of modern land-use change in China: Using remote sensing techniques, Quaternary Sciences (in Chinese), 2000, 20(3): 229—239.
10. Liu Jiyuan, Macro-scale Survey and Dynamic Study of Natural Resources and Environment of China by Remote Sensing (in Chinese), Beijing: China Science and Technology Press, 1996.
11. Zhuang Dafang, Liu Jiyuan, Liu Mingliang, Research activities on land use/land cover change in the past ten years in China using space technology, Chinese Geographical Science,1999, 9(4): 330—334.
12. Liu Mingliang, Tang Xianming, Liu Jiyuan et al., Research on scaling effect based on 1km grid cell data, Journal of Remote Sensing(in Chinese), 2001, 5(3): 183—189.
13. Johnson, R D., Kasischke, E. S, Change vector analysis: A technique for the multispectral monitoring of land cover and condition, Int. J. Remote Sens., 1998, 19: 411—426.
14. Huang Bingwei, Draft of the complex physical geographical division of China, Kexue Tongbao (Chinese Science Bulletin) (in Chinese), 1959, (18): 594—602.
15. Zhou Lisan, Theories and Practices on Agricultural Division of China (in Chinese), Hefei: University of Science and Technology of China Press, 1993.
16. Zhang Wen, Zhuang Dafang, Hu Wenyan, Area summarization in establishing the national resources and environmental database, Journal of Remote Sensing (in Chinese), 2000, 21(4): 304—310.
17. Sha Wanying, Shao Xuemei, Huang Mei, Climate warming and its impact on natural regional boundaries in China in the 1980s, Science in China, Ser. D, 2002, 45(12): 1099—1113.



Main type of land-use change in each cell. 1. Shrinking (decreasing) type. Shrinking type represents the former kind of land use with maximal occupation in each 10km × 10km grid cell in changed parts, i. e. paddy land, dry farming land, woodland, grassland, water body, unused land and built-up area transformed into other kinds of land use. 2. Expanding (increasing) type. Expanding type represents the maximal occupation in changed parts, i.e. other kinds of land use transformed into paddy land, dry farming land, grassland, water body, unused land and built-up area. By comparison of the two maps, the main characteristics of spatial pattern on land use transformation matrix can be discovered. The intensity of transformation can be found in Plate II.



Land-use change and its regionalization map in China during 1995—2000. Different color degrees represent the dynamic degree of main land-use change, 0.05%—2%, 2%—10%, 10%—20% and 20%—100% (set S the area of each grid cell), i.e. the percentage of transformed land-use area occupying the overall cell area. The zone name of each code: 1. Northeast Da and Xiao Hinggan Mts—woodland/grassland to arable land conversion zone; 2. eastern part of Northeast China— woodland/grassland to arable land conversion zone; 3. Northeast China Plain—dry land and paddy field bi-directional conversion zone; 4. Huang-Huai-Hai Plain and Changjiang River Delta—arable land to built-up areas conversion zone; 5. Sichuan Basin—arable land to built-up areas conversion zone; 6. North China Plain and Loess Plateau—grassland to arable land conversion zone; 7. northwest China—reclamation and abandonment of arable lands coexisting zone; 8. Central China Plain—water body fluctuation and built-up areas expansion coexisting zone; 9. southeast hilly areas—woodland to arable land conversion zone; 10. coastal southeast China—grassland to man-made forest bi-directional conversion zone; 11. southwest China—woodland to grassland, woodland/grassland to arable land conversion zone; 12. Qinghai-Tibet—no change or little change zone.



Land-use change area of main type. 1. Farmland; 2. woodland; 3. grassland; 4. built-up area. The legend represents the net change area (hm^2) in each 10 km×10 km cell, i.e. the difference between increased area and decreased area of this land-use type.