J. Geogr. Sci. 2016, 26(5): 515-530
DOI: 10.1007/s11442-016-1283-2

Land use transitions and their dynamic mechanism: The case of the Huang-Huai-Hai Plain

LIU Yongqiang[1], *LONG Hualou[2]

1. Faculty of Architectural, Civil Engineering and Environment, Ningbo University, Ningbo 315211, Zhejiang, China;
2. Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China

Abstract: Land use transition refers to changes in land use morphology, including dominant morphology and recessive morphology, of a particular region over a period of time driven by various factors. Recently, issues related to land use transition in China have attracted interest among a wide variety of researchers as well as government officials. This paper examines the patterns of land use transition and their dynamic mechanism in the Huang-Huai-Hai Plain during 2000–2010. First, the spatio-temporal patterns of land use transition, their characteristics and the laws governing them were analyzed. Second, based on the established conceptual framework for analyzing the dynamic mechanism of land use transition, a spatial econometric regression analysis method was used to analyze the dynamic mechanism of the five types of major land use transition in the Huang-Huai-Hai Plain at the county level. Land use pattern changes in the study area were characterized by an increase in construction land, water body and forested land, along with a decrease in farmland, unused land and grassland. The changes during 2000–2005 were much more significant than those during 2005–2010. In terms of factors affecting land use transitions, natural factors form the basis, and they have long-term effects. Socio-economic factors such as population and GDP, however, tend to determine the direction, structure, size and layout of land use transition over shorter time periods. Land law and policy factors play a mandatory guiding and restraining role in land use transitions, so as to improve the overall efficiency of land use. Land resource engineering is also an important tool to control land use transitions. In general, the five types of major land use transition were the result of the combined action of various physical, social and economic factors, of which traffic condition and location condition had the most significant effects, i.e. they were the common factors in all land use transitions. Understanding the spatio-temporal process of land use transitions and their dynamic mechanisms is an important foundation for utilizing land resources, protecting regional ecological environment and promoting sustainable regional socio-economic development.

Received: 2016-01-08 **Accepted:** 2016-02-15
Foundation: National Natural Science Foundation of China, No.41171149, No.41130748; The National Key Technology R&D Program of China, No.2014BAL01B05; Non-profit Industry Financial Program of Ministry of Land and Resources of China, No.201511004-3
Author: Liu Yongqiang (1982–), PhD and Lecturer, specialized in land use transition and environmental effects. E-mail: liuyq.12b@igsnrr.ac.cn
***Corresponding author:** Long Hualou (1971–), PhD and Professor, specialized in rural restructuring, urban-rural development and land use transition. E-mail: longhl@igsnrr.ac.cn

Keywords: land use transition; dynamic mechanism; farming area; Huang-Huai-Hai Plain

1 Introduction

China is undergoing rapid socio-economic transformation development, at the same time the land use is experiencing a dramatic transition in both depth and breadth. Land use transition, as a new approach to the comprehensive study of land-use and land-cover (LULC) change refers to the change in land use morphology corresponding to the accompanying socio-economic development transition (Cai, 2001; Long, 2014a; Lambin and Meyfroidt, 2010). Land use morphology, which is the core content of land use transition, usually includes dominant morphology and recessive morphology. Dominant morphology means the quantity, structure and spatial pattern of the land, while recessive morphology, which is not easily detected compared to dominant morphology, includes the characteristics of quality, property rights and management mode, and input and output capacity of the land (Long, 2015). At present, the study of regional land use transitions is receiving increasing attention, and driving factors and their mechanism of land use change are the most important components for study (Kong, 2012; Lv *et al*., 2013; Liu *et al*., 2015a; Liu *et al*., 2015b), which can provide important references for the analysis of the mechanism of land use change (Li, 2002). Lambin and Meyfroidt (2010) considered that land use transition emphasizes the non-linear process of land use change and was closely related to the changes in other social and natural systems. They concluded, moreover, that land use transition was caused by negative feedback due to the depletion of key resources or by social and economic changes and innovations.

Previous studies on the dynamic mechanism of LULC change focused mainly on the area change in land use types and their driving factors in terms of economic, social and natural behavior to reveal the driving forces of LULC change in China (Li *et al*., 2001; Li *et al*., 2015). The results showed that large scale land use change was affected mainly by natural factors over long periods of time (Shao *et al*., 2007) and by social and economic factors over short periods (Long and Li, 2002; Xie and Li, 2008). Previous land use transition studies mainly considered the following three aspects: (1) the selection of driving forces of land use change initially focused on the physical attributes of land resources because the natural driving force data are easy to acquire, analyze and simulate, as a result, the understanding of land use transitions was unclear and not comprehensive; (2) a large number of studies focused on regions of fragile ecological environment, such as rapid economic development zones, rapid urban expansion areas, arid and semi-arid regions, but there was relatively little research into traditional agricultural areas; (3) with the development of "3S" technology and mathematical statistics, research methods of land use change have been continually improved, but the method of land use transitions itself has not matured. Research on land use transitions mainly used the most significant land use transition type as the research object; however, the less significant influence of other land use transitions of an area was often ignored (Liu and Zhu, 2010). This paper examines the spatio-temporal dynamic patterns of land use transitions at the county level in the Huang-Huai-Hai Plain, which is experiencing rapid urban–rural transformation development, using high-resolution Landsat TM (Thematic Mapper) data from 2000, 2005 and 2010, and uses a spatial econometric regression method to analyze the correlation between land use transitions and their driving forces.

The analysis of the dynamic mechanism of land use transitions in this paper focuses mainly on the change in land use dominant morphology, while the change in land use recessive morphology is analyzed qualitatively. This paper not only considers the increase or decrease in area of a certain type of land use transition, but also distinguishes its direction of flow, in or out, in order to carry out a more detailed analysis of the dynamic mechanism of land use transitions. Finally, by examining the spatio-temporal dynamic patterns of land use transitions, we hope to grasp the main characteristics of the five types of land use transition and to clarify the key factors driving the transition process and its mechanism of action.

2 Study area and data

2.1 Study area

The Huang-Huai-Hai Plain, the study area, is located south of the Yanshan Mountains, north of the Dabie Mountains, east of the Taihang Mountains and Funiu Mountains and west of the Bohai and Yellow seas, and includes the areas of five provinces and two municipalities, i.e. the whole of Shandong, most of Beijing, Tianjin, Hebei and Henan, and the northern parts of Anhui and Jiangsu, and covers an area of approximately 400 thousand km^2. The Huang- Huai-Hai Plain has a population of at least 210 million (2009) and is generally representative of China's plains as a whole. Its land area and population account for 31.7% and 52.6%, respectively, of the total plain area and plain population of China as a whole (Li *et al*., 2012; Liu *et al*., 2015b). The farmland of Huang-Huai-Hai Plain accounts for about one-sixth of China's total and ranks first in terms of land reclamation rate, with 50 million ha sowing area, 33% of the country's total, and producing 35%–40% and 60%–80% of China's wheat and corn, respectively, which has played an important role in ensuring national food security (Kong *et al*., 2014; Li *et al*., 2012). Except for the Jiaodong Peninsula, the Huang-Huai-Hai Plain consists mainly of alluvial plain of flat terrain with deep soil that is suitable for farming (Guo *et al.*, 1991), and the importance of grain production in the Huang-Huai-Hai Plain is increasing. A series of agriculture and food production support policies began in 2004 that promoted the grain yield in the Huang-Huai-Hai Plain significantly: the total grain output of approximately 136 million tons in 2008 increased by 27.61% compared to 2000. Unfortunately, the water shortage in the Huang-Huai-Hai Plain and the pollution that diffuses into it from various agricultural sources are becoming critical problems hindering regional development (Kong *et al*., 2014; Qiu, 2010).

2.2 Data sources

The vector data of LULC changes was obtained through detection analysis of historical Landsat TM (Thematic Mapper) satellite images taken in 2000, 2005 and 2010 by the China National Environmental Monitoring Center. Social and economic data was obtained from the China Statistical Yearbook (2001–2011), the China Population Statistics Yearbook (2001–2011), the China County (City) Social Economic Statistical Yearbook (2001–2011), the China Regional Economic Statistical Yearbook (2001–2011) and the Statistical Yearbook of Beijing, Tianjin, Hebei, Shandong, Henan, Anhui and Jiangsu. The data for provincial and county boundaries, government residents and roads and rivers were from the national fundamental geographic information system of the national database at the scale of

1:4000000 (http://nfgis.nsdi.gov.cn).

3 Methods

3.1 Land use transition analysis

Based on these Landsat TM data, LULC were classified into six types: farmland, water body, forested land, grassland, unused land and construction land used mainly for industry, mining and transportation as well as urban and rural settlements. Then, the changes among the six different LULC types were measured using ESRI's ArcGIS spatial analyst module (Long *et al.*, 2007).

$$P_{loss(i),j} = (P_{j,i} - P_{i,j}) / (P_{i.} - P_{.i}) \times 100,\ i \neq j \tag{1}$$

$$P_{gain(i),j} = (P_{i,j} - P_{j,i}) / (P_{i.} - P_{.i}) \times 100,\ i \neq j \tag{2}$$

where $P_{loss(i),j}$ is the percentage taken by type j in the total "conversion loss" of category row i; $P_{gain(i),j}$ is the percentage taken by type j in the total "conversion gain" of category row i; $P_{i,j}$ and $P_{j,i}$ are individual entries in the change matrix A.

3.2 Driving factor selection and parameterization

3.2.1 Driving factor selection of land use transition

Land use transition is a result of natural, social, economic, legal, institutional and engineering factors interacting with each other within a certain region. Therefore it is influenced not only by physical conditions but also by economic, technical, social and other factors (Long, 2015; Chen and Zhang, 2011). These were divided into the following driving factors: natural, social and economic, law and policy and land resource engineering (Figure 1).

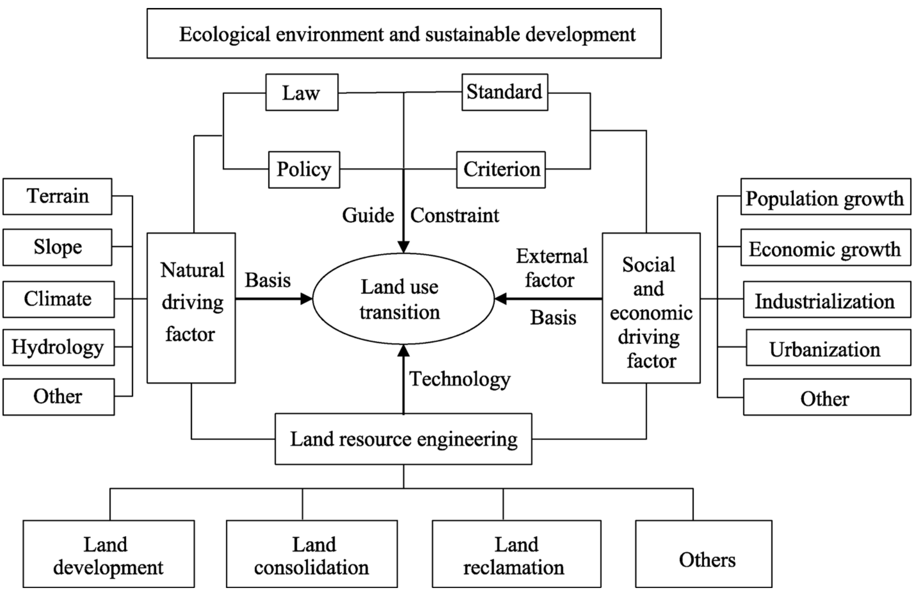

Figure 1 Conceptual framework for dynamic mechanism of land use transition

(1) Natural driving factor

From the perspective of spatial analysis, hydrological and geomorphological factors are usually chosen for driving force analysis at the small scale because they are different spatially and easy to express in a spatially quantitative way. Climatic factors can usually be applied at large or medium scales. Thus, climatic factors were selected as natural factors considering the large span of the Huang-Huai-Hai Plain from north to south. Accordingly, three kinds of natural driving factors, including terrain condition (elevation), hydrological condition (distance to the main river) and climatic condition (average annual rainfall) were chosen as natural driving factors.

(2) Social and economic driving factor

The effects of social and economic factors were obvious over a relatively short period of time, especially the effects of human activities (Long and Li, 2012). With better location conditions and higher urbanization level, the eastern coastal area of the Huang-Huai-Hai Plain had more significant impacts on land use transitions compared with the other regions. Considering the actual situation of the study area, the following factors were chosen, including total population, GDP per capita, rural per capita net income, urbanization rate, local financial expenditure and added value of primary industry, as the social and economic driving factor. In addition, the distance to provincial, municipal and county-level administrative centers were chosen as the characterization factor of location condition and the distance to the main road and railway as the characterization factor of traffic condition.

(3) Law and policy driving factor

Given the economic and ecological benefits and sustainable development deriving from land use transitions, the government needs to draft laws and policies to guide or constrain the latter, such as farmland protection, returning farmland to forests, water-saving agriculture, coastal zone management policy and so on. Studies have shown that land management policy had a more significant influence on land use change than any other driving factor, such as population or urbanization (Zhu *et al.*, 2001).

(4) Land resource engineering driving factor

Land development, consolidation and reclamation all belong, in essence, to the category of land resource engineering and technology (Liu, 2015; Long, 2014b). Land resource engineering and technology had already provided a proven important support for the conversion of unused land (saline) to farmland in the Yellow River Delta of the Huang-Huai-Hai Plain, and they are becoming ever more important in regulating land use transition (Long, 2014b). Present day China is facing a more severely polluted atmosphere, along with water and soil pollution issues that compel us to seek new land resource engineering, technology and other related solutions.

3.2.2 Driving factor quantification and spatialization

This paper selected mainly terrain, hydrology and climate as natural factors and population and other external influences as socio-economic factors of land use transition in the Huang-Huai-Hai Plain. As some driving factors are impossible or difficult to quantify, such as law, policy, land resource engineering and technology, the analysis was carried out in a qualitative way. Specific steps are as follows:

(1) The terrain condition was characterized by elevation; the traffic condition was char-

acterized by distance to the main road and the main railway; the hydrological condition was characterized by distance to the main river; and the local condition was characterized by distance to the county, municipal or provincial administrative center. First, the raster data was obtained by calculating the shortest distance from each pixel to the target source through the Euclidean Distance tool in ArcGIS. Second, the raster data of 90 m resolution DEM and the shortest distance obtained above were transferred into the point layer by the Raster to Point tool, so that each DEM and the shortest distance had elevation and distance information, respectively, associated with it. Third, an overlay analysis was carried out with the above point layers and the county (city)-level administrative region layer, so that each point in the data layer had both the elevation and administrative information associated with it, and the shortest distance data had the distance and administrative information. Finally, the attributes of the point layer thus obtained were exported.

(2) The climatic condition was characterized by mean annual rainfall which came from the original measured data of rainfall observation stations. First, the information for mean annual rainfall was imported into ArcGIS to obtain the point layer of rainfall observation stations. Second, Thiessen Polygons of each rainfall observation station were created using the Thiessen Polygons tools in ArcGIS. Third, overlay analysis with the county (city)-level administrative region layer was carried out so that each surface datum point had the rainfall and administrative information associated with it. Finally, the data for these two steps were exported and the elevation and the average distance to the target source were obtained using the Pivot Table in Microsoft Excel.

(3) Social and economic external driving factors were characterized by the total population, GDP per capita, rural per capita income, urbanization rate, local financial expenditure and the added value of primary industry. The method for quantification and spatialization of these factors was similar to that for internal factors, and the main work involved was the use of the Join tool in ArcGIS to import the changes in the above factors into the research unit (Figure 2).

3.3 Spatial econometric regression analysis

Based on our land use transition analysis of the Huang-Huai-Hai Plain, spatial econometric regression models, including Ordinary Least Squares (OLS), Spatial Lag Model (SLM) and Spatial Error Model (SEM), were used to explain and reveal the inner correlationships between land use transitions and their driving factors among 15 driving factors and five categories of land use transition. The equations used in the three spatial econometric regression models are explained as follows:

The OLS model explains the relationship between a dependent variable and a collection of independent variables. The value of the dependent variable is defined as a linear combination of the independent variables plus an error term:

$$y_i = \beta_0 + \sum_{j=1}^{k} \beta_j x_{ij} + \varepsilon_i \tag{3}$$

where y_i is the dependent variable, x_{ij} are the independent variables, β_0 is a constant term, β_j are the regression coefficients, and ε_i are the normally distributed errors of prediction.

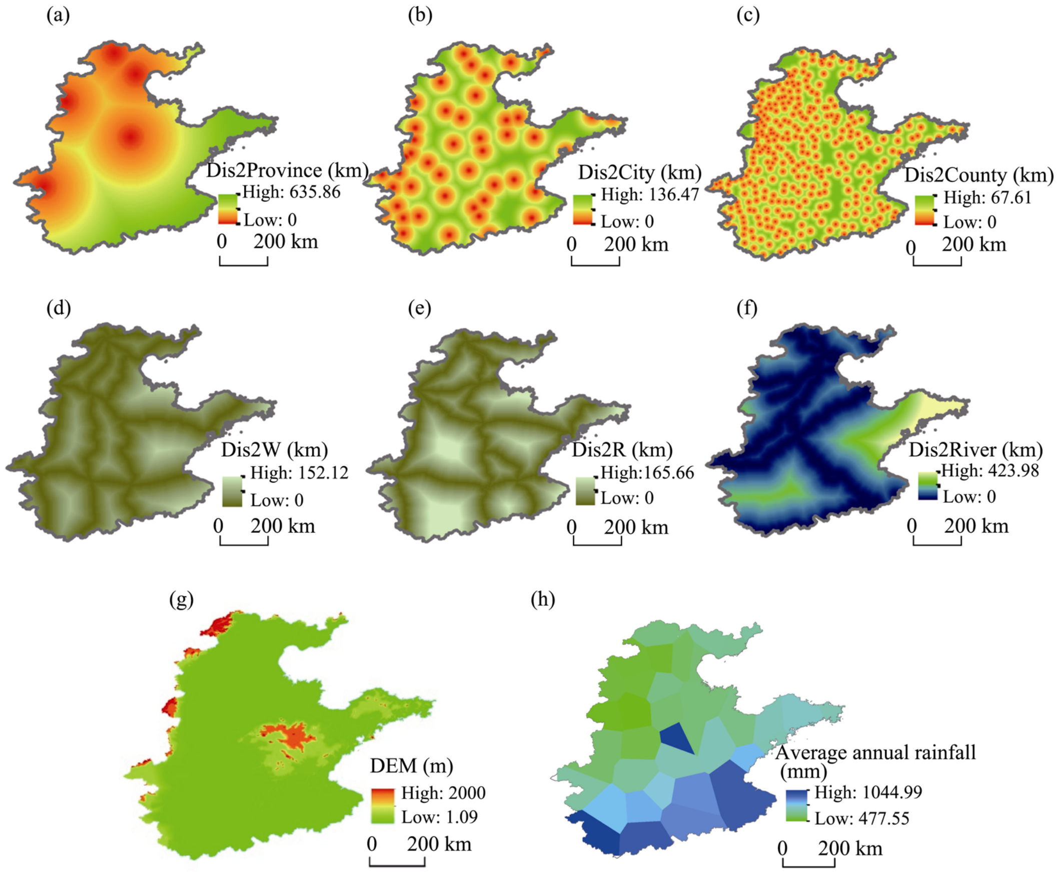

Figure 2 Quantitative spatial distribution of the driving factors of land use transition in the Huang-Huai-Hai Plain

Note: *: Significance at 10%; **: significance at 5%; ***: significance at 1%.

Dis2Province: distance to province-level administrative center; Dis2City: distance to city-level administrative center; Dis2County: distance to county-level administrative center; Dis2W: distance to main railway; Dis2R: distance to main road; Dis2River: distance to main river.

SLM assumes that the value of the dependent variable y in a site depends on the values of it in neighboring regions. It is thus a formulation of the idea of a spatial spillover. For example, the indicator values in one area will be affected by the surrounding areas. SLM is expressed as follows (Anselin *et al*., 2006):

$$y = \rho Wy + X\beta + \varepsilon \tag{4}$$

where y is the variation of five categories of land use transition in the Huang-Huai-Hai Plain in each grid, X contains a set of explanatory variables for the regression relationship, with β as the corresponding regression coefficient, ρ is a spatial autoregressive coefficient indicating the extent to which variations in the observations of y are explained by the average of the neighboring observation values, ε is the model error term, and W is the spatial weight matrix.

Compared with SLM, the spatial dependence in the SEM enters through the errors rather than through the neighboring values of the dependent variable in the SLM (Anselin *et al*., 2006). SEM is specified as:

$$y = X\beta + \varepsilon \tag{5}$$

$$\varepsilon = \lambda W\varepsilon + \mu \tag{6}$$

where y, X, β and W are the same as those in Eq. (4), λ is a spatial autoregressive coefficient, ε is the regression residual, and μ is the normally distributed random error.

4 Results

4.1 Land use transitions in the Huang-Huai-Hai Plain

In order to analyze the internal structural variability of LULC in the study area, a spatial overlay analysis was carried out based on the three interpreted land use maps. Three maps of land use changes during the periods 2000–2005, 2005–2010 and 2000–2010 were obtained (Figure 3) and a change matrix of each compared LULC type in 2000 and 2010 was obtained (Table 1). Land use changed significantly over the whole period 2000–2010 in the Huang-Huai-Hai Plain, which was characterized by decreases in farmland, unused land and grassland of 7.28%, 38.83% and 9.63%, respectively, and increases in construction land, water body and forested land of 45.36%, 27.09% and 5.88%, respectively. From the perspective of construction land change, built-up areas expanded very rapidly, from 4,423,668 ha in 2000 to 6,430,442 ha in 2010 (an increase of 2,006,774 ha), especially the expansions of Beijing, Tianjin, the northwest of Anhui Province and the north of Jiangsu Province which were most significant (Figure 3 and Table 1). In contrast, farmland decreased from 29,066,375 ha in 2000 to 26,949,362 ha in 2010 (Table 1). The distribution of increased construction land was coupled roughly with decreased farmland (Figure 3). In addition, it can be clearly seen that the changes in the first five years were much more significant than those in the following five years (Figure 3).

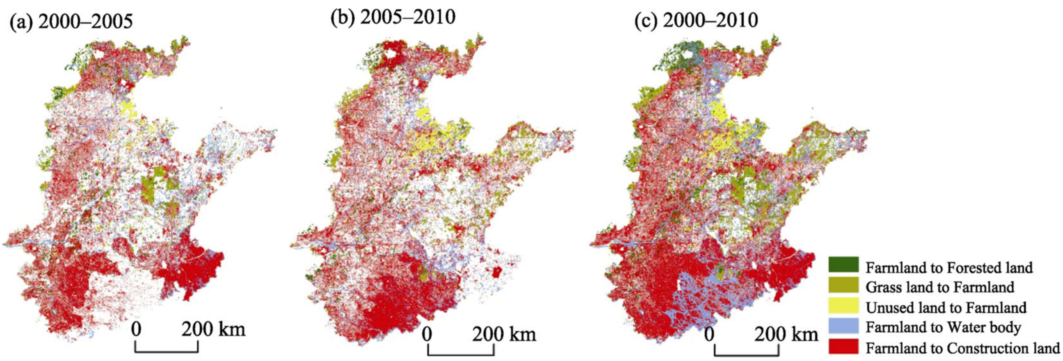

Figure 3 Change pattern of land use in the Huang-Huai-Hai Plain during 2000–2010

In order to explore the internal conversion between different LULC types, which took place between 2000 and 2010, the change (decrease or increase) in a LULC type in 2010 relative to 2000 was treated as a result of several "loss or gain" conversions (Long *et al.*, 2007). The expansion in construction land was caused mainly by a decrease in farmland, grassland and unused land, accounting for 90.84%, 2.47% and 2.26%, respectively (Table 2). The increase in forested land arose mainly from the transition from farmland, accounting for 60.29% of the total increased area due to the "returning farmland to forest" policy. Also, with the increase in population and food safety pressures, some beaches, as well as hillside land and other unused land, were reclaimed for farmland, accounting for 59.33% of the total change in unused land area. The increase in water body area came mainly from farmland transition, accounting for 76.63% of the total change in water body area.

Table 1 Change matrix of each compared land use type in 2000 and 2010 in the Huang-Huai-Hai Plain (ha)

LULC type in 2000	LULC type in 2010						
	Farmland	Forested land	Grassland	Water body	Construction land	Unused land	Total
Farmland	25235074	320182	155761	502219	2806220	46919	29066375
Forested land	222594	1542866	99994	18297	68499	6538	1958788
Grassland	193778	147565	1358491	33527	76311	57686	1867359
Water body	200816	20237	25600	800867	68214	30148	1145882
Construction land	927849	36499	31946	77544	3341342	8487	4423668
Unused land	169250	6592	15783	23804	69856	63729	349013
Total	26949362	2073941	1687575	1456258	6430442	213506	38811084

Table 2 Internal conversions between land use types from 2000 to 2010 and the percentages taken by corresponding types in such loss or gain conversions

LULC type	Loss or gain in 2010 (%)	Type (1)	Percent (%)	Type (2)	Percent (%)	Type (3)	Percent (%)	Type (4)	Percent (%)	Type (5)	Percent (%)
FL	–7.28	CL	73.24	WB	13.11	FL	8.36	GL	4.07	UL	1.22
FR	5.88	FL	60.29	GL	27.79	CL	6.87	WB	3.81	UL	1.24
GL	–9.63	FL	38.08	FR	29.00	CL	15.00	UL	11.34	WB	6.59
WB	27.09	FL	76.63	CL	11.83	GR	5.12	UL	3.63	FL	2.79
CL	45.36	FL	90.84	GL	2.47	UL	2.26	FL	2.22	WB	2.21
UL	–38.83	FL	59.33	CL	24.49	WB	8.34	GL	5.53	FL	2.31

Note: FL: farmland; CL: construction land; FR: forested land; WB: water body; GL: grassland; UL: unused land.

From the viewpoint of spatial distribution (Figure 3), farmland that was transformed to construction land was widely distributed in the study area, especially in places with better location conditions. Farmland that was transformed to forested land occurred mainly in two kinds of places: one with mountains, hills and beaches, which are not suitable for growing plants, and the other with poor economic conditions. Farmland located in mountains, hills and beaches, especially in areas surrounding Beijing as well as central and southern Shandong Province with poor growing conditions, was gradually restored to forested land. In less developed regions, accompanying an increase in migrant workers, farmland was also gradually transformed to forested land. Such places are distributed mainly in the agricultural plain areas in Shandong, Henan and Hebei provinces. Farmland that was transformed to a water body occurred mainly in Jiangsu, Anhui, Tianjin and eastern Shandong provinces. The farmland here was changed mainly to aquaculture land and salt pans. Grassland that was transformed to farmland occurred mainly in hilly areas, especially in the west of Hebei

Province and the central and southern areas of Shandong Province. Unused land that was transformed to construction land occurred mainly in the beach of the Yellow River and the coastal area of Tianjin.

4.2 Analysis of dynamic mechanism of land use transition

By using a spatial econometric regression analysis method derived from previous studies, a correlation analysis was performed between five main land use transition types and their driving factors in the Huang-Huai-Hai Plain (Anselin *et al*., 2006). First, the SHP format file and the attribute table file were prepared in ArcGIS10.3 and then the spatial weight matrix was generated in GeoDa software based on the above files. Second, choosing five land use transition types at the county level as the dependent variables and the distance to the main road, urbanization rate and other quantitative driving factors as the independent variables, then using the spatial weights file and selecting the regression model in GeoDa software, the quantitative relationship of land use transitions and their driving factors, including the direction and intensity with which the driving factors acted on land use transition, were analyzed. Finally, the efficiencies of the three regression models were compared according to the results of the analysis: if the Lagrange multiplier (error) was more significant than the Lagrange multiplier (lag), SLM was more efficient, otherwise SEM was more efficient; if both were not significant, the OLS model was more efficient. The results of the spatial dependence test showed that the Lagrange multiplier (error) was more significant than the Lagrange multiplier (lag), indicating that SLM was more efficient in our analysis (Table 3). Therefore, SLM was chosen to analyze the correlations between the five main land use transition types and their driving factors in this study. In terms of the fitting effect detection of the regression model, in addition to the fitting coefficient R^2, there is also the log likelihood (LogL), the Akaike information criterion (AIC) and the Schwartz criterion (SC). The greater the LogL and the smaller the AIC and SC, the better the model fitting effect (Wu and Li, 2006). The results show that the fitting efficiency of SLM and SEM were better than that of OLS (Table 4).

Table 3 Results of spatial dependence test of land use transitions in the Huang-Huai-Hai Plain

Spatial dependence test	FL to CL	FL to FR	FL to WB	GL to FL	UL to FL
Lagrange Multiplier (lag)	8.0688^{***}	5.1099^{**}	24.4261^{***}	16.5650^{***}	2.9741^{*}
Robust LM (lag)	9.4343^{***}	3.2083^{*}	3.9966^{**}	25.0583^{***}	15.7590^{***}
Lagrange Multiplier (error)	2.4292	2.8466^{*}	20.8213^{***}	4.0138^{**}	0.4368
Robust LM (error)	3.7947^{*}	0.9451	0.3918	12.5071^{***}	13.2217^{***}

Note: FL: farmland; CL: construction land; FR: forested land; WB: water body; GL: grassland; UL: unused land.
*: Significance at 10%; **: significance at 5%; ***: significance at 1%.

The spatial econometric regression analysis results at the county level showed that all the factors had significant effects on the five land use transitions, except for distance to the municipal administrative center and highway traffic mileage. Generally speaking, the five types of land use transition in the Huang-Huai-Hai Plain were the results of interaction of a variety of driving factors, such as natural factors, the social and economic factor, the law and policy factor and the land engineering factor, during which the transportation and location conditions were estimated to be the common driving factors as both had significant impacts on all

Table 4 Spatial regression analysis results of land use transitions and their driving factors in the Huang-Huai-Hai Plain

Driving factor	Farmland to Construction land			Farmland to Forested land			Farmland to Water body			Grassland to Farmland			Unused land to Farmland		
	OLS	SLM	SEM	OLS	SLM	SEM	OLS	SLM	SEM	OLS	SLM	SEM	OLS	SLM	SEM
Dis2R	−143.66[b]	−64.15[c]	−345.97[c]	−1014.76[b]	−840.36[b]	−956.53[b]	−219.61	−157.95	359.36	−67.93	56.68	−0.61	−119.17	−130.19	−111.42
Dis2W	1077.73	833.62	773.48	775.34	680.93	811.69	551.28	337.83	−217.11	2249.05[c]	1726.61[b]	2099.82[b]	2841.64[c]	2551.55[c]	2729.74[c]
Dis2County	−37103.58[c]	−34827.11[c]	−36055.71[c]	8503.34[a]	8194.15[a]	7746.31[a]	15659.97[c]	13451.48[c]	12528.61[c]	14970.72[c]	15661.88[c]	14803.22[c]	11609.99[c]	10453.65[c]	10745.89[c]
Dis2City	−2859.03	−2679.38	−2745.47	−1155.81	−1091.21	−1157.22	−589.72	−444.40	268.42	248.68	95.65	24.97	1005.55	854.57	950.47
Dis2Province	−3083.95	−2332.59	−2944.74	−299.85	−214.50	−222.14	676.04	347.25	604.22	−165.77	−165.06	−219.61	−790.56[c]	−719.48[b]	−794.60[c]
Average annual rainfall	13.62[b]	10.37[a]	13.46[a]	−0.64	−0.76	−0.74	3.10[c]	2.01[b]	4.52[c]	−2.29	-1.76	−1.82	−0.52	-0.27	-0.31
DEM	−11.14[b]	−9.39[a]	−9.76[a]	1.44	1.45	1.66	−2.11[a]	−1.90[a]	−2.13[b]	9.98[c]	7.92[c]	8.55[c]	−5.70[c]	−4.96[c]	−5.18[c]
Dis2River	−2947.68[b]	−2222.54[a]	−2638.73[a]	411.39	248.48	352.53	−589.09[c]	−432.30[c]	−715.66[c]	1172.07[b]	607.47[a]	927.70[a]	605.80	529.57	619.79
Added value of the first industry	−1525.45	−1275.89	−1312.93	453.28	453.90	454.08	499.67[c]	368.64[c]	238.88[c]	144.30	95.26	102.22	253.81	173.78	191.78
Total population	7385.19[b]	8113.04[b]	8167.44[b]	203.72	458.61	468.64	−716.75	−646.39	−658.79	−2143.30	−2323.95	−2457.62	635.92	499.99	416.40
GDP per capita	−250.03	−174.60	−253.39	−63.93	−84.08	−87.48	−1.91	−41.70	−125.35	−26.56	−79.92	−97.86	−20.52	−52.57	−64.42
Rural per capita net income	1410.13	1173.76	1233.80	931.87[c]	873.62[c]	944.45[c]	−457.65	−266.91	167.18	300.02	366.44	472.22	−325.93	−331.86	−366.70
Highway traffic mileage	12.01	23.54	4.40	−71.05	−56.52	−48.91	−65.48	−36.86	−15.16	186.24	243.53	224.56	73.90	66.80	67.23
Urbanization rate	−1502.34	−2919.67	−3709.90	5878.68[c]	5484.91[b]	5743.23[b]	2588.86	1857.16	1635.77	2615.92	3486.18	3940.19	602.06	556.56	577.76
Local financial expenditure	−4.80	−5.25	−4.65	−1.52	−1.53	−1.88	3.50[c]	3.25[c]	2.94[c]	−2.97	−2.68	−2.59	0.17	−0.30	−0.24
W-Y		0.21[c]			0.21[c]			0.40[c]			0.27[c]			0.17[b]	
Lambda			0.15[a]			0.19[b]			0.60[c]			0.22[b]			0.11
R^2	0.54	0.57	0.55	0.30	0.33	0.32	0.65	0.71	0.74	0.47	0.51	0.49	0.20	0.22	0.21
LogL	−1852.52	−1848.75	−1851.23	−1584.22	−1581.36	−1582.46	−1561.42	−1547.93	−1543.94	−1659.46	−1652.62	−1657.06	−1662.15	−1660.5	−1661.77
AIC	3743.04	3737.5	3740.47	3206.44	3202.72	3202.93	3160.85	3135.87	3125.89	3356.92	3345.24	3352.13	3362.3	3361	3361.55
SC	3804.53	3802.23	3801.96	3267.93	3267.45	3264.42	3222.34	3200.6	3187.38	3418.41	3409.96	3413.62	3423.8	3425.73	3423.04

Note: a: significance at 10%; b: significance at 5%; c: significance at 1%; Dis2R: distance to main road; Dis2W: distance to main railway; Dis2City: distance to city-level administrative center; Dis2County: distance to county-level administrative center; Dis2Province: distance to provincial-level administrative center; Dis2R: distance to main river.

types of land use transition. Moreover, the spatial econometric regression analysis results of farmland that was transformed to forested land and unused land that was transformed to farmland were not ideal because these two types of land use transition were distributed so centrally in the Huang-Huai-Hai Plain that they affected the results of the regression analysis; the other three types of land use transition were ideal in behavior. In addition, the distance to the county-level administrative center had a significant impact on the five land use transitions among all the driving factors although its direction of action and intensity were different . The other driving factors had no significant impacts on the five land use transition types. For example, law and policy driving factors only had a significant effect on the farmland that was transformed to forested land and water body, while the increase in population only had a significant effect on grassland and unused land that was transformed to farmland. The detailed analysis of the dynamic mechanism of the five types of land use transition is as follows:

(1) Farmland that was transformed to construction land was distributed widely in the Huang-Huai-Hai Plain. The transition from farmland to construction land had a significant correlation with the distance to the county-level administrative center and the main road at the 1% significant negative level, with the total population at the 5% significant positive level, with the average annual rainfall at the 10% significant positive level, and with DEM and the distance to the main river at the 10% significant negative level. Therefore, the main driving factors for farmland that was transformed into construction land were the distance to the county-level administrative center, the main road and the main river, the total population, the average annual rainfall and DEM, indicating that farmland that was transformed into construction land occurred mainly close to towns, main roads and rivers. Areas with dense population, greater average annual rainfall and flat terrain were also prone to trigger this type of land use transition. Among the above driving factors, the distance to the county-level administrative center and the main road had the most significant impact on farmland that was transformed into construction land, indicating that farmland with better location conditions was more likely to be transformed into construction land. For example, in rural China, farmers have traditionally liked to build their houses along the sides of roads, which has caused loss of farmland. In particular, the size of the total population had significant effects on farmland that was transformed into construction land but had no significant effects on the other four land use transition types. Therefore, with increase in population, farmland was rapidly transformed into construction land, especially if it had good location conditions.

(2) The transition from farmland to forested land had a significant correlation with rural per capita net income at the 1% significant positive level, with the urbanization rate at the 5% significant positive level, with the distance to the main road at the 5% significant negative level, and with the distance to the county-level administrative center at the 10% significant positive level. Therefore, the main driving factors of farmland that was transformed into forested land were rural per capita net income and urbanization rate and distance to the main road and the county-level administrative center. In particular, rural per capita net income and urbanization rate only had a significant effect on the transition of farmland to forested land but had no significant effect on the transition of the other four land use transition types. Through investigation in the rural areas of Shandong Province the number of migrant workers was found to be increasing, as this can bring them higher income in the form of wages.

Against this background, an increasing number of farmers planted trees instead of food crops on their own farmland when they traveled to find work. In addition, the local government, driven by economic interests, did not actually oppose tree planting on farmland because it brought increased revenue (Zhao *et al*., 2012). This can explain why a large quantity of farmland was transformed into forested land at a rapid rate during 2000–2010. Farmland in ecologically fragile areas was easily affected by "returning farmland to forest", "ecological forestry" and other related policies, such as "plain afforestation" in Beijing.

(3) The transition from farmland to water body involved mainly the transformation to aquaculture land. This had a significant correlation with the distance to the county-level administrative center, the added value of the primary industry and local financial expenditure at the 1% significant positive level, with the distance to main rivers at the 1% significant negative level, with average annual rainfall at the 5% significant positive level, and with DEM at the 10% significant negative level. Therefore, the main driving factors of farmland that was transformed into water body were the distance to the main river, the average annual rainfall, DEM, the distance to the county-level administrative center, the added value of the primary industry and local financial expenditure, indicating that farmland that was transformed into water body occurred mainly close to main rivers, far away from county administrative centers and in places with flat terrain and greater average annual rainfall which had good natural conditions for aquaculture. The changes in added value of the primary industry and local financial expenditure were the direct external driving forces for the transition from farmland into water body, but they had no significant effect on the transition of the other four land use transition types. This study in Shandong and Henan provinces also proved the results of the above analysis. In order to improve local fiscal revenue and agricultural production, these areas tried to increase the scale of aquaculture, so the area of the water body was enlarged. The essence of the transition from farmland to water body is the transition from the cultivation of traditional grain crops to aquaculture driven by profit and guided by local policies.

(4) The transition from grassland to farmland had a significant correlation with the distance to the county-level administrative center and DEM at the 1% significant negative level and with distance to the main railway and the main river at the 5% significant positive level. Therefore, the main driving factors of grassland that was transformed to construction land were the distance to the county-level administrative center, the main railway, the main river and DEM, indicating that grassland that was transformed into farmland occurred mainly far away from the county-level administrative center, the main railway and river, but was likely to occur in hilly areas with high terrain. As is well known, an increase in population and food pressures was the major reason for grassland to be transformed into farmland, but the analysis results showed that the main areas of grassland that were transformed into farmland were not the same as the areas with higher population density. Therefore, the total population factor did not show a significant correlation with the transition of grassland to farmland. Grassland that was transformed into farmland occurred mainly in hilly areas with ecologically fragile environments in the Huang-Huai-Hai Plain, thus these areas under great population and food pressures led to such a transition. It is a vicious circle that the expansion of farmland led to a reduction in grassland and the destruction of ecological systems in hilly areas. Thus, there needs to be a slow down or cessation in the trend of grassland being

transformed into farmland in these areas in order to promote the recovery of vegetation and increase the trend in farmland being restored to forested land and grassland.

(5) The transition from unused land to farmland had a significant correlation with the distance to the main railway at the 1% significant positive level, with DEM at the 1% significant negative level, with the distance to the county-level administrative center at the 5% significant positive level, and with the distance to the provincial-level administrative center at the 5% significant negative level. Therefore, the main driving factors for the transformation of unused land to farmland were the distance to the county-level administrative center, the provincial-level administrative center, the main railway and DEM, indicating that unused land that was transformed to farmland occurred mainly in areas with low terrain, close to the provincial-level administrative center, far away from the county-level administrative center and the main railway. The results of the analysis showed that the main areas of unused land that were transformed into farmland were not the same as those areas with higher population density. Therefore, in the analysis of the driving mechanism of unused land that was transformed into farmland, the variation in total population did not show a significant correlation either. The Yellow River Delta in Shandong Province was the most typical area of unused land that was transformed into farmland in the Huang-Huai-Hai Plain and *The Official Reply of the State Council on the Development Plan of the Yellow River Delta Efficient Ecological Economic Zone* (State Council, 2009) pointed out that "constructing the Yellow River Delta into a nationally important reserve land resource development zone". Based on the premise of not destroying the ecological system, it is right that the gradual trend for the transition of unused land to suitable farmland, which reflects the influence of national laws and their associated driving policy, be advanced (Wang *et al*., 2005). Moreover, the technology and expertise obtained from past wasteland and tideland reclamation could provide important technical support in this endeavor.

5 Discussion and conclusions

This paper investigated five types of land use transition in the Huang-Huai-Hai Plain based on Landsat TM image data for the years 2000, 2005 and 2010 using ArcGIS software and the established conceptual framework of the dynamic mechanism of land use transition. A spatial econometric regression analysis method was used to analyze the dynamic mechanism of these five types of major land use transition. The results indicated that land use patterns in this region changed significantly and were characterized by an increase in construction land, water body and forested land, along with a decrease in farmland, unused land and grassland during the study period. The changes during the period 2000–2005 were much more significant than those during 2005–2010. In the first five years, land use transition was characterized mainly by farmland and unused land that was transformed into construction land and farmland that was transformed into forested land, grassland and water body. In the following five years, land use transition was characterized mainly by farmland that was transformed into construction land and water body as well as forested land and grassland and unused land that were transformed into farmland.

Land use transition is a result of natural, social, economic, legal, institutional and engineering factors interacting with each other in a specific region. On this basis, the conceptual framework of the dynamic mechanism of land use transition was established, which includes a natural driving factor, a social and economic driving factor, a law and policy driving factor and a land engineering driving factor. Then, based on the county-level spatial econometric regression analysis, it was found that traffic condition and location condition, which both belong to the social and economic driving factor, had significant effects on all five types of land use transition, and so they can be regarded as the common driving factors of land use transition in the Huang-Huai-Hai Plain. In addition, the dynamic mechanisms of the five types of land use transition are different in terms of both the direction and intensity with which the driving factors acted on land use transition.

Land use transition in the Huang-Huai-Hai Plain is based on regional, natural and geographical conditions and is a comprehensive result of economic development, population flow, policy control and the ideas and customs of farmers all interacting with each other. Local governments at different levels should not only consider all the major driving factors of land use transition, the law of regional differentiation and social and economic development, but they also need to fully consider the suitability and degree of difficulty of different types of land use transition. Only in this way can land consolidation, development, reclamation and other land resource engineering be advanced more scientifically. On this premise, land use transition would take place in line with the appropriate regional, economic and social development stage of each area. In future, more attention should be paid to the study of land recessive morphology changes by focusing on the small spatial scale in order to promote land resource management transition (Long, 2015), e.g., transforming pure quantitative management to quantitative, qualitative and ecologically comprehensive management and optimizing the allocation and effective use of land resources.

References

Anselin L, Syabri I, Kho Y, 2006. GeoDa: An introduction to spatial data analysis. *Geographical Analysis*, 38(1): 5–22.

Cai Y, 2001. A study on land use/cover change: The need for a new integrated approach. *Geographical Research*, 20(6): 645–652. (in Chinese)

Chen B, Zhang F, 2011. Trend and priority areas in land use research of China. *Geographical Research*, 30(1): 1–9. (in Chinese)

Guo H, Xu Y, Yao J, 1991. Rural Geography in the Huang-Huai-Hai Region. Shijiazhuang: Hebei Science and Technology Press. (in Chinese)

Kong X, 2012. The Influence of Land Use Transition of Regional Peasant Household on Farmland Quality. Beijing: Science Press. (in Chinese)

Kong X B, Lai R, Li B G *et al*., 2014. Fertilizer intensification and its impacts in China's HHH plains. *Advances in Agronomy*, 125: 135–169.

Lambin E F, Meyfroidt P, 2010. Land use transitions: Socio-ecological feedback versus socio-economic change. *Land Use Policy*, 27: 108–118.

Li P, Li X, Liu X, 2001. Macro-analysis on the driving forces of the land use change in China. *Geographical Research*, 20(2): 129–138. (in Chinese)

Li T, Long H, Liu Y *et al*., 2015. Multi-scale analysis of rural housing land transition under China's rapid urbanization: The case of Bohai Rim. *Habitat International*, 48: 227–238.

Li X, 2002. Explanation of land use change. *Progress in Geography*, 21(3): 195–203. (in Chinese)

Li Y, Liu Y, Long H, 2011. Study on the pattern and types of rural development in the Huang-Huai-Hai region.

Geographical Research, 30(9): 1637–1647. (in Chinese)

Li Y, Liu Y, Long H, 2012. Characteristics and mechanism of village transformation development in typical regions of the Huang-Huai-Hai Plain. *Acta Geographica Sinica*, 67(6): 771–782. (in Chinese)

Liu R, Zhu D, 2010. Methods for detecting land use changes based on the land use transition matrix. *Resources Science*, 32(8): 1544–1550. (in Chinese)

Liu Y, 2015. Integrated land research and land resources engineering. *Resources Science*, 37(1): 1–8. (in Chinese)

Liu Y, Liao L, Long H *et al*., 2015a. Effects of land use transitions on ecosystem services value: A case study of Hunan province. *Geographical Research*, 34(4): 691–700. (in Chinese)

Liu Y, Long H, Li T *et al*., 2015b. Land use transitions and their effects on water environment in Huang-Huai-Hai Plain, China. *Land Use Policy*, 47: 293–301.

Long H, 2014a. Land use policy in China: Introduction. *Land Use Policy*, 40: 1–5.

Long H, 2014b. Land consolidation: An indispensable way of spatial restructuring in rural China. *Journal of Geographical Sciences*, 24(2): 211–225.

Long H, 2015. Land use transition and land management. *Geographical Research*, 34(9): 1607–1618. (in Chinese)

Long H, Li T, 2012. The coupling characteristics and mechanism of farmland and rural housing land transition in China. *Journal of Geographical Sciences*, 22(3): 548–562.

Long H, Li X, 2002. Analysis on regional land use transition: A case study in a transect of the Yangtze River. *Journal of Natural Resources*, 17(2): 144–149. (in Chinese)

Long H, Tang G, Li X *et al*., 2007. Socio-economic driving forces of land-use change in Kunshan, the Yangtze River Delta Economic Area of China. *Journal of Environmental Management*, 83(3): 351–364.

Lv L, Zhou S, Zhou B *et al*., 2013. Land use transformation and its eco-environmental response in process of the regional development: A case study of Jiangsu province. *Scientia Geographica Sinica*, 33(12): 1442–1449. (in Chinese)

Qiu J, 2010. China faces up to groundwater crisis. *Nature*, 466: 308.

Shao J, Li Y, Wei C *et al*., 2007. The drivers of land use change at regional scale: Assessment and prospects. *Advances in Earth Science*, 22(8): 798–808. (in Chinese)

Wang J, Su F, Zhou C *et al*., 2005. On effects of coastal location and management policy on land use changes in coastal zone: A case study of Golden Coastal Region in Changli County. *Geographical Research*, 24(4): 520–527. (in Chinese)

Wu Y, Li J, 2006. A spatial econometric analysis of industry total factor productivity in China's provincial regions. *Scientia Geographica Sinica*, 26(4): 385–391. (in Chinese)

Xie H, Li B, 2008. Driving forces analysis of land-use pattern changes based on a logistic regression model in the farming-pastoral zone: A case study of Ongiud Banner, Inner Mongolia. *Geographical Research*, 27(2): 294–304. (in Chinese)

Zhang X, Kong X, 2014. Cropland sustainable use impacted by groundwater depletion in China's HHH Plains. *China Land Sciences*, 28(5): 90–96. (in Chinese)

Zhao Y, Li X, Xin L *et al*., 2012. The driving forces of "poplar expansion and cropland shrinkage" in the North China Plain: A case study of Wen'an County, Hebei Province. *Geographical Research*, 31(2): 323–332. (in Chinese)

Zhou N, Hao J, Xing T *et al*., 2012. The spatial configuration of transport superiority in Huang-Huai-Hai Plain. *Economic Geography*, 32(8): 23–31. (in Chinese)

Zhu H, He S, Zhang M, 2001. Driving forces analysis of land use change in Bohai Rim. *Geographical Research*, 20(6): 669–678. (in Chinese)