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Characterizing Spatiotemporal Pattern of Land Use Change and Its Driving Force Based on GIS and Landscape Analysis Techniques in Tianjin during 2000–2015

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Abstract: The spatial and temporal characteristics and driving factors analysis of regional land use are the core scientific problems in the research of ecological environment and human sustainable development. It is also an important basis for the government to formulate land management policy. Based on the land use maps of 2000, 2005, 2010 and 2015, this article analyzed the spatiotemporal pattern of land use change in Tianjin, and determined the relative importance of each driving factor of land use change. The main features of land use change were the continuous expansion of built-up land (1386.89 km^2/74.73% gains) and the decrease of arable land area (1181.60 km^2/16.84% losses). The area and intensity of land use change were not completely consistent, such as Wuqing and Jixian. The hotspots of land use change mainly were located in the main urban region in Tianjin, around the suburban settlements and Binhai New Area. The landscape pattern in the research region has also changed significantly. The Largest patch index (LPI) and largest shape index (LSI) of arable land showed an increasing trend, and the degree of landscape fragmentation of arable land was deepened. The trend of landscape index of built-up land was similar to that of arable land, but the change intensity was more severe. In addition, the article also used the stepwise regression analysis in the multiple regression to analyze the relative importance of various driving factors, indicating that the driving factors of the built-up land and arable land change were obviously different in different periods. Government policies also have a significant impact on land use change, such as establishing the Tianjin Binhai New Area (TBNA).

Keywords: spatial pattern; landscape pattern index; land use dynamic change; driving factor; Tianjin

1. Introduction

Land use/land cover change (LUCC) has been a traditional and important research topic in both local and globe scales. It is widely acknowledged that the LUCC is a primary cause of ecological environment deterioration and habitat destruction. Human activities often accelerate the speed of LUCC, especially in economically active regions. Land use change influences the global ecological environment and sustainable human development [1–3]; thus, it has received attention from an increasing number of researchers worldwide. In-depth studies of land use/cover change (LUCC) have been conducted on various scales and achieved extensive valuable results [4–10]. These results mainly include findings regarding spatiotemporal changes in land use [11–14], the relation between land use change and its driving forces [15,16], the simulation of land use change [17–19], and the impact of land use change [19–23]. Over the previous 30 years, the globe has experienced rapid urbanization.

With migration to central cities, human activities have not only changed original land cover types in central cities but also profoundly influenced the process of land use change [24]. China, the largest developing country in the world, is also experiencing a transition from an agricultural society to an industrial and information society. In this country, the population has concentrated in the major cities of regions, particularly in the Beijing-Tianjin-Hebei region, Yangtze River Delta, and Pearl River Delta. In these regions, the land use/cover types have undergone profound changes. Large areas of arable land, wood land, grass land, and unused land have been converted to built-up land, with profound changes in regional land structures [25–28]. Sustainable land use is an inevitable choice for the region development as land resources continue to decrease. To better manage and effectively use land resources, it is critical to monitor land use change and its driving forces in these regions [29,30].

Efficient utilization of land resources is an important approach to sustainable land use. Sustainable land use means that the development, utilization, protection and management of land resources is aimed to coordinate the relationship between people and land and between people and resources and environment to meet the needs of contemporary people and future generations survival and development through a series of rational land use management in the specific period and geographical condition. The core content of sustainable land use is coordination and justice [31]. Sustainable land use needs to understand the quantitative and spatial characteristics of regional land use [32], to study the core driving forces of regional land use change [33], to assess the ecological importance of land use [34], to reconstruct the land use structure [35] and to explore the dynamic mechanism of land use change [36]. Thus, a comprehensive understanding of status and characteristics of regional land use can provide scientific guidance for the regional land use management departments to formulate polices of sustainable land use. Being one of the three largest economically developed regions in China, the Beijing-Tianjin-Hebei region is a hotspot of rapid urbanization and development [37] and land use change has been particularly intense there after 2000 [38]. At the national strategic level, the Beijing-Tianjin-Hebei region is the core area of North China, including Beijing, Tianjin, Hebei, Shanxi and Neimenggu. The capital city of Beijing has always been China's political, economic, and cultural center and is the economic core of the Beijing-Tianjin-Hebei region. However, Beijing has encountered increasingly serious problems in urban planning and land use with the constant expansion of the city. These urban problems are mainly manifested as traffic congestion and land use tensions. To promote synergistic development of the Beijing-Tianjin-Hebei region, the State Council of China promulgated the "Beijing-Tianjin-Hebei Synergistic Development Plan". The main purpose of the plan was to reduce the non-capital functions of Beijing (non-capital function, a concept proposed by Chinese Government to promote regional development, mainly refers to the relatively low-end, low value-add economic management and service functions) and transfer some industries from Beijing to the surrounding areas, particularly Tianjin. This movement is bound to cause dramatic land use change in Tianjin. Learning the characteristics of historic land use change and its driving forces in Tianjin is conducive to rational planning of future land use patterns in Tianjin. Existing research concerning the characteristics of land use change in the Beijing-Tianjin-Hebei region has focused mainly on Beijing [39–42] and the entire region [43–47], while less work has focused on Tianjin specifically [48,49]. Studies of land use in Tianjin have included no detailed analysis of the intensity of land use change, the spatial characteristics of land use transitions, and the landscape index since 2000. The majority of previous studies of land use change in Tianjin qualitatively analyzed the causes of this change [49,50]. Fewer quantitative studies are available, and there is a particular lack of studies evaluating the relative importance of driving factors of land use change and investigating the variations in driving forces. The study was conducted at the following three levels: first, land use classification data for Tianjin were used to explore the spatiotemporal dynamics of land use in the study area based on a detailed analysis of quantitative, spatial, and dynamic changes in land use in Tianjin since 2000, the land types considered in this study mainly include ecological land (wood land, grass land, water body, unused land), arable land and built-up land. Second, changes in the quantities and spatial structure of land use will inevitably change regional landscape patterns. In this study, the landscape index was used to analyze the change in the landscape pattern of land use in Tianjin, which allowed us to fully understand the overall state of land use change in Tianjin on the landscape scale. Finally, a multivariate regression model was used to quantitatively analyze the relative importance of various driving factors of land use in Tianjin and their changes during the study period. This study is expected to provide scientific data and a basis for decision-making regarding land planning in Tianjin to allow the city to better take on the non-capital functions of Beijing and promote the synergetic development of the Beijing-Tianjin-Hebei region.

Based on the characteristics of land use change in Tianjin from 2000 to 2015, the study provides detailed land use data for land use management. The departments of land use management can formulate the land use planning strategies for the characteristics of regional land use change to make rational use of ecological land, arable land and built-up land according to the quantitative and spatial distribution of land use change. In order to ensure the rational development of the region land use, the ecological land and arable land should be protected so as to promote the level of the sustainable land use in Tianjin, reduce the fragmentation of arable land and improve the quantity and quality of ecological land. At the same time, the weight of land use driving forces can promote the land management departments to formulate targeted land control measures and reduce the negative impact of the main driving factors on land use. Therefore, the research results have an important innovation value to land use management departments.

2. Study Area and Data Sources

The Tianjin study area encompasses the region of 116°43′–118°04′E, 38°34′–40°15′N. As Figure 1 shows, Tianjin is located in the northeastern part of the North China Plain. It is located on the western shore of the Bohai Sea and near the Yanshan Mountains, which are to the north. The five tributaries of the Haihe River converge in Tianjin, and the Haihe River traverses the city. Tianjin is the central city of the economic zone around the Bohai Sea in China and is the transportation hub of northern and northeastern China. Tianjin measures 11,916.9 km^2 in area, making it the largest coastal city in China in terms of land area. The Tianjin Binhai New Area (TBNA) has been called "the third pole of economic growth in China". Tianjin is situated at the downstream ends of nine rivers, and large areas consist of water bodies. Local wetlands measure 2487.8 km^2, accounting for 20.9% of the total land area of Tianjin. There are more than 100 reservoirs and lakes, 98 primary and secondary streams, and more than 5800 ponds and depressions. National and provincial nature reserves including the Qilihai Wetland, Beidagang Wetland, Dahuangbao Wetland, and Tuanbowa Wetland cover ~63.6% of the total wetland area of Tianjin. In addition to water, the major land uses in Tianjin are arable land and built-up land. Small areas of wood land and grass land are distributed mainly in the Yanshan Mountains to the north.

Tianjin governs 17 districts and counties including nine urban districts (Nankai, Heping, Hexi, Hedong, Hebei, Dongli, Jinnan, Xiqing, and Beichen), Wuqing District, Baodi District, Ninghe District, Jinghai District, and Jixian, and the TBNA includes Tanggu District, Dagang District, and Hangu District (Figure 1). The population of Tianjin is 15.47 million (2015), 10.27 million (2015) of which are urban residents, indicating a highly urban population. The urban population is mainly concentrated in the urban districts and the TBNA. The city has a multi-center structure, with the urban districts and the TBNA as the centers containing large populations and resources. As a major port city in northern China, Tianjin has long been an important economic center in northern China and the core city in the economic development zone around the Bohai Sea. With the continual expansion of the population and economic development, land use in Tianjin has experienced constant and profound changes. In particular, the TBNA became a state-level economic development zone in 2005. Since then, China and Tianjin have formulated numerous regional development policies to promote the development of the TBNA, consisting mainly of infrastructure construction and industrial transfer. These policies played an important role in social development in Tianjin, while some of the policies directly influenced land use decisions. Therefore, we selected Tianjin as the study area. Quantitative study of the characteristics and spatial pattern of land use change can improve our understanding of the mechanism of land use change and help in developing more-effective regional land development planning and natural resource management policies.

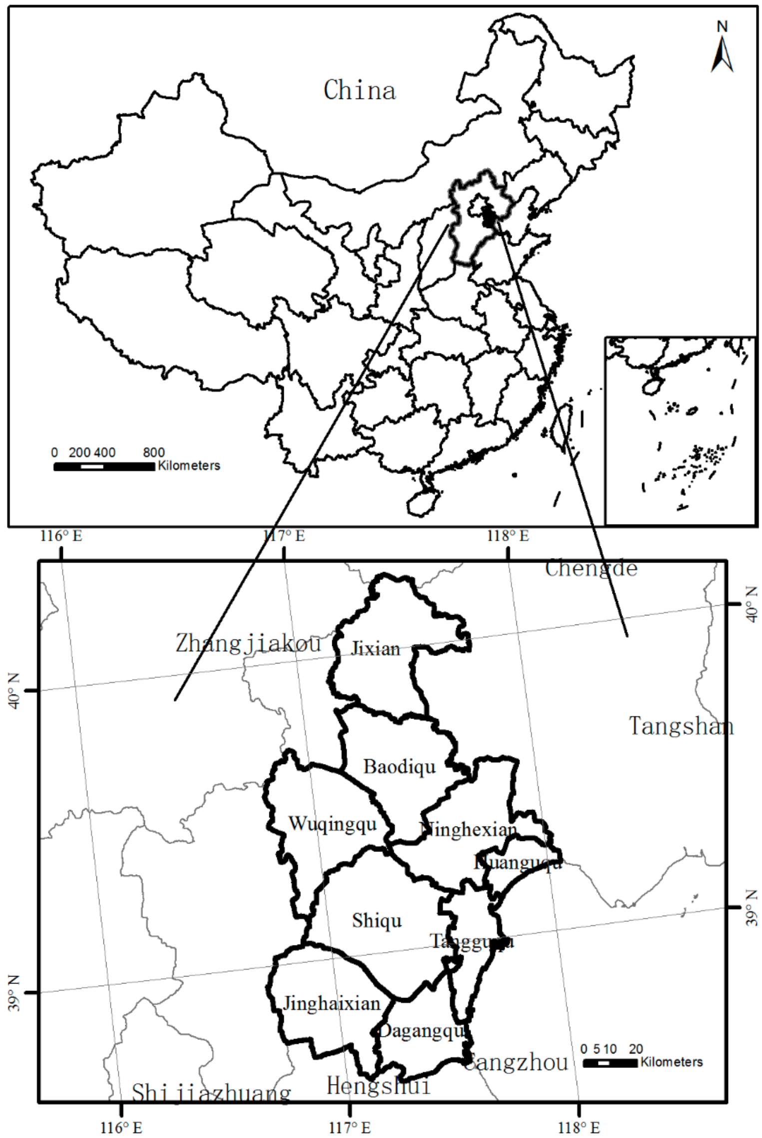

Figure 1. Location of Study Area.

The research chose land use data and socio-economic statistic data for analysis. The classification data of land use (30 m resolution) was provided by the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) in 2000, 2005, 2010 and 2015. The land use database was acquired by the rapid extraction of Human–Computer interaction based on remote sensing spectrum information. The Landsat TM images were interpreted to build the 30 m resolution land use database covering the whole of China from 2000 to 2015. While the Landsat TM data could not cover the whole of China or the quality of TM images was poor, the CCD multispectral data of HJ-1 could be as a supplement [51–53]. In order to ensure the quality and consistency of data acquisition, the researchers examined the quality of each data and the process of data integration. Before the early development of land use database, the field investigation would be carried out to access a large number of records and photos in the autumn of the north or in the spring of the south in China. Ten percent of counties of China were randomly selected to carry out accuracy verification of land use database.

The accuracy of the comprehensive evaluation of land use type was more than 94.3%, which met the user mapping accuracy of 30 m resolution [51,53].

The data, with the accuracy over 90%, met requirements for land use change analysis [53–55]. Based on IGBP LUCC and the research objective, a land use classification system (Tier I) was adopted. The system included six categories: arable land, wood land, grass land, water body, built-up land and unused land. To increase understanding of regional land use characteristics, field investigations and interviews were also conducted in Tianjin.

To analyze the driving forces of land use change in Tianjin, we used socio-economic statistical data, mainly data from the *Tianjin Statistical Yearbook* (2000–2015) [56], including economic development data and population data. Previous studies have shown that land use change is driven by numerous factors, among which population change and economic development are the most important [57–60]. Therefore, we selected four representative elements associated with population and economic development for analysis: the permanent population (PP), urban population (UP), gross national product (GDP), and fixed asset investment (FAI). These elements were used to analyze the mechanisms driving changes in the areas of built-up land and arable land in Tianjin, which in turn will provide scientific data and a basis for decision-making for land use planning and rational land use in this city.

3. Methods

There were four methods used in this study. The land use change intensity and land use transfer matrix were used to analyze the temporal and spatial characteristics of land use change in Tianjin. The land use change intensity referred to the area change rate of main land types of each grid in the period, which could detect the regional differences of land use change. The grid with the higher land use change intensity showed the larger area of land use change. The land use transfer matrix was a common land use change analysis method, which could obtain the area and spatial location of land use change to reflect the dynamic change characteristics of land use. From the macroscopic point of view, the landscape pattern index was used to analyze the characteristics of the landscape pattern change when the area and spatial distribution of land use changed in the region, which was one of the characteristics of regional land use change. In addition, this study also used the stepwise regression model to detect the influence of driving forces of land use change. The area and driving factors were input into the model to acquire the weight of driving factors.

3.1. Dynamic Changes in Land Use

The rate of land use change can reflect the trend and intensity of regional land use change. To evaluate the land use changes in the study area, we used the rate of land use change to analyze the trend of land use change in Tianjin during the 2000–2015 period.

$$T_{land} = \frac{A_{t2} - A_{t1}}{A_{t1}} \times 100 \quad (1)$$

where T_{land} is the rate of change of a given type of land use, A_{t2} and A_{t1} are the areas of the land use at time points $t1$ and $t2$, respectively, and t is the interval of the study period. T_{land} reflects the general trend of change in a specific land use. To further analyze the spatial distribution of land use change intensity in the study area, we performed a grid analysis based on existing research results [61]. The study area was divided into 1 km × 1 km cells, and land use data were plotted on the resulting grid. Information regarding major land use types was assigned to each cell to obtain the spatial distribution of land use change intensity and to analyze the spatial distribution of changes in land use in the study area.

3.2. Characteristics of Land Use Transitions

The land use transition matrix in Equation (2) was used to reveal the land use structure at a specific time in the region. This matrix quantitatively describes the process of conversions between various land types at the beginning and end of the study, and it indicates the conversions among the various land uses/covers [62]. We used land use data for Tianjin at four time points marking three time periods between 2000 and 2015. Spatial analysis and statistical analysis were conducted on the land use data in four stages using the spatial analysis modules of ArcGIS 10.3 (Environmental Systems Research Institute (Esri): Redlands, CA, USA, 2014) and ENVI 5.3 (Exelis Visual Information Solutions: Boulder, CO, USA, 2015) to obtain land use transition matrices for the periods of 2000–2005, 2005–2010, and 2010–2015 in Tianjin. The land use transition matrices can identify the intensity and direction of conversion between various land uses, thereby allowing for in-depth analysis of the quantities and structural characteristics of land use changes in the study area over the 15-year interval. Meanwhile, we developed a map of land use transitions during the three periods using the post-processing module of image classification in ENVI 5.3 (Exelis Visual Information Solutions: Boulder, CO, USA, 2015). This map was used to analyze the spatial variations in land use transitions in Tianjin over the 15-year interval and to explore the active areas of land use change.

$$Area_{ij} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & \cdots & A_{1n} \\ A_{21} & A_{22} & A_{23} & \ldots & A_{2n} \\ A_{31} & A_{32} & A_{33} & \ldots & A_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ A_{n1} & A_{n2} & A_{n3} & \cdots & A_{nn} \end{bmatrix} \tag{2}$$

where n is the total number of land use/cover types, i and j range from 1 to n, and $Area_{ij}$ is the area of conversion from land use i to land use j within the time range of t to $t + 1$.

3.3. Patterns of Spatial Changes in Land Use

Regional land use change is bound to alter the regional landscape structure and influence the sustainable development of a regional eco-environment [63]. The landscape pattern index has been extensively used to describe the structure and pattern of a regional landscape and to express the spatial distribution and forms of patches of land uses. LPIs also reflect the overall characteristics of regional land use structure and the characteristics of transitions in spatial patterns of regional land use [64–67]. Thus, we calculated the LPIs for our land type grid using Fragstats 4.2 software (UMass Landscape Ecology Lab: Amherst, MA, USA, 2015) to characterize the spatial patterns of changes in land use in Tianjin.

Number of patches (NP) is equal to the total number of patches of a patch class in the landscape at the class level. It reflects the spatial level of the landscape, often used to represent the heterogeneity of landscape, the size of the NP value is also positively correlated with the fragmentation of landscape. The general rule is that the higher the NP, the higher the fragmentation.

Largest patch index (LPI) LPI is a dominance index that quantifies the percentage of the largest patch in the total landscape area. When the largest patch in the landscape is small, LPI approaches 0; when the entire landscape consists of a single patch, the LPI is 100. LPI can help to determine the dominant type of landscape, the value of which can represent the intensity and frequency of interference, reflecting the direction and strength of human activities.

The largest shape index (LSI) represents the relationship between a landscape boundary and a landscape area. This index reflects the irregularities of landscape patches. The LSI is calculated using the Equation (3)

$$\text{LSI} = \frac{0.25E}{\sqrt{A}} \tag{3}$$

where E is the total length of boundaries of all patches in the landscape, and A is the total area of the landscape. When the LSI = 1, the landscape consists of a single patch, and as the patch becomes irregular, the LSI increases. The LSI reflects the landscape shape: the higher the LSI, the more complex the shape.

3.4. Driving Forces of Land Use Change

In the multivariate linear regression model, variables that have multicollinearity can be filtered and removed using a stepwise regression. First, the explained variable is simply regressed on each explanatory variable taken into consideration. Then, based on the regression equation that corresponds to the explanatory variable making the largest contribution to the explained variable, the remaining explanatory variables are introduced stepwise. Following the stepwise regression, the explanatory variables that eventually remain in the model are important and exhibit no significant multicollinearity. In multivariate linear regression (MLR), the standardized regression coefficient is a dimensionless unit that can be used to compare the intensity of the impact of each independent variable on the dependent variable. Generally, a greater absolute value of a standardized regression coefficient indicates a greater impact of the independent variable on the dependent variable on the premise of statistical significance. We performed stepwise regression on typical land use areas and selected driving factors. The standardized regression coefficient of each driving factor was obtained, and the impacts of the selected driving factors on land use changes were analyzed. The statistical analysis was performed using SPSS 22 (International Business Machines Corporation (IBM): Armonk, MA, USA, 2015).

4. Research Results

4.1. Analysis of Spatiotemporal Changes in Land Use in Tianjin

4.1.1. Quantities and Spatial Distribution of Land Use

Based on the land use classification data for Tianjin spanning the 2000–2015 period, we developed four spatial distribution maps of land use at four different times in Tianjin (Figure 2). We also obtained a year-based statistical table of the quantities of land uses (Table 1) in Tianjin and analyzed the quantities and spatial characteristics of land use changes in Tianjin since 2000. The results showed that the major land use/cover in Tianjin was arable land, followed by built-up land and water. Arable land was generally distributed throughout the study area except in the mountainous area of Jixian in the north. This arable land was interlaced with rural settlements and showed a high degree of fragmentation. Its area accounted for ~50% of the total land area and decreased from 51.61% in 2000 to 47.53% in 2015. During that period, the arable land area shrank by ~4%, at a rate of 25.68 km^2/year. This rate of decrease was relatively high mainly because large areas of arable land underwent urbanization in Tianjin.

Built-up land was the second largest land use in the study area. Built-up land was distributed mainly around the main districts in central Tianjin and the TBNA and showed a distinct trend of concentration. A dispersed distribution of built-up land was noted in rural settlements in the northern and southern areas of Tianjin. Built-up land accounted for approximately 20% of the total land area and showed rapid growth, increasing from 13.65% in 2000 to 22.09% in 2015. During this period, built-up land increased ~8.44%, at a growth rate of 81.78 km^2/year, or ~2%. This increase in built-up land was alarming and was the highest among all land uses, reflecting rapid expansion of the city and constant growth of industrial development in Tianjin.

Water was another major land use/cover in Tianjin and was distributed mainly in the east-central part of the study area, around the Haihe River, and in the port area of the TBNA adjacent to the Bohai Sea. Tianjin lies adjacent to the lower reaches of the Haihe River estuary, which contains numerous rivers, reservoirs, and lakes. These water bodies include the Haihe River; the Tuanbowa Reservoir, Yadian Reservoir, Yuqiao Reservoir of Jixian, Jinhu Lake, and Dongli Lake in the south; and the massive harbor in the TBNA in the east. Water constituted ~12% of the land area, although its area fluctuated: it decreased from 14.33% in 2000 to 10.26% in 2010 (a decrease of ~4%) but increased from 10.26% in 2010 to 12.51% in 2015 (an increase of nearly 2%). The decrease in water area from 2000 to 2010 was mainly due to continual shrinking of natural water bodies, whereas the increase from 2010 to 2015 was attributed mainly to an increase of harbor areas in the TBNA.

There were small areas of wood land, grass land, and unused land in the study area. These three land uses constituted only 2.51%, 0.73%, and 0.19% of the total land area, respectively, in 2015. Their distributions were relatively constant and exerted little impact on the land distribution pattern. Marine land cover appeared only in 2010. (The emergence of marine land cover was due to the marine reclamation land in the coast of Tianjin. In 2010, marine reclamation land had not yet been completed, only to determine the boundaries of reclamation. The area was covered by seawater within the boundaries. Therefore, the land use type was defined as the ocean. In 2015, the marine reclamation land had been completed, the region became land and was developed for built-up land.) Thus, the trends in these land types were not analyzed further.

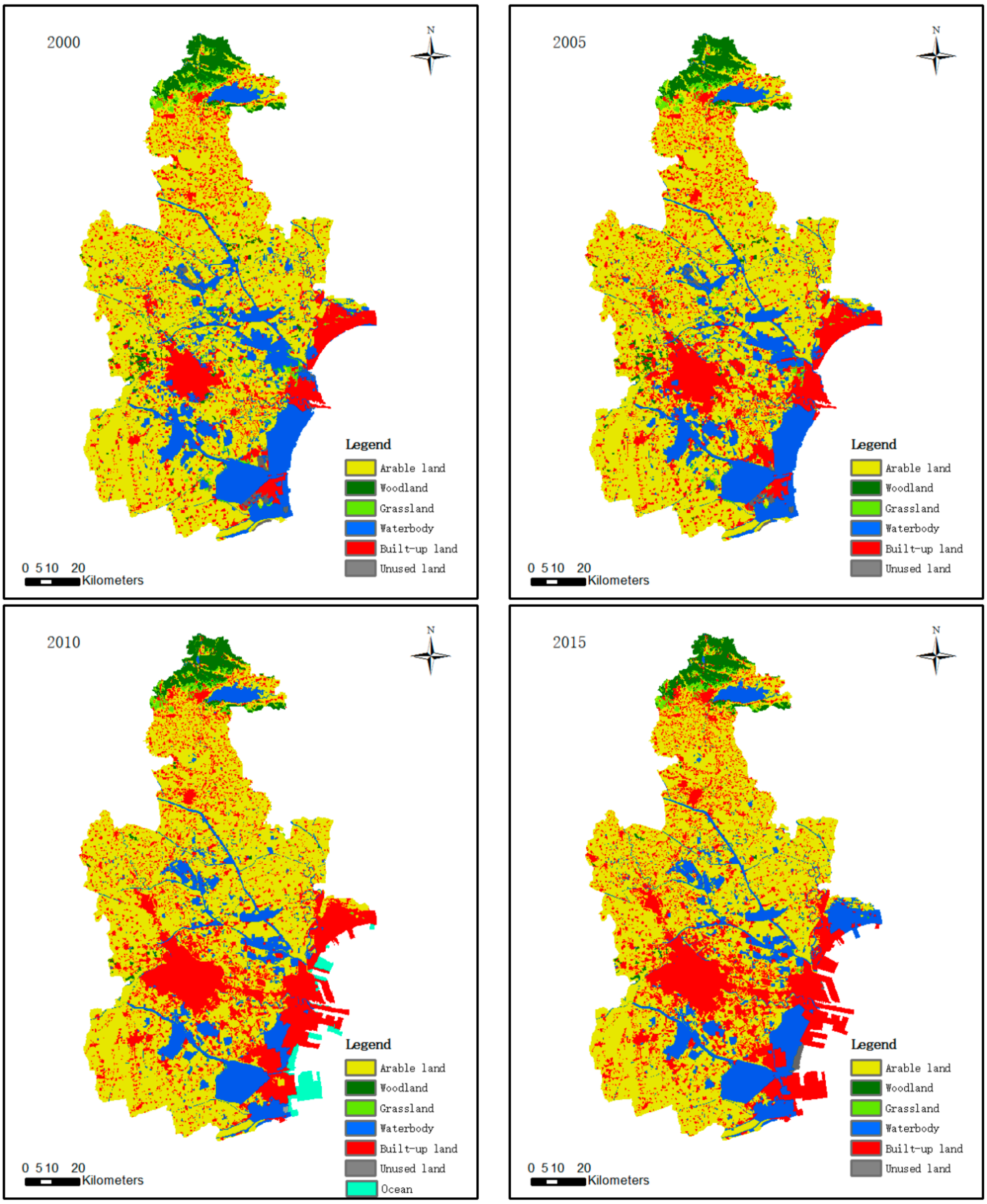

Figure 2. Land use spatial distribution in Tianjin from 2000 to 2015.

Table 1. Land use type structure in Tianjin.

Land Type		2000	2005	2010	2015
Arable land	Area (km^2)	7017.84	6809.35	6921.41	6632.58
	Proportion (%)	60.51	58.71	57.97	55.55
Wood land	Area (km^2)	465.96	446.96	349.50	349.92
	Proportion (%)	4.02	3.85	2.93	2.93
Grass land	Area (km^2)	225.14	194.45	99.12	101.86
	Proportion (%)	1.68	1.68	0.83	0.85
Water body	Area (km^2)	1948.64	1822.30	1412.46	1745.99
	Proportion (%)	16.80	15.71	11.83	14.62
Built-up land	Area (km^2)	1855.98	2263.56	2963.62	3082.72
	Proportion (%)	16.00	19.52	24.82	25.82
Unused land	Area (km^2)	85.00	61.93	6.26	26.87
	Proportion (%)	0.73	0.53	0.05	0.23
Ocean	Area (km^2)	0	0	187.5	0
	Proportion (%)	0	0	1.57	0

4.1.2. Analysis of Land Use Change Intensity

Land use change intensity can reflect the development rate and intensity of regional land use. To study the spatial distribution of land use change intensity in Tianjin, we calculated the land use change intensity in Tianjin using a Equation (1), followed by grid transformation. Figure 3 shows that, during the 2000–2005 period, the total area of land use changes in the study area measured ~3753 km^2; the annual rate of change was 625.5 km^2/year. The regions of land use changes varied significantly: the primary region was located in the central districts and the TBNA. The area of land use change in the municipal district of Tianjin was 1303 km^2, accounting for ~34.7% of the total area of land use change. Smaller areas of land use change were identified in the north and south. The average intensity of land use change was 3.69% in Tianjin during the 2000–2005 period. The hotspots were located in the municipal districts, Tanggu District, and Dagang District, where the change intensities were 9.89%, 5.96% and 4.62%, respectively. These three regions showed the most intense land use changes in Tianjin.

During the 2005–2010 period, the land use change markedly accelerated. The area of regional land use change was 9465 km^2, which represents an increase of nearly 1.5-fold compared with the previous period. The annual rate of change was 1577.5 km^2/year. More hotspots appeared in other places outside the municipal districts of Tianjin. During this period, the most significant characteristic was that land use changes occurred in rural settlements and around the districts and counties in Tianjin, particularly Wuqing, Jixian and Baodi, where the area of land use change was ~4219 km^2 (~44.6% of the total area of land use change). The average intensity of land use change in Tianjin was 12% during this period, which was an almost three-fold increase compared with the previous period. The land use intensity increased significantly, and the hotspots included the municipal districts of Tianjin, Tanggu District, and Hangu District, where the change intensities were 23.9%, 20.8%, and 19.2%, respectively. These districts were hotspots of land use in Tianjin during this period.

During the 2010–2015 period, the rate of land use change was markedly higher than that of the previous period. The area of regional land use change was 4124 km^2, which was only approximately half of that of the 2005–2010 period. The annual rate of change was 687.3 km^2/year. These land use changes occurred mainly in the municipal districts of Tianjin, Wuqing District, and Jixian. The land use change intensity in Tianjin was 3.36%, similar to that of the 2010–2015 period. The hotspots were located in the Hangu District, Tanggu District, and municipal districts, where the change intensities were 6.29%, 5.74% and 4.88%, respectively.

The above analysis revealed that the area and intensity of land use change in Tianjin gradually increased during the 2000–2010 period and peaked in 2010; the land use change intensity decreased during the 2010–2015 period. The area and intensity of regional land use change were not completely consistent. Regions with large areas of land use change such as Wuqing and Jixian might display low change intensities. During this period, the hotspots of land use change in Tianjin were concentrated in the municipal districts and the TBNA (Tanggu, Dagang, and Hangu). These two regions generally contained the largest areas and intensities of land use change during the various periods, mainly due to the urban development planning in Tianjin and the state-level new area of TBNA.

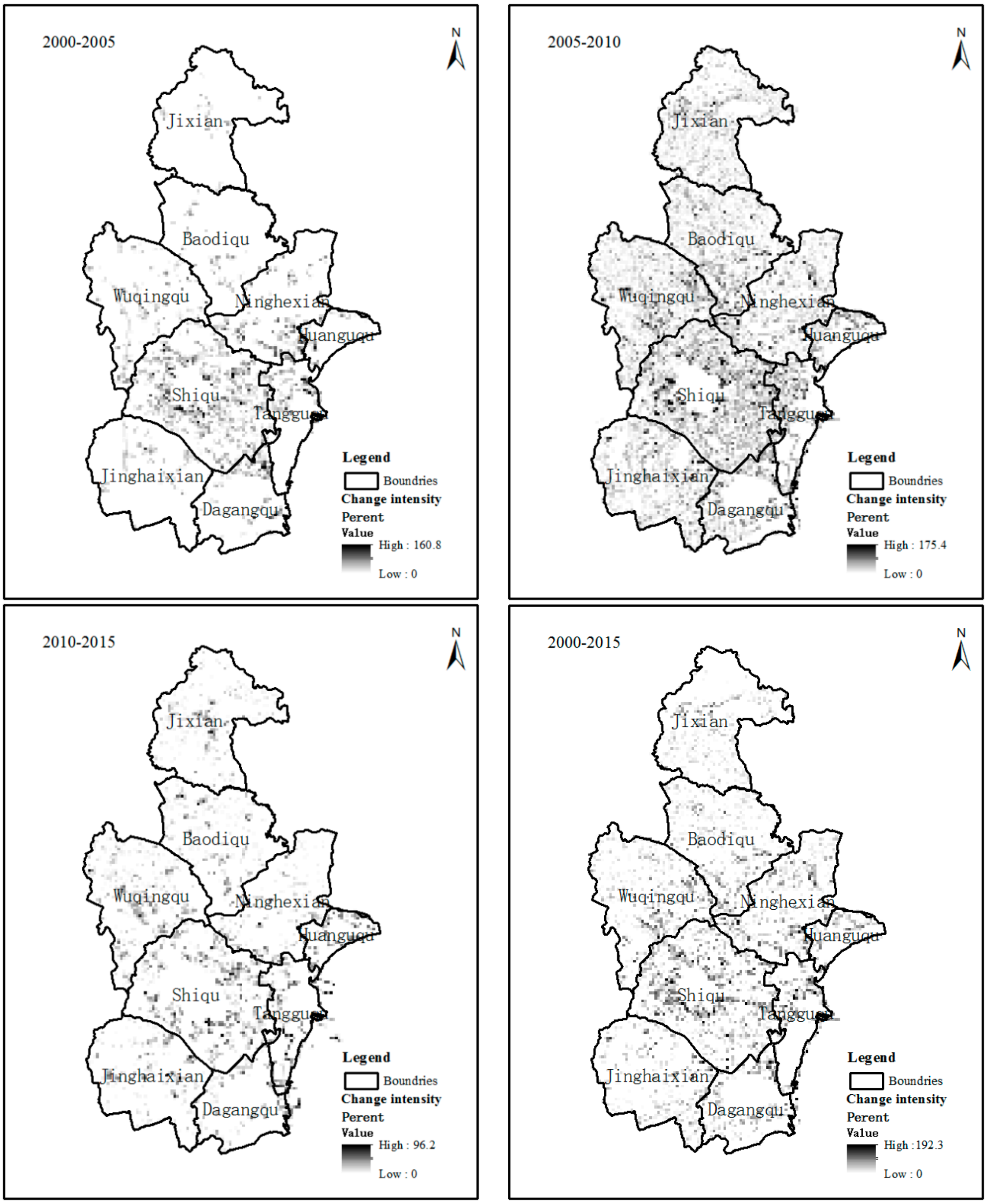

Figure 3. Spatial distribution of land use change intensity from 2000 to 2015.

4.2. Analysis of Land Use Transition Characteristics

4.2.1. Analysis of Main Land Use Conversions

Tables 2–5 show the land use transition matrices for the study area during the 2000–2005, 2005–2010, and 2010–2015 periods, respectively. During the 2000–2005 period (Table 2), arable land was mainly converted to built-up land and water; of these, built-up land ranked highest and accounted for ~92% of the decrease in arable land. Meanwhile, there was conversion of 83.67 km^2 of arable land to water and built-up land, accounting for 82% of the conversion. Thus, the land uses/covers most closely related to arable land were built-up land and water, particularly the former. This pattern can be attributed to the land policy of "Balance of Arable Land" in China: arable land taken up by building construction must be compensated for by a corresponding area of arable land. Wood land was converted mainly to built-up land and arable land. This conversion measured 21.31 km^2, which accounted for 4.7% of the wood land area in 2000. The major land type conversion from wood land was arable land. Grass land and water were converted mainly to built-up land and arable land. The land area converted from grass land was relatively small, and 39.8 km^2 was converted to water. The major land type conversions from water were arable land and grass land, i.e., 75.9% of the land area converted in water body. A small area of built-up land was converted, mainly to arable land, whereas a large area was converted to built-up land, i.e., ~19%, by 2005. The major land type conversions from built-up land were arable land and water. Large areas of unused land were converted, mainly to built-up land and water. The loss of unused land accounted for ~36.9% of the unused land in 2000, while a very small area was converted to unused land. This trend reflects the rapid land development associated with the economic development during this period.

During the 2005–2010 period (Table 3), the land use transition matrix differed from that of the previous period because of an addition of marine land to land use in 2010. The marine land type was mainly converted from water and built-up land. Other land types did not change in terms of their directions of conversion. Nonetheless, the converted land area significantly increased, indicating an increase in regional land use intensity. Among the various land uses, the area converted from built-up land to arable land showed the largest increase: a 26-fold increase. There was conversion of 613.21 km^2 of arable land to built-up land, which was a two-fold increase compared with the previous period. These findings indicate that conversions between arable and built-up land became more frequent in the study area. This trend slowed during the 2010–2015 period (Table 4). The area of built-up land converted to arable land decreased, whereas the area converted to water significantly increased. No changes were noted in the conversion directions of other land types, and the converted area decreased. These phenomena indicate that land development tended to be stable in the study area during this period.

To further understand the changes in major land types in Tianjin, we calculated the net area of conversions from major land types in the city during the 2000–2015 period. Table 6 shows that the net area of conversion from arable land to built-up land was always positive and relatively large. This trend suggests that arable land was continually being lost to built-up land during this period. During the 2000–2010 period, the net area of conversion from arable land to water was negative, indicating that water was an important supplementary source of arable land during this period. However, this trend reversed during the 2010–2015 period. This finding suggests that in addition to being converted mainly to built-up land, arable land was also converted to water during this period, further exacerbating the reduction of arable land. The net area of conversion from built-up land to water was similar to that of conversion from arable land to water. During the first two periods, water provided one of the sources of built-up land; however, during the 2010–2015 period, 284.62 km^2 of built-up land was converted to water. The land use transitions in Tianjin were characterized mainly by a rapid decrease in arable land, a significant increase in built-up land, and drastic fluctuations in the area of water. Table 7 provides more detailed information regarding land use change based on categories in different periods.

Table 2. Conversion matrix of land use from 2000 to 2005.

2000		2005					
		Arable Land	Wood Land	Grass Land	Water Body	Built-Up Land	Unused Land
Arable land	km^2	6707.18	2.45	0.38	21.54	286.28	0.00
	%	95.57	0.03	0.01	0.31	4.08	0.00
Wood land	km^2	9.10	444.49	0.00	0.15	12.21	0.00
	%	1.95	95.39	0.00	0.03	2.62	0.00
Grass land	km^2	9.14	0.00	189.04	8.68	18.28	0.00
	%	4.06	0.00	83.96	3.86	8.12	0.00
Water body	km^2	68.12	0.00	2.66	1782.50	95.32	0.03
	%	3.50	0.00	0.14	91.47	4.89	0.00
Built-up land	km^2	15.55	0.01	2.34	4.61	1833.46	0.00
	%	0.84	0.00	0.13	0.25	98.79	0.00
Unused land	km^2	0.26	0.00	0.02	4.82	18.01	61.89
	%	0.31	0.00	0.03	5.67	21.19	72.81

Table 3. Conversion matrix of land use from 2005 to 2010.

2005		2010						
		Arable Land	Wood Land	Grass Land	Water Body	Built-Up Land	Unused Land	Ocean
Arable land	km^2	6043.51	0.92	0.86	150.47	613.21	0.00	0.00
	%	88.76	0.01	0.01	2.21	9.01	0.00	0.00
Wood land	km^2	75.22	345.67	0.61	1.86	23.49	0.00	0.00
	%	16.83	77.36	0.14	0.42	5.26	0.00	0.00
Grass land	km^2	52.70	0.68	92.99	12.15	35.89	0.00	0.00
	%	27.11	0.35	47.83	6.25	18.46	0.00	0.00
Water body	km^2	318.70	0.10	0.05	1186.24	300.77	0.04	13.40
	%	17.52	0.01	0.00	65.20	16.53	0.00	0.74
Built-up land	km^2	407.45	2.06	4.60	42.39	1806.75	0.00	0.26
	%	18.00	0.09	0.20	1.87	79.82	0.00	0.01
Unused land	km^2	22.95	0.00	0.00	19.32	13.42	6.22	0.01
	%	37.07	0.00	0.00	31.20	21.67	10.04	0.02

Table 4. Conversion matrix of land use from 2010 to 2015.

2010		2015					
		Arable Land	Wood Land	Grass Land	Water Body	Built-Up Land	Unused Land
Arable land	km^2	6612.24	3.22	5.24	56.81	243.85	0.05
	%	95.53	0.05	0.08	0.82	3.52	0.00
Wood land	km^2	0.94	346.62	0.02	0.04	1.88	0.00
	%	0.27	99.18	0.01	0.01	0.54	0.00
Grass land	km^2	0.27	0.00	96.59	1.11	1.15	0.00
	%	0.27	0.00	97.45	1.12	1.16	0.00
Water body	km^2	13.73	0.00	0.00	1385.47	13.26	0.00
	%	0.97	0.00	0.00	98.09	0.94	0.00
Built-up land	km^2	5.41	0.08	0.01	297.88	2660.24	0.00
	%	0.18	0.00	0.00	10.05	89.76	0.00
Unused land	km^2	0.00	0.00	0.00	4.04	0.70	1.52
	%	0.00	0.00	0.00	64.53	11.14	24.33
Ocean	km^2	0.00	0.00	0.00	0.64	161.65	25.30
	%	0.00	0.00	0.00	0.34	86.17	13.49

Table 5. Conversion matrix of land use from 2000 to 2015.

2000		2005					
		Arable Land	Wood Land	Grass Land	Water Body	Built-Up Land	Unused Land
Arable land	km^2	5835.86	3.38	3.14	183.98	991.06	0.05
	%	83.16	0.05	0.04	2.62	14.12	0.00
Wood land	km^2	81.07	344.21	0.65	2.30	37.61	0.00
	%	17.40	73.89	0.14	0.49	8.07	0.00
Grass land	km^2	55.59	0.71	93.39	25.74	49.65	0.00
	%	24.70	0.31	41.49	11.44	22.06	0.00
Water body	km^2	339.36	0.09	0.23	1322.49	276.14	7.33
	%	17.44	0.00	0.01	67.97	14.19	0.38
Built-up land	km^2	297.13	1.47	4.42	175.84	1376.92	0.14
	%	16.01	0.08	0.24	9.47	74.19	0.01
Unused land	km^2	23.10	0.00	0.01	27.94	32.43	1.51
	%	27.18	0.00	0.01	32.87	38.16	1.78

Table 6. Conversion net transfer-out (NT) for arable land, built-up land and Water body with other land use types in different periods.

Type Change		2000–2005	2005–2010	2010–2015	2000–2015
AL to BL	km^2	270.73	205.77	238.44	693.93
	%	3.86	3.02	3.44	9.89
AL to WB	km^2	−46.58	−168.24	43.09	−155.38
	%	−0.66	−2.40	0.62	−2.21
WB to AL	km^2	46.58	168.24	−43.09	155.38
	%	2.39	9.32	−3.05	7.97
WB to BL	km^2	90.70	258.38	−284.62	100.30
	%	4.65	14.31	−20.15	5.15
BL to AL	km^2	270.73	−205.77	−238.44	−693.93
	%	−11.96	−9.09	−8.05	−37.39
BL to WB	km^2	−90.70	−258.38	284.62	−100.30
	%	−4.89	−11.42	9.60	−5.40

Note: AL, arable land; BL, built-up land; WB, waterbody; NT, net transfer-out in area.

Table 7. The land use budget in different periods (unit: %).

	2000–2005				
	Gains	Losses	Swaps	Net Changes	Total Changes
Arable land	1.46	4.43	2.91	2.97	5.88
Wood land	0.53	4.61	1.06	4.08	5.14
Grass land	2.40	16.04	4.81	13.63	18.44
Water body	2.04	8.53	4.09	6.48	10.57
Built-up land	23.17	1.21	2.43	21.96	24.39
Unused land	0.04	27.19	0.08	27.15	27.23
	2005–2010				
	Gains	Losses	Swaps	Net Changes	Total Changes
Arable land	12.88	11.24	22.48	1.64	24.12
Wood land	0.84	22.64	1.68	21.80	23.48
Grass land	3.15	52.17	6.30	49.02	55.32
Water body	12.43	34.80	24.86	22.36	47.23
Built-up land	43.59	20.18	40.36	23.42	63.77
Unused land	0.06	89.96	0.12	89.90	90.02

Table 7. *Cont.*

	2010–2015				
	Gains	**Losses**	**Swaps**	**Net Changes**	**Total Changes**
Arable land	0.29	4.47	0.59	4.17	4.76
Wood land	0.94	0.82	1.65	0.12	1.77
Grass land	5.32	2.55	5.10	2.77	7.87
Water body	25.52	1.91	3.82	23.61	27.43
Built-up land	14.26	10.24	20.47	4.02	24.49
Unused land	405.19	75.67	151.34	329.53	480.86
	2000–2015				
	Gains	**Losses**	**Swaps**	**Net Changes**	**Total Changes**
Arable land	11.35	16.84	22.69	5.49	28.18
Wood land	1.21	26.11	2.42	24.90	27.32
Grass land	3.76	58.51	7.51	54.75	62.26
Water body	21.37	32.03	42.74	10.66	53.40
Built-up land	74.73	25.81	51.62	48.92	100.54
Unused land	8.84	98.22	17.68	89.38	107.06

Note: total change: expresses the overall change (gains and losses) between two land use change maps (dates); Net change: the absolute balance of the sum of gains and losses for each land use category; Swaps: the difference between total change and net change that expresses a change of allocation without a change of quantity.

4.2.2. Spatial Distribution of Land Use Transitions

Figure 4 illustrates the distribution of land use transitions in the study area during the three periods between 2000 and 2015 (the area of minimum surface > 40 km^2). Land use transitions occurred mainly around urban and rural settlements in Tianjin and in the TBNA. The area of land use transition was largest during the 2005–2010 period, and the land use transition was the most intense during this period. This pattern occurred mainly because the TBNA was listed in the "Eleventh Five-Year Plan" and was included in national development strategies in 2005. Thus, it became a state-level new area supported by state priorities for development and opening. Correspondingly, the city of Tianjin entered a stage of high-speed development during the period of 2005–2010, which also promoted large-scale frequent transitions of land use in this city. Given the different characteristics of land use transitions during the various periods, we analyzed the spatial differences in the transitions of major land use types (arable land, water, and built-up land) in Tianjin on the scale of counties and districts.

Arable land underwent the most intense transition. During the 2000–2005 period, arable land transitions mainly occurred around the old main districts in central Tianjin, including Wuqing and Tanggu. This arable land was converted mainly to built-up land. During this urban development, agriculture gradually weakened, and large areas of arable land were converted to built-up land due to expansion of the city. During the 2005–2010 period, the area of arable land transition significantly expanded. Key arable land transitions also occurred in Hangu and Jinghai in addition to those around the main districts of Tanggu, and Wuqing. Another pattern characterizing this period was the conversion of arable land around rural settlements. This conversion was mainly due to the intensive use of rural land as a result of re-zoning in rural settlements and their surrounding areas. In the southern part of Baodi and northeastern part of Wuqing, some arable land was also converted to water. During the 2010–2015 period, arable land transitions in the main districts of Tianjin were concentrated mainly in the eastern part of the main districts and in Wuqing and Jinghai.

During the 2000–2005 period, transition of water areas occurred mainly in Ninghe County in the east and northeast of Tianjin, in the TBNA, and in the southern part of the urban districts. Water was converted mainly to arable land in Ninghe and to built-up land in the southern part of the urban districts and in the TBNA. During the 2005–2010 period, the water transition area continued to expand. Beyond Ninghe, transitions of water to farmland occurred in the southern part of the urban districts, northern Jinghai, and southern Baodi. Meanwhile, large areas of water were converted to built-up land in the eastern and southern parts of Tanggu near the Bohai Sea. This change occurred mainly because the establishment of the TBNA promoted port construction in Tianjin and thus some areas of water were converted to port facilities. During the 2010–2015 period, the transitions of water occurred mainly in Tanggu, Hangu and Dagang Districts of the TBNA. These waters near the sea were converted to built-up land.

Conversion to built-up land occurred mainly during the 2000–2015 period, and the area of built-up land expanded in various districts and counties during this period. Due to agricultural land consolidation, built-up land around rural settlements in the rural area of Tianjin was partially converted to arable land during the 2005–2010 period. Some built-up land was converted to water in northern Hangu and in eastern and southern Tanggu during the 2010–2015 period, mainly due to port construction in the TBNA.

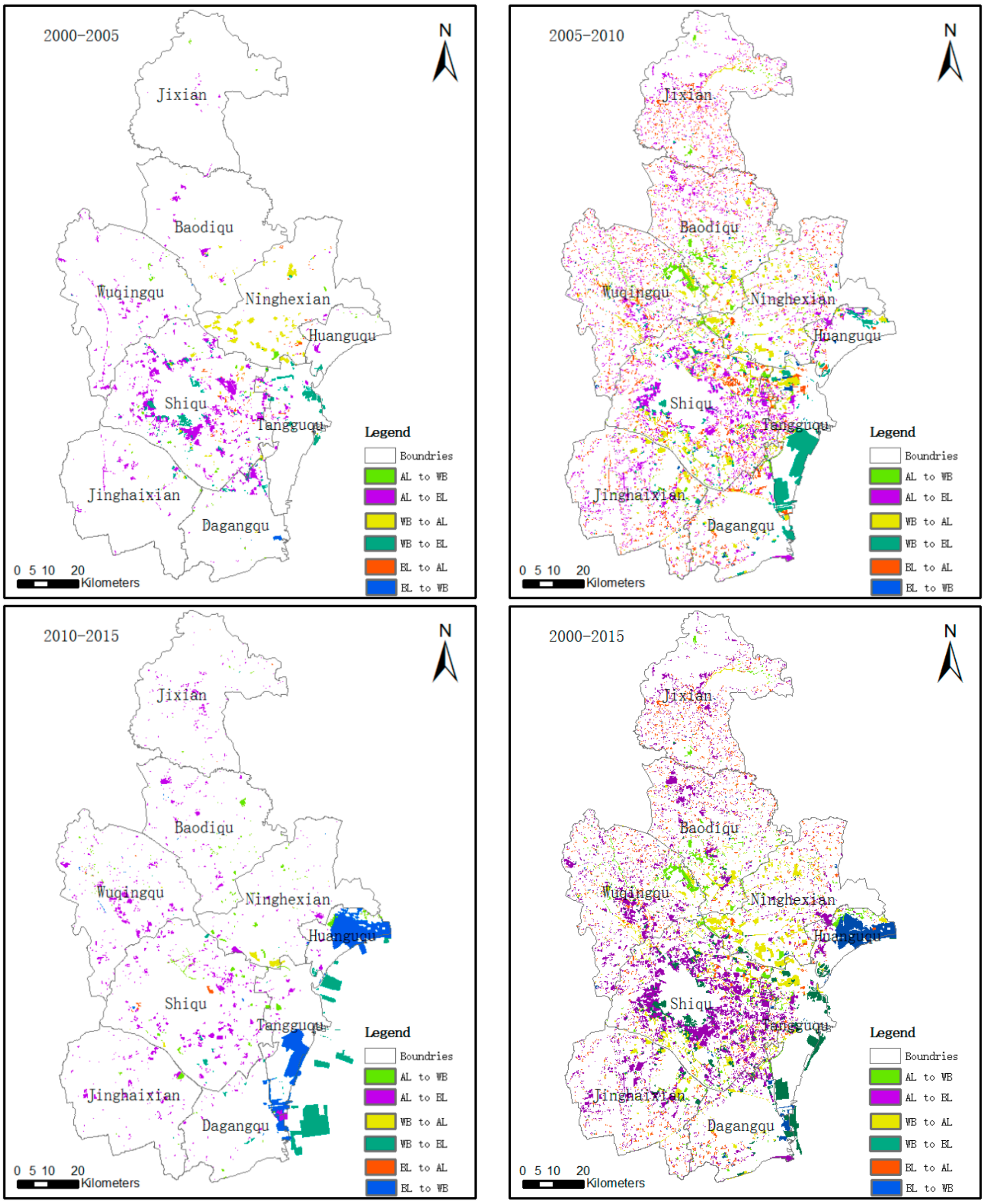

Figure 4. Spatial distribution of land use transition from 2000 to 2015. Note: The minimum surface is 40 km^2 to choose six transitions from the total.

4.3. Metrics of Land Use Change

With the changes in areas and the spatial distribution of land use in Tianjin from 2000 to 2015, the spatial pattern and shape of land use also underwent corresponding changes. We calculated the LPI of land use in Tianjin using Fragstats 4.2 and explored the characteristics of LPI changes for various land types in the study area. Table 8 shows that during the 2000–2015 period, the LPIs of various land types differed. Although the area of arable land continued to decrease, its number of patches (NP) initial increased, then decreased, and then increased again. By 2005, the NP of arable land in the study area had increased to 292, and the fragmentation of arable land was greatest during the 2000–2005 period. The LPI showed fluctuating increases, and reached a maximum of 20.1% in 2010. This changed indicates that despite the increasing impact on arable land by human activity, land consolidation was occurring with the changes in arable land use. Thus, arable land use became more intensive and advantageous. Its LSI continually increased and reached 58.54 in 2015, indicating that the shapes of arable land patches became more irregular under the impact of human activities.

The area of water decreased in Tianjin between 2000 and 2010. This area increased by 2015, but the increase was small. The NP of water body rapidly increased every year. In particular, during the 2005–2015 period, the NP of water increased 71%, indicating the increasing fragmentation of water areas during this period. During the period of 2000–2010, the LPI of water decreased significantly. In particular, in 2005–2010, the LPI of water decreased 74%. The LPI increased again by 2015, which was mainly related to the acceleration of urbanization and occupation of large water areas in Tianjin. The LSI of water also decreased, but relatively little. This decrease indicates that the shapes of water patches became more regular, in contrast to the trend in arable land. The discrepancy between different land use types was mainly due to different land use strategies applied to water and arable land.

Over the study period, the NP of built-up land constantly increased, by ~26%, while the built-up land area increased 66%. This change indicates that, despite the increase in the NP of built-up land, more increase occurred in the area of built-up land during this period, with a moderate degree of fragmentation. However, the LPI of built-up land sharply increased, by a factor of nearly three, from 2.38% to 6.66%. This increase indicates a clear pattern of aggregation of built-up land in Tianjin. The LSI of built-up land increased every year, indicating that the shapes of built-up land patches gradually became more irregular. This trend was similar to that of the arable land and reflected a close conversion relationship between these two land uses (arable land and built-up land). The areas of the other three land uses (wood land, grass land and unused land) constantly decreased, and their NPs, LPIs, and LSIs decreased. This trend reflects the increasingly smaller scale and concentrated distribution of the three land types in Tianjin.

On a landscape scale, the NP of landscape in Tianjin increased every year, and this increase was relatively large. This increase suggests that, against a background of increased urbanization intensity, the fragmentation of land use increased significantly in the study area. The LSI increase indicated that the shapes of the patches became increasingly irregular. The indices on the landscape scale of the study area exhibited trends similar to those of the landscape indices of built-up land, suggesting that the landscape change was mainly influenced by built-up land in Tianjin.

Table 8. Landscape metrics change of land use from 2000 to 2015.

Land Use Type	NP				LPI (%)				LSI			
	2000	2005	2010	2015	2000	2005	2010	2015	2000	2005	2010	2015
Arable land	209	292	210	235	13.08	13.00	20.07	19.22	48.59	51.02	54.59	58.54
Wood land	257	262	78	80	2.19	2.19	2.00	2.02	22.30	21.83	16.07	16.50
Grass land	251	283	108	116	0.28	0.27	0.26	0.17	29.99	30.85	22.10	22.95
Water bady	588	589	838	1010	12.67	11.85	3.08	5.00	40.17	39.68	34.69	35.63
Built-up land	2821	2809	3476	3582	2.38	3.49	6.31	6.66	62.86	64.31	65.46	68.92
Unused land	31	34	4	5	0.18	0.17	0.03	0.19	11.52	11.08	3.72	3.46
Landscape	4157	4269	4732	5028	13.08	12.99	20.07	19.22	45.75	47.38	47.25	50.14

4.4. Analysis of Driving Forces

4.4.1. Economic and Population Development

Research has shown that regional land use change is driven by various factors. Population aggregation and economic development are two major driving forces of land use change [68–70]. Built-up land and arable land show high correlations with regional population size and economic development [71,72]. Due to the dual urban-rural structure in China, there are huge differences between urban and rural areas in terms of infrastructure, employment opportunities, education levels, and health care. These differences promote the migration of rural populations to cities, which is an important driving factor affecting regional land use change. Therefore, we selected Permanent Population (PP) and Urban Population (UP) as the driving factors regarding the population. Since its reform and opening, China has experienced rapid economic development, particularly in the China's Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta regions. During the 2000–2015 period, average annual Gross Domestic Product (GDP) grew nearly 10-fold in Tianjin and the reached 1.6 trillion Yuan in 2015. With the growth of the economy and rising incomes, the government invested in infrastructure and raised living standard in cities, which increased the amount of built-up land while shrinking the area of arable land. At the same time, the growth of infrastructure and residential buildings would significantly increase Fixed Assets Investment (FAI). Therefore, we selected GDP and FAI as the indicators of driving forces at the level of economic development. Data regarding these driving factors were derived from the *Tianjin Statistical Yearbook* [56].

Over the 16 years, the population and economic level showed uninterrupted growth in Tianjin. In particular, the FAI increased 21-fold by 2015 compared with that in 2000 (Figure 5). As might be expected, this development was the main cause of the increase in built-up land and the decrease in arable land. The population in the study area also increased every year. Irrespective of resident population or household registration population, there was a 1.5-fold increase. Among the household registration population, the rural household registration population decreased 5%. This trend was due to the migration from rural to urban areas, which also exacerbated the reduction of arable land and increase in built-up land.

To study the differences in the impacts of economic factors for regional populations on land use change in Tianjin, we established regression relationships among built-up land, arable land, and the driving factors by stepwise regression using a multivariate linear regression model. We also determined the impacts of the driving factors on the changes in land uses (the standardized coefficient is a dimensionless unit that can be used to compare the intensity of the impact of each independent variable on the dependent variable. Generally, a greater absolute value of a standardized coefficient indicates a greater impact of the independent variable on the dependent variable. MLR: multivariate linear regression.). Table 9 lists the standardized regression coefficients of built-up land and arable land on the driving factors in Tianjin during the 2000–2015 period. Among the four selected driving factors, the GDP and FAI representing the level of economic development exerted the largest impacts on the areas of built-up land and arable land. The GDP had the larger absolute value of the standardized regression coefficient (3.649 for BL, 5.682 for AL), indicating that GDP was the most important factor driving the changes in the areas of building and arable land. These impacts suggest that, overall, the level of economic development had a greater impact on built-up land and arable land than the demographic factors in the Tianjin region during the 2000–2015 period. The former was the most important driving force of the changes in land use areas and transitions between land uses in this region.

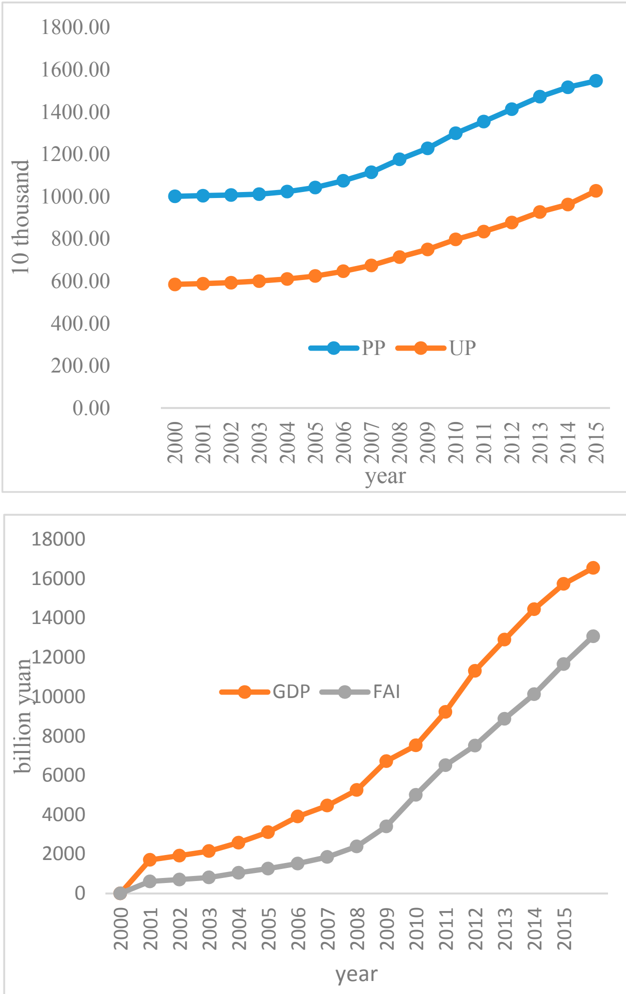

Figure 5. Change tendency of population and economic factor in Tianjin from 2000 to 2015. Note: PP, Permanent Population; UP, Urban Population; GDP, Gross Domestic Product; FAI, Fixed Assets Investment.

However, the driving factors of the change in built-up land and arable land areas were markedly different during the three periods. During the 2000–2005 period (Table 10), the FAI was the major driving factor of the change in BL area. The UP was the major driving factor that influenced the change in AL area. This change occurred mainly because with increasing UP, the expansion of living space caused the decrease in arable land area. During the 2005–2010 period (Table 11), the major driving factors changed. The UP became the major driving factor of changes in the BL area; there were no clear driving factor of changes in AL area during this period. During the 2010–2015 period (Table 12), the change in BL was mainly influenced by the GDP. There were two major factors influencing AL: the PP and GDP. The GDP had the larger absolute value of the standardized regression coefficient (4.620), indicating that GDP was the most important factor driving the changes in the areas of arable land These results indicate that the major driving factors of changes in the BL and AL varied, in agreement with previous findings [73]. The time scale is a key issue in studies of land use change. The driving forces of land use change may vary with different levels of socio-economic development. Therefore, the variation in the driving forces of land use change must be taken into consideration in the dynamic simulation of land use, and fixed driving factors should not be used to simulate land use change throughout the study period.

Table 9. MLR Standardized coefficients of BL and AL from 2000 to 2015.

	PP	UP	GDP	FAI
BL	-	-	3.649	−2.804
AL	-	-	−5.682	4.995

Significance, $p < 0.05$.

Table 10. MLR Standardized coefficients of BL and AL from 2000 to 2005.

	PP	UP	GDP	FAI
BL	-	-	-	0.923
AL	-	−0.932	-	-

Significance, $p < 0.01$.

Table 11. MLR Standardized coefficients of BL and AL from 2005 to 2010.

	PP	UP	GDP	FAI
BL	-	0.992	-	-
AL	-	-	-	-

Significance, $p < 0.01$.

Table 12. MLR Standardized coefficients of BL and AL from 2010 to 2015.

	PP	UP	GDP	FAI
BL	-	-	0.984	-
AL	3.664	-	−4.620	-

Significance, $p < 0.01$.

4.4.2. Government Policies

The government's land planning and industrial development policies can significantly influence land use change [74]. China has a population of 1.3 billion and faces serious food security and environmental problems. The government must develop the economy and improve living standards while maintaining environmental protections. During rapid economic development, more land will be taken up by housing, transportation, and industry. Large areas of arable land and unused land have been occupied, while built-up land has increased rapidly (Table 1). During the 2000–2005 period, the pace of development in Tianjin was relatively slow, leading to a large gap in the level of economic development between the municipal districts and other areas in the city. Thus, the size of built-up land expanded rapidly in the municipal districts (Figures 2 and 4), while the expansion was relatively slow in the other areas. In 2005, the TBNA was established. This area was listed in the "Eleventh Five-Year" plan and was included in the national development strategy. The TBNA became a state-level new area supported by state priorities for development and opening. As promoted by the national policies, many new projects were implemented, leading to rapid development of the TBNA and a significant increase in the amount of built-up land. Tianjin is an important port city in northern China. To develop the local shipping industry, the TBNA accelerated the pace of land reclamation from the sea and port construction. Large areas of water near the shore were gradually converted to built-up land of harbor. Tianjin changed from a mono-centric to a dual-centric city, which led to regional development between the centers and expansion of built-up land in the connecting zones (Figure 4). These changes demonstrate that policies play a major role in the regional land use change. The expansion of built-up land has taken up large amounts of arable land resources. To ensure food security, China has implemented numerous policies to protect arable land. The most well-known policy is the "Basic Farmland Protection System", which ensures that China has at least 1.2 million km^2

of basic farmland for cultivation and ensures the nation's general self-sufficiency in food. The other policy is "Balance of Arable Land", which specifies that the conversion of arable land in one location is compensated for elsewhere. These land policies have slowed the loss of arable land. In the present study, we found that when arable land was converted during the period of 2000–2015, large areas of land were converted from built-up land (Tables 2–5). This conclusion is similar to the conclusions of other researchers and may be attributed to the terrain. Tianjin is a plain area, thus arable land converted from built-up land is more convenient. This was very different from other regions, such as in the Bale Mountains, Ethiopia and Nairobi, Kenya, where arable land was mainly converted from natural vegetation [61].

In the aspect of the sustainable land use management, with the deepening of the coordinated development of the Beijing-Tianjin-Hebei region, Tianjin will undertake more economic development functions, which brings up new challenges to the sustainable land use. Through this study, it was found that the main problem of sustainable land use was ecological land reduction and fragmentation, especially arable land, grass land and unused land (Tables 1–7) in Tianjin. In addition, urban population and GDP were the main driving forces of land use change (Tables 9–12). Therefore, in the sustainable management of Tianjin, the departments should pay attention to the unified planning of ecological land to prohibit the occupation of arable land, reduce the fragmentation and improve the function of ecological land. On the other hand, the departments should control the size of urban population and ensure a reasonable range of GDP growth to improve the use efficiency of built-up land to improve the level of sustainable land use. The government policies have an important impact on regional land use. Land management departments to implement sustainable land use policies will promote the efficient utilization and sustainable development of regional land in Tianjin, improve the level of regional land management.

In future study, the land use quantity and spatial distribution data can provide the basic data for the evaluation of sustainable land use in Tianjin. The level of sustainable land use will be obtained to analyze the spatial difference of sustainable land use in Tianjin so that the land management departments can refine the policies of the sustainable land in the different regions.

5. Conclusions

Land use change is an important component of regional ecological environment change, and also profoundly affects the intensity and process of regional ecological environment change. At the same time, the social and economic activities of human being are the main driving forces influencing the dynamic change of regional land use. Understanding the spatial and temporal dynamics of regional land use provides data support for the development of regional land use strategies. In this article, we have explored the quantitative and spatial pattern characteristics of land use change since 2000. The main driving factors of land use change have been analyzed in Tianjin in combination with the socio-economic data of Tianjin.

Through the research, we summarized the following conclusions from the six aspects, including the main land use types and the area change of land use in Tianjin from 2000 to 2015, the spatial differentiation characteristics and hotspot regions of land use change intensity, the quantity and spatial distribution of land use transfer, landscape pattern change characteristics of land use and driving forces of land use change.

(1) Arable land is main land use type in Tianjin, followed by built-up land and water body. In 2000, these three land use types accounted for accounted for about 93.31% of the land use area in Tianjin, which increased to 95.99% in 2015. The area of wood land, grass land and unused land was small, which had a weak influence on the regional land use change. The results showed that the quantitative feature of land use change was the continuous decrease of arable land area and the continuous expansion of built-up land area. The area of arable land decreased from 51.61% in 2000 to 47.53% in 2015, at a rate of 25.68 km^2/year; the area of built-up land increased from 13.65% in 2000 to 22.09% in 2015, at the growth rate of 81.78 km^2/year

(2) From the view of land use change intensity, the area of land use change in Tianjin was about 3753 km^2 in 2000–2005, and the change rate was 625.5 km^2/year. The regional variation of land use change was significant. The key area of land use change was in the central city of Tianjin and Binhai New Area, including urban area, Tanggu District and Dagang District, which was the most intensely changed regions in Tianjin. The intensity value of land use change was 9.89%, 5.96% and 4.62%. In the period of 2005–2010, the land use change was significantly accelerated. The area of land use change was 9465 km^2, which was nearly 1.5 times higher than that of the previous period. The change rate was 1577.5 km^2/year. Land use hotspots have also changed, mainly appeared around the rural residential area in Wuqing, Jixian and Baodi and around counties in Tianjin. In 2010–2015, the rate of land use change was showed down in Tianjin. The area of land use change was 4124 km^2, the hotspots were located in Huangu District, Tanggu District and Urban area.

(3) From the view of the quantitative characteristics of land use transfer, from 2000 to 2005, the main transferred-out land type of arable land was built-up land and water body, among which the built-up land was the largest, accounting for 92% of transferred-out area, while the area transferred arable land from the water body and built-up land was about 83.67 km^2, accounting for about 82% of transferred-in area. The main land transferred-out from built-up land was arable land, which the area was small. The transferred-in area was large, accounting for 19% of built-up land in 2005. It was mainly transferred from arable land and water body. In 2005–2010, the area converted from built-up land to arable land showed the largest increase: a 26-fold increase. However, there was 613.21 km^2 arable land transferred from built-up land, which was increased by two times compared with the previous stage, reflecting the conversion between arable land and built-up land was more frequent. During the 2010–2015 period, the area of built-up land transferred to arable land decreased to 5.41 km^2, and the area transferred to water body decreased to 297.88 km^2. From the net transfer area point of view, the net area of arable land transferred-out built-up land was always positive during the period. In the period of 2000–2010, the area of arable land transferred-out water body was negative, while this value was positive in 2010–2015, indicating that arable land was transferred out water body in addition to built-up land. This led to rapid reduction of arable land area.

(4) From the spatial characteristics of land use transfer, the land use transfer mainly occurred in the urban area, around the suburban residential areas and in the TBNA during the period. The land transfer area was the largest, and the intensity was the strongest in 2005–2010. The transfer of arable land occurred around the main urban area in the center of Tianjin, and in Wuqing and Tanggu in 2000–2005. The area of arable land transfer was significantly expanded in 2005–2010. The key regions were concentrated around the rural settlements. From 2000 to 2005, the water body transfer mainly occurred in the east of Tianjin and Ninghe country, TBNA and in the south of urban area. In 2005–2010, the transfer area of water body was expanding in the south of urban area and Baodi, in the north of Jinghai in addition to Ninghe. Some of built-up land were converted to arable land around the rural settlements in the suburbs of Tianjin, some were transferred to water body in the north of Hangu, in the east and south of Tanggu, which was mainly due to the regional adjustment of port construction of TBNA.

(5) From landscape pattern point of view, the NP of arable land experienced a trend of increasing first and then decreasing in Tianjin. The LPI and LSI showed a trend of fluctuating increase, the fragmentation of arable land was deepened. The NP of the water body increased rapidly year by year, and the LPI and LSI of water body show a decreasing trend, indicating that the shape of the water body patches became more regular, which was opposite to that of arable land. This was mainly due to the different management strategies of water body and arable land. The trend of landscape index of built-up land was similar to that of arable land, but the intensity of change was more intense. In the level of landscape, the change trend of index was similar to that of built-up land, which showed that the landscape change was mainly affected by the built-up land in Tianjin.

(6) In stepwise regression, the normalized regression coefficients are dimensionless units that can be used to compare the influence magnitude of each independent variables on dependent variables and reduce the multicollinearity of variables. The driving force analysis of land use change showed that the driving factors of built-up land and arable land change had obvious differences at different periods. During the period from 2000 to 2005, FAI was the main driving factor affecting the change of BL area. UP was the main driving factor affecting the change AL area in 2005–2010, the main driving factor of BL change became UP, and there was no significant driving factor in this period. In 2010–2015, the main driving factor of BL change was GDP. There were two driving factors of AL change, including PP and GDP, GDP was the most important factor driving the changes in the areas of arable land. This showed that the driving factors of land use change were different at different stages. The driving factors change at different stages, which should be considered in the process of land use simulation.

We also discussed the impact of government policy factors on land use change. Land policies that the department formulate have a direct impact on regional land use change, such as arable land protection policy. The industrial layout and regional development strategies have an indirect impact on land use change. For example, in 2005, TBNA was set up and included in the "Eleventh Five-Year Plan", became the national development strategy, which indirectly accelerated the process of the land use change in the relevant regions. The change of land use pattern requires a lot of labor, material resources and financial resources; therefore, the Government should be more comprehensive and prudent in formulating the land policies.

Based on the results of this article, we can see that the spatial differentiation characteristics of land use were very obvious in Tianjin. It is necessary to formulate some land policies that are suitable for the characteristics of regional land use change. The regional land use efficiency should be improved under the premise of protecting arable land. From the view of land use distribution, the built-up land was mainly concentrated in urban area and TBNA of Tianjin, which was expanding rapidly, especially TBNA (Figure 2). In the context of arable land resource protection, the land management department should formulate land policies to restrict the expansion rate of built-up land in Tianjin, control the increase of built-up land and encourage the conversion of stock built-up land into ecological land. At the same time, the industries that need occupy the larger area land should be transferred to the other regions, such as Ninghe and Baodi. According to the landscape index, the fragmentation of arable land is more serious than other natural land use types in Tianjin (Table 8). When the land use policies are formulated, the relevant departments of the government should consider the arable land protection and try to avoid the impact of expansion of built-up land on the fragmentation of arable land, such as the allocation of arable land reserves, restrictions on urban unconventional occupation of arable land.

GDP and FAI are the main driving forces for the built-up land increase (Tables 9–12). When developing the economy, the government should take into account the carrying capacity of land and avoid over-exploitation. Land use patterns have a significant impact on population agglomeration (Tables 9–12). In formulating land use policies, land management department should consider planning land resources rationally to avoid excessive population aggregation. Finally, when the departments formulate the land development strategies, it is important to focus on the regions in which land use changes severely (Figure 3). If necessary, the land management department should limit the rate of land use transfer in the violent area of land use change in order to ensure adequate reserve land.

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References

1. King, R.S.; Baker, M.E.; Whigham, D.F.; Weller, D.E.; Jordan, T.E.; Kazyak, P.F.; Hurd, M.K. Spatial considerations for linking watershed land cover to ecological indicators in streams. *Ecol. Appl.* **2005**, *15*, 137–153. [CrossRef]
2. Anett, S.T.; John, C.B.; Danny, K.T.; Roger, M. Interacting watershed size and landcover influences on habitat and biota of Lake Superior coastal wetlands. *Aquat. Ecosyst. Health* **2011**, *14*, 443–455.
3. Tao, Z.; Yang, X. Predicting Nitrogen Loading with Land-Cover Composition: How Can Watershed Size Affect Model Performance? *Environ. Manag.* **2013**, *51*, 96–107.
4. Munroe, D.K.; Müller, D. Issues in spatially explicit statistical land-use/cover change (LUCC) models: Examples from western Honduras and the Central Highlands of Vietnam. *Land Use Policy* **2007**, *24*, 521–530. [CrossRef]
5. Su, C.H.; Fu, B.J.; Lu, Y.H.; Lu, N.; Zeng, Y.; He, A.; Lamparski, H.L. Land use change and anthropogenic driving force: A case study in Yanhe River Basin. *Chin. Geogr. Sci.* **2011**, *21*, 587–599. [CrossRef]
6. Grecchi, R.C.; Gwyn, Q.H.; Bénié, G.B.; Fromaggio, A.R. Land use and land cover changes in the Brazilian Cerrado: A multidisciplinary approach to assess the impacts of agricultural expansion. *Appl. Geogr.* **2014**, *55*, 300–312. [CrossRef]
7. Liu, J.Y.; Kuang, W.H.; Zhang, Z.X.; Xu, X.L.; Qin, Y.W.; Ning, J.; Zhou, W.C.; Zhang, S.W.; Li, R.D.; Yan, C.Z.; et al. Spatiotemporal characteristics, patterns and causes of land use changes in China since the late 1980s. *J. Geogr. Sin.* **2014**, *69*, 3–14. [CrossRef]
8. Lópezcarr, D.; Davis, J.; Jankowska, M.M.; Grant, L.; Lópezcarr, A.C.; Clack, M. Space versus Place in Complex Human-Natural Systems: Spatial and Multi-Level Models of Tropical Land Use and Cover Change (LUCC) in Guatemala. *Ecol. Model.* **2012**, *229*, 64–75. [CrossRef] [PubMed]
9. Zhan, C.; Xu, Z.; Ye, A.; Su, H. LUCC and its impact on run-off yield in the Bai River catchment upstream of the Miyun Reservoir basin. *J. Plant Ecol.* **2011**, *4*, 61–66. [CrossRef]
10. Martínez, S.; Mollicone, D. From Land Cover to Land Use: A Methodology to Assess Land Use from Remote Sensing Data. *Remote Sens.* **2012**, *4*, 1024–1045. [CrossRef]
11. Weng, Q. Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modelling. *J. Environ. Manag.* **2002**, *64*, 273–285. [CrossRef]
12. Mottet, A.; Ladet, S.; Coque, N.; Gibon, A. Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees. *Agric. Ecosyst. Environ.* **2006**, *114*, 296–310. [CrossRef]
13. Seto, K.C.; Woodcock, C.E.; Song, C.; Huang, X.; Lu, J.; Kaufmann, R.K. Monitoring land-use change in the Pearl River Delta using Landsat TM. *Int. J. Remote Sens.* **2002**, *23*, 1985–2004. [CrossRef]
14. Suazo-Ortuño, I.; Lopez-Toledo, L.; Alvarado-Díaz, J.; Martinez-Ramos, M. Land-use Change Dynamics, Soil Type and Species Forming Mono-dominant Patches: The Case of Pteridium aquilinum, in a Neotropical Rain Forest Region. *Biotropica* **2015**, *47*, 18–26. [CrossRef]
15. Mundia, C.N.; Aniya, M. Dynamics of land use/cover changes and degradation of Nairobi City, Kenya. *Land Degrad. Dev.* **2010**, *17*, 97–108. [CrossRef]
16. Skokanová, H.; Havlíček, M. Driving Forces and Land Use Changes in the Lower Dyje River Area, Czech Republic, in the Period 1840–2006. Available online: http://web.natur.cuni.cz/geografie/vzgr/monografie/man_in_the_landscape/17skokanova.pdf (accessed on 18 April 2007).
17. Rgjr, P.; Cornell, J.D.; Cas, H. Modeling the spatial pattern of land-use change with GEOMOD2: Application and validation for Costa Rica. *Agric. Ecosyst. Environ.* **2001**, *85*, 191–203.
18. Pal, J.S.; Giorgi, F. Land use effects on climate in China as simulated by a regional climate model. *Sci. China Earth Sci.* **2007**, *50*, 620–628.
19. Wang, Y.L.; Feng, J.M.; Gao, H. Numerical simulation of the impact of land cover change on regional climate in China. *Theor. Appl. Climatol.* **2014**, *115*, 141–152. [CrossRef]
20. Pathirana, A.; Denekew, H.B.; Veerbeek, W.; Zevenbergen, C.; Banda, A.T. Impact of urban growth-driven landuse change on microclimate and extreme precipitation—A sensitivity study. *Atmos. Res.* **2014**, *138*, 59–72. [CrossRef]

21. Mcalister, J.J.; Smith, B.J.; Sanchez, B. Forest clearance: Impact of landuse change on fertility status of soils from the São Francisco area of Niterói, Brazil. *Land Degrad. Dev.* **1998**, *9*, 425–440. [CrossRef]
22. Chu, J.D. Effects of land use change on selected hydrologic processes in a subwatershed of the Shihmen reservoir watershed in Taiwan. *Shock* **2014**, *43*, 711–714.
23. Gupta, S.C.; Kessler, A.C.; Brown, M.K.; Schuh, W.M. Reply to comment by Keith E. Schilling on "Climate and agricultural land use change impacts on streamflow in the upper Midwestern United States". *Water Resour. Res.* **2016**, *52*, 5697–5700. [CrossRef]
24. Matinfar, H.R.; Panah, S.K.A.; Zand, F.; Khodael, K. Detection of soil salinity changes and mapping land cover types based upon remotely sensed data. *Arab. J. Geosci.* **2013**, *6*, 913–919. [CrossRef]
25. Dong, J.; Zhuang, D.; Xu, X.; Ying, L. Integrated Evaluation of Urban Development Suitability Based on Remote Sensing and GIS Techniques—A Case Study in Jingjinji Area, China. *Sensors* **2008**, *8*, 5975–5986. [CrossRef] [PubMed]
26. Zhang, W.Z.; Wang, C.S.; Lv, X.; Fan, J. Coupling relationship between land use change and industrialization and urbanization in the Zhujiang River Delta. *Acta Geogr. Sin.* **2003**, *58*, 677–685.
27. Long, H.; Tang, G.; Li, X.; Heilig, G.K. Socio-economic driving forces of land-use change in Kunshan, the Yangtze River Delta economic area of China. *J. Environ. Manag.* **2007**, *83*, 351–364. [CrossRef] [PubMed]
28. Zhang, H.; Uwasu, M.; Hara, K.; Yabar, H. Sustainable Urban Development and Land Use Change—A Case Study of the Yangtze River Delta in China. *Sustainability* **2011**, *3*, 1074–1089. [CrossRef]
29. Yagoub, M.M.; Kolan, G.R. Monitoring coastal zone land use and land cover changes of Abu Dhabi using remote sensing. *J. Indian Soc. Remote Sens.* **2006**, *34*, 57–68. [CrossRef]
30. Satir, O.; Erdogan, M.A. Monitoring the land use/cover changes and habitat quality using Landsat dataset and landscape metrics under the immigration effect in subalpine eastern Turkey. *Environ. Earth Sci.* **2016**, *75*, 1118. [CrossRef]
31. Shen, Q.P.; Chen, Q.; Tang, B.S.; Yeung, S.; Hu, Y.C.; Cheung, G. A system dynamics model for the sustainable land use planning and development. *Habitat Int.* **2009**, *33*, 15–25. [CrossRef]
32. Xie, H.Y.; Liu, G.Y. Spatiotemporal differences and influencing factors of multiple ropping index in China during 1998–2012. *J. Geogr. Sci.* **2015**, *25*, 1283–1297. [CrossRef]
33. Xie, H.L.; He, Y.F.; Xie, X. Exploring the factors influencing ecological land change for China's Beijing-Tianjin-Hebei Region using big data. *J. Clean. Prod.* **2017**, *142*, 677–687. [CrossRef]
34. Xie, H.L.; Yao, G.R.; Liu, G.Y. Spatial evaluation of ecological importance based on GIS for environmental management: A case study in Xingguo County of China. *Ecol. Indic.* **2015**, *51*, 3–12. [CrossRef]
35. Yao, G.R.; Xie, H.L. Rural spatial restructuring in ecologically fragile mountainous areas of southern China: A case study of Changgang Town, Jiangxi Province. *J. Rural Stud.* **2016**, *47*, 435–448. [CrossRef]
36. Xie, H.L.; Wang, P. Exploring the Dynamic Mechanisms of Farmland Abandonment Based on a Spatially Explicit Economic Model for Environmental Sustainability: A Case Study in Jiangxi Province, China. *Sustainability* **2014**, *6*, 1260–1282. [CrossRef]
37. Yi, Y.; Zhao, Y.Z.; Ding, G.D.; Cao, Y. Effects of urbanization on landscape patterns in a mountainous area: A Case Study in the Mentougou District, Beijing, China. *Sustainability* **2016**, *8*, 1190. [CrossRef]
38. Wang, M.; Yan, X. A Comparison of two methods on the climatic effects of urbanization in the Beijing-Tianjin-Hebei metropolitan area. *Adv. Meteorol.* **2015**, *2015*, 352360. [CrossRef]
39. Wu, Q.; Li, H.Q.; Wang, R.S.; Paulussen, J.; He, Y.; Wang, M.; Wang, B.H.; Wang, Z. Monitoring and predicting land use change in Beijing using remote sensing and GIS. *Landsc. Urban Plan.* **2006**, *78*, 322–333. [CrossRef]
40. Duan, Z.; Verburg, P.H.; Zhang, F.; Yu, Z.R. Construction of a land-use change simulation model and its application in Haidian District, Beijing. *Acta Geogr. Sin.* **2004**, *59*, 1037–1047.
41. Zhang, W.W.; Yao, L.; Li, H.; Sun, D.F.; Zhou, L.D. Research on land use change in Beijing Hanshiqiao wetland nature reserve using remote sensing and GIS. *Procedia Environ. Sci.* **2011**, *10*, 583–588. [CrossRef]
42. Yu, D.; Srinivasan, S. Urban land use change and regional access: A case study in Beijing, China. *Habitat Int.* **2016**, *51*, 103–113.
43. Li, Y.; Zhang, Q. Human-environment interactions in China: Evidence of land-use change in Beijing-Tianjin-Hebei Metropolitan Region. *Hum. Ecol. Rev.* **2013**, *20*, 26–35.
44. Wu, J.S.; Cao, Q.W.; Shi, S.Q.; Huang, X.L.; Lu, Z.Q. Spatio-temporal variability of habitat quality in Beijing-Tianjin-Hebei Area based on land use change (China). *Chin. J. Appl. Ecol.* **2015**, *26*, 3457–3466.

45. Xie, H.L.; Kung, C.C.; Zhao, Y. Spatial disparities of regional forest land change based on ESDA and GIS at the county level in Beijing-Tianjin-Hebei area. *Front. Earth Sci.* **2012**, *6*, 445–452. [CrossRef]
46. Xie, H. Analysis of Regionally Ecological Land Use and Its Influencing Factors Based on a Logistic Regression Model in the Beijing-Tianjin-Hebei Region, China (Chinese). *Resour. Sci.* **2011**, *33*, 2063–2070.
47. Haas, J.; Ban, Y. Urban growth and environmental impacts in Jing-Jin-Ji, the Yangtze, River Delta and the Pearl River Delta. *Int. J. Appl. Earth Obs.* **2014**, *30*, 42–55. [CrossRef]
48. Xie, Z.L.; Liu, J.Y.; Ma, Z.W.; Duan, X.F.; Cui, Y.P. Effect of surrounding land-use change on the wetland landscape pattern of a natural protected area in Tianjin, China. *Int. J. Sustain. Dev. World* **2012**, *19*, 16–24. [CrossRef]
49. Lu, Y.; Lu, Y.; Zong, Y. Ecological planning of land use in the central area of Tianjin, China. *J. Environ. Sci.* **1996**, *25*, 421–424.
50. Liu, B.; Huang, Y.; Fu, J.; Jiang, D. Analysis on Spatio-temporal Change and Driving Forces of Land Use in Tianjin Harbor (Chinese). *J. Geogr. Inf. Sci.* **2012**, *14*, 270–278.
51. Liu, J.Y.; Zhang, Z.X.; Xu, X.L.; Kuang, W.H.; Zhou, W.C.; Zhang, S.W.; Li, R.D.; Yan, C.Z.; Yu, D.S.; Wu, S.X.; et al. Spatial patterns and driving forces of land use change in China during the early 21st century. *J. Geogr. Sci.* **2010**, *20*, 483–494. [CrossRef]
52. Zhang, Z.X.; Zhao, X.L.; Wang, X. *Remote Sensing Monitoring of Land Use in China*; Star Maps Publishing: Beijing, China, 2012.
53. Liu, J.Y.; Liu, M.L.; Zhuang, D.F.; Zhang, Z.X.; Deng, X.Z. Study on spatial pattern of land-use change in China during 1995–2000. *Sci. China Earth Sci.* **2003**, *46*, 373–384.
54. Liu, J.Y.; Zhan, J.Y.; Deng, X.Z. Spatio-temporal patterns and driving forces of urban land expansion in China during the economic reform era. *AMBIO* **2005**, *34*, 450–455. [CrossRef] [PubMed]
55. Liu, J.Y.; Zhang, Q.; Hu, Y.F. Regional differences of China's urban expansion from late 20th to early 21st century based on remote sensing information. *Chin. Geogr. Sci.* **2012**, *22*, 1–14. [CrossRef]
56. Statistics Bureau of Tianjin. *Tianjin Statistical Yearbook (2000–2015)*; China Statistics Press: Beijing, China, 2015.
57. Zhan, J.; Shi, N.; He, S.J.; Lin, Y.Z. Factors and mechanism driving the land-use conversion in Jiangxi Province. *J. Geogr. Sci.* **2010**, *20*, 525–539. [CrossRef]
58. Turner, B.L.; Meyer, W.B.; Skole, D.L. Global Land-Use/Land-Cover Change: Towards an Integrated Study. *AMBIO* **1994**, *23*, 91–95.
59. Lo, C.P.; Yang, X. Drivers of Land-Use/Land-Cover Changes and Dynamic Modeling for the Atlanta, Georgia Metropolitan Area. *Photogramm. Eng. Remote Sens.* **2002**, *68*, 1073–1082.
60. Xie, Y.C.; Yu, M.; Tian, G.J.; Xing, X.R. Socio-economic driving forces of arable land conversion: A case study of Wuxian City, China. *Glob. Environ. Chang.* **2005**, *15*, 238–252. [CrossRef]
61. Du, X.D.; Jin, X.B.; Yang, X.L.; Yang, X.H.; Zhou, Y.K. Spatial pattern of land use change and its driving force in Jiangsu Province. *Int. J. Environ. Res. Public Health* **2014**, *11*, 3215–3232. [CrossRef] [PubMed]
62. Wang, J.F. *Spatial Data Analysis Tutorial*; Science Press: Beijing, China, 2010.
63. Fu, B.J.; Liu, S.L.; Lu, Y.H.; Chen, L.D.; Ma, K.M.; Liu, G.H. Comparing the soil quality changes of different land uses determined by two quantitative methods. *J. Environ. Sci.* **2003**, *15*, 167–172.
64. Griffith, J.A.; Martinko, E.A.; Price, K.P. Landscape structure analysis of Kansas at three scales. *Landsc. Urban Plan.* **2000**, *52*, 45–61. [CrossRef]
65. Stanfield, B.J.; Bliss, J.C.; Spies, T.A. Land ownership and landscape structure: A spatial analysis of sixty-six Oregon (USA) Coast Range watersheds. *Landsc. Ecol.* **2002**, *17*, 685–697. [CrossRef]
66. Herold, M.; Scepan, J.; Clarke, K.C. The Use of Remote Sensing and Landscape Metrics to Describe Structures and Changes in Urban Land Uses. *Environ. Plan. A* **2002**, *34*, 1443–1458. [CrossRef]
67. Jaafari, S.; Sakieh, Y.; Shabani, A.A.; Danehkar, A.; Nazarisamani, A. Landscape change assessment of reservation areas using remote sensing and landscape metrics (case study: Jajroud reservation, Iran). *Environ. Dev. Sustain.* **2015**, *17*, 1–17. [CrossRef]
68. Dewan, A.M.; Yamaguchi, Y. Using remote sensing and GIS to detect and monitor land use and land cover change in Dhaka Metropolitan of Bangladesh during 1960–2005. *Environ. Monit. Assess.* **2009**, *150*, 237–249. [CrossRef] [PubMed]
69. Nagendra, H.; Munroe, D.K.; Southworth, J. From pattern to process: Landscape fragmentation and the analysis of land use/land cover change. *Agric. Ecosyst. Environ.* **2004**, *101*, 111–115. [CrossRef]

70. Zhang, H.H.; Jin, X.B.; Wang, L.P.; Zhou, Y.K.; Shu, B.R. Multi-agent based modeling of spatiotemporal dynamical urban growth in developing countries: Simulating future scenarios of Lianyungang city, China. *Stoch. Env. Res. Risk A.* **2015**, *29*, 63–78. [CrossRef]
71. Hu, X.H.; David, H.K. The emergence of affluence in Beijing: Residential social stratification in china's capital city. *Urban Geogr.* **2001**, *22*, 54–77. [CrossRef]
72. Tendaupenyu, P.; Magadza, C.H.D.; Murwira, A. Changes in landuse/landcover patterns and human population growth in the Lake Chivero catchment, Zimbabwe. *Geocarto Int.* **2017**, *32*, 1–34. [CrossRef]
73. Hazell, P.; Wood, S. Drivers of change in global agriculture. *Philos. Trans. R. Soc. B Biol. Sci.* **2008**, *363*, 495–515. [CrossRef] [PubMed]
74. Teka, K.; Rompany, A.V.; Poesen, J. Assessing the role of policies on land use change and agricultural development since 1960s in northern Ethiopia. *Land Use Policy* **2013**, *30*, 944–951. [CrossRef]