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Land-Use/Cover Change and Driving Mechanism on the West Bank of Lake Baikal from 2005 to 2015—A Case Study of Irkutsk City

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Abstract: Lake Baikal is located on the southern tableland of East Siberian Russia. The west coast of the lake has vast forest resources and excellent ecological conditions, and this area and the Mongolian Plateau constitute an important ecological security barrier in northern China. Land-use/cover change is an important manifestation of regional human activities and ecosystem evolution. This paper uses Irkutsk city, a typical city on the West Bank of Lake Baikal, as a case study area. Based on three phases of Landsat remote-sensing image data, the land-use/cover change pattern and change process are analyzed and the natural factors and socioeconomic factors are combined to reveal driving forces through the partial least squares regression (PLSR) model. The results show the following: (1) From 2005 to 2015, construction land expanded, and forestland was converted into construction land and woodland. In addition, grass land, bare land, and cultivated land were converted into construction land, and the woodland area increased. The annual changes in land use from 2005 to 2010 were dramatic and then slowed down from 2010 to 2015. (2) The main reasons for the change in land-use types were urban expansion and nonagricultural development caused by population migration. The process of urbanization from external populations to urban agglomeration and the process of reverse urbanization from a central urban population to urban suburbs jointly expanded urban construction land area. As a result, forestland, grass land and bare land areas on the outskirts of cities were continuously reduced. After the disintegration of the Soviet Union, land privatization led to a decline in the farm economy, the emergence of agricultural land reclamation and urban expansion; in addition, the implementation of the "one-hectare land policy" intensified development in suburban areas, resulting in a reduction of forestland and grass land areas. The process of constructing the China-Mongolia-Russia Economic Corridor has intensified human activities in the region, and the prevention of drastic changes in land cover, coordination of human-land relations, and green development are necessary.

Keywords: land-use and land cover change; driving mechanism; Lake Baikal; PLSR

1. Introduction

Land-use/land cover change (LUCC) is a programmatic, cross-cutting research project consisting of the following two international projects: the International Geosphere and Biosphere Project (IGBP) and the Global Environmental Change Humanities Project (IHDP) [1]. The purpose is to reveal the basic process of interaction, penetration, and influence with the natural environment that is closely related to human daily production and life and the continuously developing social environment [2]. IGBP closed at the end of 2015 after three decades of coordinating international research on global change. In 2013, a new initiative gathering all previous global environmental change programs was established and named 'Future Earth' [3]. Future Earth is a 10-year international research program jointly initiated by ICSU (International Council for Science), ISSC (International Social Science Council) and others that will provide critical knowledge required for societies to face the challenges posed by global environmental change and to identify opportunities for a transition to global sustainability. Land system science is one of the priorities under the Future Earth initiative [4]. This purpose is an important direction for LUCC research to strengthen the analysis of the driving forces of LUCC, especially the impact and role of socioeconomic factors, and to make scientific judgments and predictions.

Located in the southern part of Eastern Siberia, Russia, Lake Baikal is an area of 31,500 km^2 and is the world's deepest and largest storage freshwater lake, containing one-fifth of the world's total fresh water. In 1996, Lake Baikal was added to the world's human cultural and natural heritage protection list. Baikal and Siberia are recognized as areas sensitive to global climate change. Scientists from the United States and Russia published a report in the journal of Global Change Biology showing that since 1946, the surface temperature of Lake Baikal has increased by an average of 1.21 degrees Celsius. The warming rate is approximately two times the average global warming rate of 0.74 degrees Celsius during the same period [5]. In recent years, due to the intensification of climate change and human activities, the amount of water coming from the upper reaches has decreased, and environmental and ecological problems in the water have attracted attention. In addition, the Siberian region is an important ecological security barrier in northern China. The vast forest ecosystem in the region has a large impact on China's climate and environment. For example, changes in the biomass of the Siberian taiga forest will affect the frequency and intensity of changes in the winter cold current in China [6].

The West Bank of Lake Baikal is a region with the highest forest coverage in Russia. The West Bank is located along the China-Mongolia-Russia cross-border railway, and since ancient times, it has been an important part of The Tea Road and an important connection area for the Eurasian Continental Bridge. The ecological environment pattern in this area is complex and diverse. The interactions between natural processes and human activities have a profound impact on China's resources, environment, and socioeconomic development.

With the construction of the China-Mongolia-Russia Economic Corridor, the region will surely become a focus for regional development. The combination of the intensification of human activities and climate change will have a profound and subsequent impact on the basin's ecosystem. The study of land-use and land-cover change in the region reveals the process and mechanism of land-use change, which can provide a basis for decision making for the prevention of ecological risks in the China-Mongolia-Russia Economic Corridor and the construction of geo-eco-service functions [7].

Currently, LUCC research is not limited to the construction of land-use/cover patterns. The quantitative analysis of its process changes and driving mechanisms have become a global focus. In the analysis process, a statistical econometric model was introduced to describe the relationship between the land-use/cover change and impact factors in a time period to reasonably adjust social and economic activities and scientifically use land resources [8]. In the existing research about LUCC driving forces, it is concluded that although climate change in the north impacted the change in cropland, policy regulation and economic driving forces were still the primary causes of LUCC across China [9]; LUCC is caused by multiple interacting factors like climate variability, soil erosion, change in market prices, economic development programs and changes in methods of production, among others. Furthermore, to obtain a better causal explanation of LUCC, future research should explain with more detail the causal effects, underlying causes involved and others [10]. There are few studies on land-use/cover change and dynamic analyses on the West Bank of Lake Baikal in Russia. After the disintegration of the Soviet Union, scientific research was relatively inhibited, and international community access was blocked for a period. Carrying out systematic research on the internal regions of Russia is difficult for international scientists. Domestic research in Russia has not been in line with the international scientific and technological community [11,12]. A literature search found few international articles on studies in the region, and Russia has paid more attention to research on the natural characteristics and physicochemical properties in the land-use process [13]. Internal regions in Russia lack land-use/cover change research, and in-depth analyses of these regions could be impactful [14].

This article selects Irkutsk city, the nearest metropolitan city on the West Bank of Lake Baikal, as a case area to carry out land-use/cover change research to analyze the process of land-use change over the years, reveal the main driving forces of land-use change, predict the future trend of land-use development, and provide useful suggestions for balancing socioeconomic development and ecological environment construction to achieve sustainable development.

2. Materials and Methods

Russia has systematically accelerated the reform of agriculture. In October, 2001 and on January 27, 2003, Russia introduced the "New Land Code" and the "Agricultural Land Transfer Law", respectively, which basically established a new framework for the Russian land system. The "Agricultural Land Transfer Law" allows free land trade and provides policy incentives for land consolidation by providing tax incentives and low-interest loans. On the one hand, the large-scale agricultural group's enclosure acquisitions have become an inevitable path for agricultural mechanization and high-efficiency operations. On the other hand, propaganda farmers are reluctant to operate independent, small- and medium-sized private farms, which has resulted in serious waste due to farmland abandonment. The promulgation and implementation of these two laws finally established a Russian private ownership system. To analyze the impact of land policy on the city of Irkutsk, comprehensive data are available. Therefore, this paper selects 2005, 2010 and 2015 as the research period.

This paper uses the United States Geological Survey (USGS) international scientific data service platform to obtain remote-sensing image data from 2005–2015 in Irkutsk, Russia. Using summer (June–September) as the research phase, Landsat remote-sensing images of the same time period in 2005, 2010, and 2015 were selected to analyze the spatiotemporal patterns and changes in the land resources in the study area. The land cover change impact factors and the main driving force were quantitatively analyzed using partial least squares regression (PLSR) methods combined with socioeconomic data to provide comprehensive land cover change information.

2.1. Overview of the Study Area

Irkutsk is the administrative center of the Irkutsk oblast of the Russian Federation. Irkutsk is located at 104°18′ east longitude and 52°17′ north latitude at the confluence of the Irkut and Angara rivers, and southeastern Irkutsk is 66 km away from Lake Baikal (Figure 1). Most of the city is mountainous, with an average elevation of 440 meters, and has a temperate continental climate [15]. The city has an area of 277 km^2, and the total population was 623,700 in 2017. The city is divided into four administrative districts, the Right bank district (118,256 people), the October district (151,015 people), the Sverdlovsk district (205,003 people), and the Leninsky district (149,462 people).

As the sixth largest city in Siberia, Irkutsk was once depressed and in decline. In the past one and a half centuries, because of its superior geographical location and exceptional natural resources, Irkutsk has once again become the center of political and business culture in eastern Siberia and one of the important transfer stations for trade between Russia and China [16].

At present, China and Russia participate in extensive strategic cooperative activities, such as political and economic activities, with complementary advantages and win-win collaborations. Under the background of the "Belt and Road" initiative of China, the Russian Eurasian Economic Alliance and the Mongolian Prairie Silk Road strategy, the Irkutsk region is becoming a key node city for the construction of the China-Mongolia-Russia Economic Corridor [17].

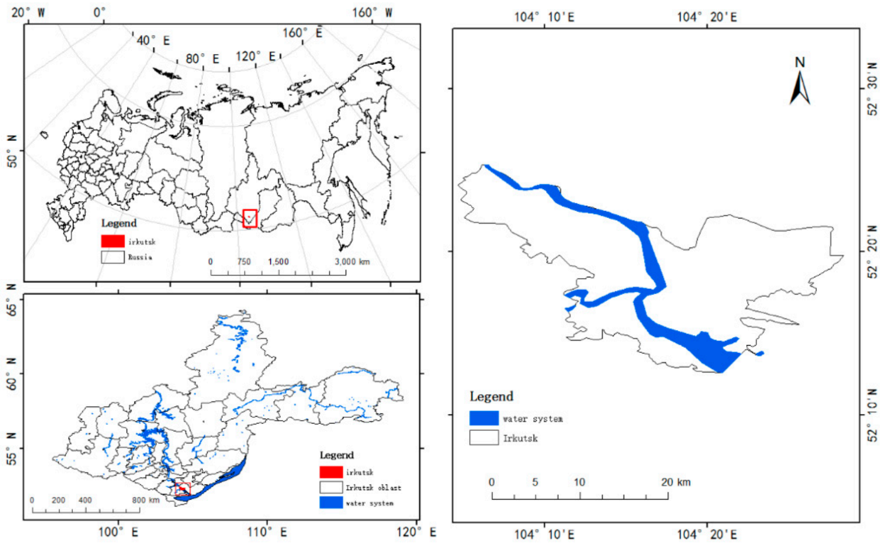

Figure 1. Location map of Irkutsk.

2.2. Methods and Data

2.2.1. Data

(1) Remote sensing image

This article obtained three remote-sensing images from the USGS platform on August 23, 2005 (Landsat 4–5 TM), September 6, 2010 (Landsat 4–5 TM), and August 19, 2015 (Landsat 8 OLI). The Landsat 4–5 TM image contains 7 bands. Bands 1–5 and 7 at a 30-m spatial resolution and Band 6 (thermal infrared) at a 120-m spatial resolution; the Landsat 8 OLI Land Imager at a 30-m spatial resolution consists of 9 bands, including the panchromatic band at a 15-m spatial resolution. The study period is during the hot and short summer in Russia when the air is dry and there are few clouds and low precipitation. The terrain types are easier to distinguish during the summer than other periods, meeting the needs of research (Table 1).

Table 1. Remote-sensing image information.

ID	Cloud %	Date	Band
LT51340242005235BJC00	43.09	2005.08.23	7
LT51340242010249MOR01	0.05	2010.09.06	7
LC81340242015231LGN01	0.02	2015.08.19	9

(2) Auxiliary data

The 90-meter-resolution SRTM digital elevation model (DEM) data set for Irkutsk city was obtained from the Consortium for Spatial Information. The data were derived from the global 3D graphical data project established by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA). Administrative division maps, 1:100,000 topographic maps, water surface layers, roads, railways, etc. of Irkutsk, Russia were obtained; and the sample points were obtained from Google Earth and the Arcbrutile plugin in ArcGIS; statistics from the Statistical Yearbook of Irkutsk were obtained from the Statistical Office of the Russian Federation.

2.2.2. Methods

(1) Data preprocessing

The remote-sensing image, water surface layers, and DEM data were clipped using the study area 1:200,000-scale administrative division base map. Land cover data for the study area during the three periods in 2005, 2010, and 2015 were extracted in addition to the river, lake and DEM data [18]. The above data were unified with the WGS1984 coordinate system under the horizontal axis Mercator projection. After geometrically correcting the image and other preprocessing, an image map of the study area was obtained through band synthesis (Figure 2).

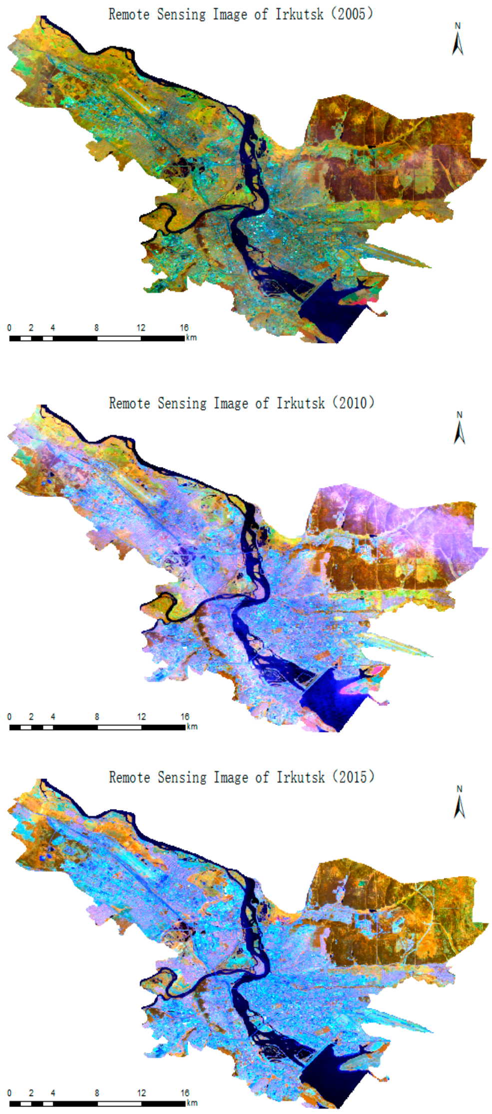

Figure 2. Study area images in 2005, 2010 (R, G, B:4,5,1), and 2015 (R, G, B:5,6,2).

(2) Object-oriented classification

Land-use classification in the study area is based on the land-use classification system in the database of resources and the environment of the Chinese Academy of Sciences. Depending on the needs of the research and the source of the data, and considering the possibility of expanding the original data type, the classification system was unified to contain seven types of new classification classes. (Due to the high forest coverage in Irkutsk city, the change is significant, and this paper divides forests into forestland and woodland, Table 2.)

Table 2. Land-use/cover classification system and type description.

Class	Description
Construction land	Mainly includes urban and rural areas, mining, transportation and other construction lands.
Cultivated land	Land covered mainly by crops that do not require irrigation or seasonal irrigation or periodic irrigation, including indistinguishable types of vegetation mosaics containing farmland.
Forestland	Forestland coverage > 60%
Woodland	15% < Forestland coverage < 60%
Grass land	Herbaceous land coverage > 15%
Bare land	Land with almost no vegetation coverage or sparse vegetation.
Water	Mainly includes rivers, lakes, reservoirs and wet and flat zones that are periodically submerged in water.

This paper uses eCognition 8.7, an object-oriented classification method, to select a variety of classification features. In the classification process, the high-resolution images are manually interpreted, and the incorrect areas are corrected to ensure high data accuracy. After the classification results are obtained, operations such as clustering statistics, removal analysis and recoding, and object fusion are performed in eCognition and ArcGIS (Table 3).

Table 3. Remote-sensing image classification process.

Year	Segmentation Scale	Classification Features	Method
2005	5	Brightness, layer1, layer2, layer3, layer4, layer5, layer6, layer7, layer8, Max.diff, Length/Width, shape index, NDVI [(L4 − L3)/ (L4 + L3)]	Nearest Neighbor
2010	5		
2015	150	Brightness, layer1, layer2, layer3, layer4, layer5, layer6, layer7, layer8, layer9, layer10, layer11, layer12, Max.diff, Length/Width, shape index, NDVI [(L5 − L4)/ (L5 + L4)]	

(3) Land-use/cover change measures

Since the conversion between land cover types is a dynamic process, in order to better clarify the direction of transfer and specific transfer between land use types in the region, spatial calculations on the three phase maps of the land use status were performed in Arcgis, which resulted in a land use type transfer matrix for each time period. Thus, the whole process of land cover change is more intuitively and quantitatively analyzed [19]. In ArcGIS, the land use status map of two different phases is merged, the data is superimposed and analyzed, the map area is calculated and the attribute table is derived, and the land use transfer matrix based on the attribute information is completed. Its mathematical expression is:

$$A_{ij} = \begin{bmatrix} A_{11} & \cdots & A_{1n} \\ \vdots & \ddots & \vdots \\ A_{n1} & \cdots & A_{nn} \end{bmatrix}$$

In the matrix, i is the land use type of k period; j is the type of land use in the period of k + 1; n is the number of land use types; $A_{ij}(i = j)$ represents the elements on the diagonal in the square matrix, which is the area of the i-class that did not transform during the study period; and $A_{ij}(i \neq j)$ is the area where the i-class is transformed into the j-class in the study period. The degree of the land-use dynamics can be used to describe the speed of land-use change in the area. The dynamic degree of single land use is the quantitative change in certain land-use types within a certain time range in a certain research area. The dynamic degree of single land use is expressed as:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \tag{1}$$

In the formula, K indicates the degree of the land-use dynamics in the study area; U_a, U_b are the area of land at the beginning and end in the study area respectively; T is the study period.

The comprehensive land-use dynamics can quantitatively describe the speed of regional land-use change, referring to the annual land-use change rate in the study area, and have a positive effect on the comparison of regional differences in land-use change and the prediction of future land-use change trends [20]. The comprehensive land-use dynamics is expressed as:

$$LC = \frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{2\sum_{i=1}^{n} LU_i} \times \frac{1}{T} \times 100\% \tag{2}$$

In the formula, LC indicates the annual rate of integrated land use change; Lui represents the land use area of i-class in the beginning; ΔLU_{i-j} represents the absolute area of the i-class land converted to non-i-class land in the period T; T is the study period [9].

(4) PLSR for selecting the LUCC driving factors

When selecting the driving factor, select the generally accepted indicators of socio-economic and natural factors. It must follow the principles of comprehensiveness, maneuverability and dynamics, and must have strong representation and dominance [21]. Choose from the aspects that reflect economic development and structural adjustment, population size and change, urbanization and industrialization development, and people's living income. The classification has been organized to group the variables [22].

Using the areas of each class in 2005, 2010 and 2015 as dependent variables, 19 independent variables were selected, such as population density, proportion of working-age population, and investment in fixed assets. The four land types of construction land, forestland, woodland, and grass land in Irkutsk city were analyzed, and a driving factor indicator system was established (Table 4).

Table 4. Driving factor indicator system.

Variable Name		Variable Definition	Unit
Y1		Construction land	km^2
Y2		Forestland	km^2
Y3		Woodland	km^2
Y4		Grass land	km^2
Population	X1	Population density	people/km^2
	X2	Immigration rate	%
	X3	Percentage of working-age population	%
	X4	Natural population growth rate	%
Urban construction	X5	Urban per capita residential area	m^2
	X6	Fixed asset investment (actual price)	million rubles
	X7	Passenger traffic	thousands
	X8	Passenger turnover	10^3 km
	X9	Car availability statistics	-
Economic development	X10	Retail turnover	million rubles
	X11	Average monthly income	ruble
	X12	Consumer price composite index (December to December of the previous year)	%
	X13	Industrial production index (for companies that do not involve small business entities)	%
	X14	Public catering turnover (percentage of last year)	%
	X15	Number of primary industry companies	-
	X16	Number of second industry enterprises	-
	X17	Number of tertiary industry companies	-
Climate	X18	Precipitation	mm
	X19	Absolute minimum temperature	°C

PLSR (Partial Least Squares Regression) was proposed by S.Wold and C.Albano in 1983; it was firstly applied to the field of chemistry [23]. Later, it was widely used in market analysis, resource utilization, engineering modeling and so on [24].

PLSR provides a method for modeling the linear regression of a large number of variables and observations [25]. The model built by PLSR is especially advantageous compared to traditional methods such as classical regression when the number of variables is large and the number of observations (sample size) is small or less than the number of variables. These criteria meet the research needs of land-use/cover change [26,27].

The PLSR extension module was installed in SPSS24.0. To eliminate the influence of dimension and variation in the variables, the independent variable and dependent variable data were normalized, the parameter settings of the PLSR model were set, and then, the model results were output.

3. Results and Discussion

3.1. Land-Use/Cover Pattern

Land-use classification maps of the study area for each year are shown in Figure 3, and the land-use-type database of the study area based on the statistics on the area of each category after classification is shown in Table 5.

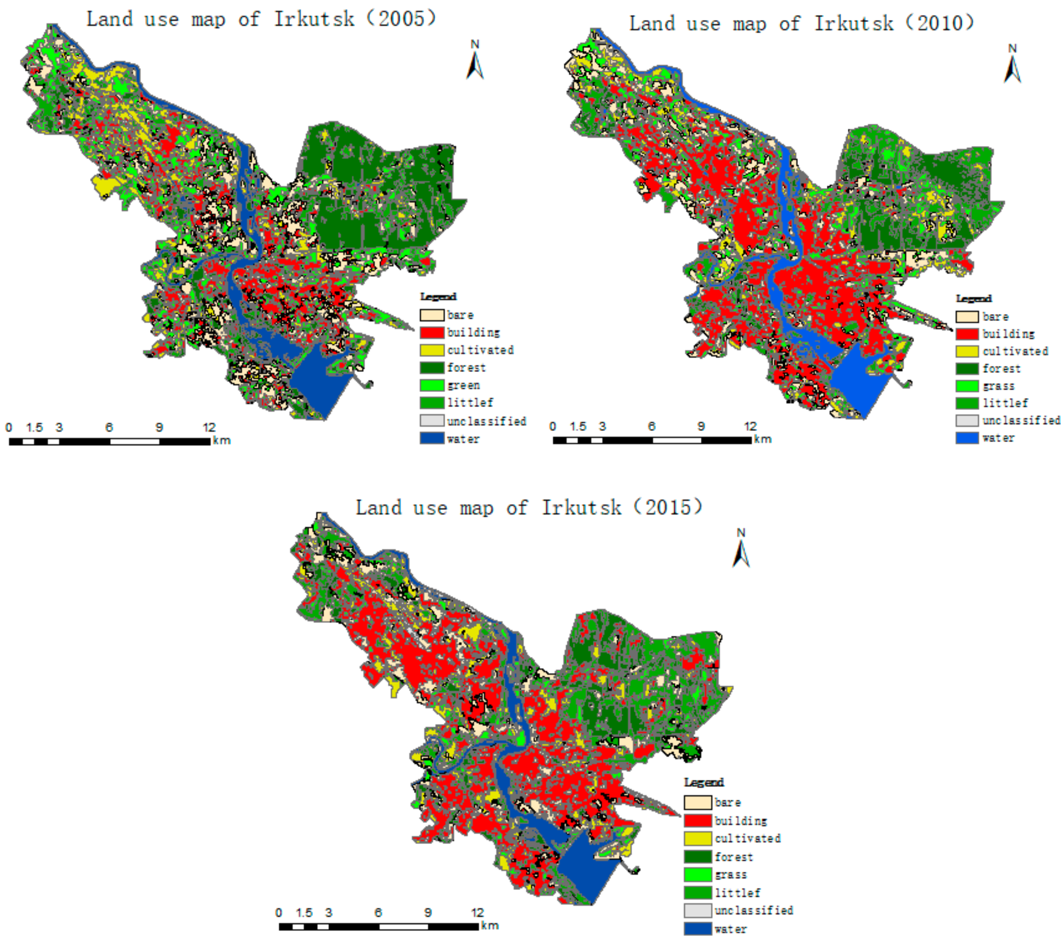

Figure 3. The land-use classification maps for 2005, 2010, and 2015.

Figure 3 and Table 5 show the following: (1) In the past 10 years, the construction land area of Irkutsk increased by 46.827 km^2, showing significant expansion. (2) The area of bare land and cultivated land decreased by 11.521 km^2 and 4.924 km^2, respectively. (3) The area of forestland

and grass land decreased significantly by 26.114 km^2 and 28.748 km^2, respectively. (4) The area of woodland increased by 24.793 km^2, and forestland was converted to woodland. (5) The water area was basically unchanged.

Table 5. Statistics of the classification area (km^2, %).

Class	Year					
	2005		2010		2015	
	Area	Percentage	Area	Percentage	Area	Percentage
Bare land	43.78	0.16	35.47	0.13	32.26	0.12
Construction land	49.15	0.18	85.68	0.31	95.98	0.35
Cultivated land	34.10	0.12	25.29	0.09	29.17	0.11
Forestland	54.96	0.20	28.72	0.10	28.85	0.10
Grass land	44.47	0.16	37.96	0.14	15.72	0.06
Woodland	23.00	0.08	34.08	0.12	47.80	0.17
Water	26.59	0.10	27.02	0.10	24.19	0.09
Unclassified	1.61	0.01	3.43	0.01	3.34	0.01

After classification, verification sample points were selected from the high-resolution images of 2005, 2010 and 2015, and the classification accuracy of the land-use classification data was evaluated (Table 6).

Table 6. Accuracy evaluation of the classification results.

Class	Year								
	2005			2010			2015		
	Sample Points	Producer Accuracy %	User Accuracy %	Sample Points	Producer Accuracy %	User Accuracy %	Sample Points	Producer Accuracy %	User Accuracy %
Bare	52	73.08	64.41	43	72.09	60.78	50	72.00	72.00
Construction land	99	71.72	91.03	95	81.05	87.50	54	77.78	79.25
Cultivated	40	75	61.22	24	75.00	60.00	31	81	65.79
Forest	50	94	88.68	55	70.91	76.47	51	75	80.85
Grass	50	82	69.49	55	70.91	66.10	46	80	75.51
Woodland	53	73.58	79.59	34	70.59	61.54	46	73.91	68.00
Water	50	94	100	45	73.33	100	53	83.02	100
Overall accuracy %		76.14			74.36			77.34	
Kappa		0.76			0.70			0.74	

The accuracy test of the different years shows that the overall accuracy of all classification results reached more than 70%, satisfying the accuracy test requirements and validating the classification results.

The quantitative statistical analysis of the main types of land-cover change, the change area and the conversion scale from 2005 to 2015 is shown in Table 7.

From 2005 to 2015, approximately 35% of the land-use types did not change. Bare land, grass land and forestland were partially transformed into construction area, accounting for 7.91%, 6.12% and 2.38%, respectively, of the conversion area. The areas of forestland, grass land, cultivated land and bare land were transformed into woodland, accounting for 6.13%, 3.04%, 2.18% and 2.02%, respectively, of the conversion area. The areas of grass land, construction land and cultivated land were transformed into bare land, accounting for 2.58%, 2.10% and 1.96%, respectively, of the conversion area. These results show that a large amount of land in Irkutsk was transformed into construction land.

Table 7. The main area types and proportions of land-cover change from 2005 to 2015.

Land-Use Type Change	Conversion Area/km^2	Percentage of Total Conversion Area/%
No change	97.98	35.26
bare–>construction land	21.99	7.91
forest–>woodland	17.03	6.13
grass–>construction land	17.00	6.12
cultivated–>construction land	13.39	4.82
grass–>woodland	8.46	3.04
grass–>bare	7.18	2.58
bare–>cultivated	6.84	2.46
forest–>construction land	6.60	2.38
grass–>cultivated	6.11	2.20
cultivated–>woodland	6.05	2.18
construction land–>bare	5.82	2.10
bare–>woodland	5.60	2.02
cultivated–>bare	5.45	1.96
Others	52.37	18.85

3.2. Land-Use/Cover Change

(1) Land-use transfer matrix

The land-use type transfer matrix from 2005 to 2010 and from 2010 to 2015 is shown in Tables 8 and 9, respectively.

According to Table 8, from 2005 to 2010, the areas of bare land, grass land and cultivated land transformed into construction land were 21.04 km^2, 14.83 km^2, and 9.78 km^2, respectively, and the area of forestland transformed into woodland was 18.58 km^2. The areas of forestland and cultivated land transformed into bare land were 8.72 km^2 and 7.3 km^2, respectively, and the areas of bare land and cultivated land transformed into grass land were 7.92 km^2 and 7.79 km^2, respectively.

According to Table 9, from 2010 to 2015, the areas of grass land and bare land transformed into construction land were 14.13 km^2 and 12.26 km^2, respectively, and the areas of cultivated land, grass land and forestland transformed into woodland were 8.01 km^2, 7.69 km^2 and 6.91 km^2, respectively. The areas of bare land transformed into woodland and cultivated land were 6.07 km^2 and 6.03 km^2, respectively. These results show that construction land is not easily converted into other land types, and grass land and bare land are easily transformed. Cultivated land can easily be converted into bare land, grass land and other land types.

(2) Land-use dynamics

From 2005 to 2015, the reduction in the bare land area slowed down, and the dynamic increase in the construction land area changed from sharp to moderate. The change in the cultivated land area rapidly decreased at first and then slightly increased. The area of forestland decreased dramatically and then was basically unchanged; the grass land area gradually decreased. The woodland area rapidly increased, and the water area slightly decreased. The annual rate of land use changed slightly after 2010 (Table 10).

Table 8. Land-use type transfer matrix from 2005 to 2010 (km^2).

2010 \ 2005	Bare	Construction Land	Cultivated	Forest	Grass	Woodland	Unclassified	Water	Total
Bare	8.47	4.78	7.30	1.73	8.72	4.37	0.03	0.05	35.45
Construction land	21.04	33.16	9.78	2.71	14.83	3.05	0.36	0.63	85.56
Cultivated	4.17	1.84	5.82	2.98	6.02	4.38	0.03	0.04	25.28
Forest	0.36	0.71	0.72	23.10	1.60	1.37	0.06	0.65	28.57
Grass	7.92	6.48	7.79	3.94	7.95	3.79	0.18	0.08	38.13
Woodland	1.52	1.17	2.28	18.58	4.48	5.85	0.09	0.22	34.18
Unclassified	0.17	0.34	0.43	0.71	0.73	0.17	0.54	0.31	3.41
Water	0.08	0.73	0.09	1.07	0.15	0.06	0.26	24.63	27.07
Total	43.72	49.20	34.22	54.81	44.48	23.05	1.55	26.61	277.65

Table 9. Land-use type transfer matrix from 2010 to 2015 (km^2).

2015 \ 2010	Bare	Construction Land	Cultivated	Forest	Grass	Woodland	Unclassified	Water	Total
Bare	6.92	9.49	5.01	1.02	6.40	2.84	0.17	0.36	25.29
Construction land	12.26	55.13	5.44	3.05	14.13	4.97	0.65	0.32	95.94
Cultivated	6.03	9.63	3.40	1.27	5.32	2.77	0.55	0.18	29.15
Forest	1.24	1.48	1.17	13.83	1.28	7.42	0.16	2.25	28.83
Grass	2.72	3.25	1.99	1.90	2.60	2.83	0.16	0.24	15.70
Woodland	6.07	5.07	8.01	6.91	7.69	12.98	0.69	0.32	47.74
Unclassified	0.06	1.16	0.16	0.03	0.56	0.05	0.61	0.70	3.33
Water	0.08	0.26	0.02	0.55	0.06	0.21	0.41	22.58	24.16
Total	28.47	85.46	25.21	28.55	38.04	34.07	3.39	26.95	270.14

Table 10. Land-use dynamics.

Class	Rate of Change from 2005 to 2010 (%)	Rate of Change from 2010 to 2015 (%)
Bare	−3.79	−1.81
Construction land	14.86	2.4
Cultivated	−5.17	3.07
Forest	−9.56	0.09
Grass	−2.93	−11.72
Woodland	9.63	8.05
Water	0.33	−2.1
Unclassified	22.58	−0.57
District	6.06	5.63

3.3. Analysis of Driving Factors of Major Land-type Changes

The adjusted R^2 values of the partial least squares model for construction land, forestland, woodland, and grass land are 0.893, 0.697, 0.991, and 0.865, respectively, and the "Y variance captured" is shown (Table 11). They all meet the accuracy requirements and demonstrate that the regression results are reliable. Based on the regression results of the model, the correlation between the area of change for each land type and its impact factor can be obtained (Table 12).

Table 11. Y variance captured.

Variable Name	Latent Factors	Y Variance
Y1 Construction land	1	0.947
	2	0.053
Y2 Forestland	1	0.849
	2	0.151
Y3 Woodland	1	0.995
	2	0.005
Y4 Grass land	1	0.933
	2	0.067

Table 12. PLSR parameters.

		Y1 Construction Land	Y2 Forest	Y3 Woodland	Y4 Grass
(Constant Term)		$\mathbf{-8.402 \times 10^{-17}}$	$\mathbf{3.474 \times 10^{-16}}$	$\mathbf{3.098 \times 10^{-16}}$	$\mathbf{-6.659 \times 10^{-16}}$
Population	X1	0.0693	−0.0695	0.0596	−0.0493
	X2	0.1189	−0.1618	0.0121	0.0547
	X3	−0.0421	0.0282	−0.0660	0.0757
	X4	0.0731	−0.0754	0.0583	−0.0447
Urban construction	X5	0.0457	−0.0338	0.0655	−0.0729
	X6	0.0761	−0.0803	0.0511	−0.1204
	X7	0.0907	−0.1039	0.0500	−0.0213
	X8	0.0751	−0.0783	0.0576	−0.0426
	X9	0.0300	−0.0105	0.0675	−0.0853
Economic development	X10	−0.0677	0.1193	0.0571	−0.0410
	X11	0.0612	−0.0567	0.0622	−0.0582
	X12	0.0398	−0.0247	0.0665	−0.0777
	X13	0.1188	−0.1602	0.0146	0.0505
	X14	−0.0231	0.0005	−0.0680	0.0904
	X15	−0.0603	0.0552	−0.0624	0.0593
	X16	0.0159	0.0095	0.0680	−0.0950
	X17	0.0519	−0.0428	0.0643	−0.0670
Climate	X18	−0.0979	0.1164	−0.0453	0.0095
	X19	0.0194	0.0048	0.0679	−0.0930

The results show the following:

(1) Immigration rate, natural population growth rate, population density and other factors that characterize population changes have a strong effect on the expansion of construction land. After the disintegration of the Soviet Union, the Russian population appeared to flow from the east to the west in Europe and from small- and medium-sized towns to large cities. Irkutsk, the central city of Eastern Siberia, is highly attractive to the surrounding small- and medium-sized towns and agricultural populations [28]. Population agglomeration promotes urban expansion and development, and population factors and cities promote each other. The data obtained from the statistical yearbook show that the population and immigration rate in the study area have an upward trend for 20 years and have become the main reasons for population growth in the city. Passenger transport, passenger transport turnover, urban per capita residential area and other factors that characterize urban construction have a great contribution, reflecting changes in the floating population. Irkutsk, as the nearest city to Lake Baikal, attracts a large number of tourists, and the migrant population has increased significantly. The migrants buy land around Baikal, build new villas, and enjoy vacations [29]. In 2017, when Putin visited the Baikal Nature Reserve, he condemned irrational economic activities and "barbaric tourists" leaving a lot of rubbish that caused extremely serious damage to the environment of Lake Baikal. He called for urgent measures to rescue Lake Baikal and ordered the Russian General Prosecutor's Office to investigate illegal activities. Russia's "Moscow Communist Youth League" reported on December 31, 2017, that residents of Irkutsk initiated a petition requesting the government to ban foreigners from buying land in the Baikal area, with a signature of 54,000. The local people have reported that foreigners are building a large number of villas and houses, which are actually illegal hotels to receive tourists. Some merchants did not do a good job of environmental protection during the commercial development and construction, which caused a certain degree of damage to the environment; due to the lack of a centralized drainage system in the town, some merchants will directly discharge the generated sewage into Lake Baikal, causing the ecology to be "barbarically" destroyed. The inflow of population has led to a rapid increase in nonagricultural industries, which has led to the expansion of urban land use and changes in the land-use structure. The suburbs experienced the largest and fastest expansion of construction land from 2005 to 2010. This expansion was related to the establishment of Russia's land privatization system, the spreading of residents from the old city to the suburbs, and an inverse urbanization trend; from 2010 to 2015, construction land use was substantially reduced.

(2) Population indicators such as migration rate, industrial production index, retail turnover, and three-industry index that characterize economic development, have the greatest effects on the reduction in forestland area, indicating that an increase in population, spatial transfer, and nonagricultural industries has an impact on urban forests. On the one hand, this has led to an increase in construction land and the transformation of forestland surrounding urban areas into construction land. Foreign population entered, cut down forest, built villas and houses [30]; on the other hand, forest coverage has decreased, and forestland farther from the city has been converted into woodland [31].

(3) Fixed asset investment and the development of secondary industries have the greatest effect on grass land reduction, indicating the impact of urban infrastructure and industrial development on grass land. Climate change has the second highest impact on grass land. Because Irkutsk is located at high latitudes, climatic conditions play a significant role, and the grass land area has a negative correlation with temperature. At the same time, as the city expands, the population and fixed asset investment increase, and the development of nonagricultural industries and the urban residential area per capita expansion are constantly utilizing areas of grass land and bare land; thus, the two areas are continuously reduced.

(4) In addition to the driving factors analyzed above, many other factors also affect the type of land-use changes, but conducting quantitative research on these factors is difficult. Among them, national and regional development policies and regulations have a direct and even far-reaching impact on the development of the research area. Since the disintegration of the Soviet Union, the population

of Russia has decreased, the population of the Siberian region has moved westward, and a large number of rural laborers, especially young laborers, have migrated to cities. Coupled with policies such as privatization of land and restructuring of collective farms, the area of cultivated land has decreased, and there has been significant abandonment of agricultural land and urban expansion in Siberia, resulting in a clear change in the original land-use patterns and trends [32]. The "one-hectare land policy" led to a significant increase in land development in suburban areas, resulting in the rapid conversion of forestland and grass land into construction land.

4. Conclusions

In this paper, a land-use/cover change analysis of Landsat remote-sensing image data from 2005, 2010, and 2015 was performed by using ArcGIS and eCognition to construct classification maps of the land-use types. Through the establishment of transfer matrices and other methods, the overall rate of land-use changes in each period, the area changes in the various types of land, and the conversion characteristics between land types were analyzed. PLSR modeling using SPSS was performed to quantitatively analyze the driving forces. The results show the following:

(1) During 2005–2015, the construction land in Irkutsk showed an upward trend; forestland was converted into construction land and grass land, bare land and cultivated land were converted into construction land, and the woodland area increased. The annual changes in land use from 2005 to 2010 were dramatic and slowed down from 2010 to 2015.

(2) Population agglomeration speeds up urban expansion, and the development of cities will in turn cause population aggregation, driving the rapid development of nonagricultural industries, expanding the area of construction land and changing the type of land use in cities [33]. The urbanization process of external populations gathering in cities and the counter-urbanization process that spreads from the central city to the suburbs has expanded urban construction land area and led to a continuous reduction in woodland, grass land and bare land in the suburbs. Due to the privatization of land, the restructuring of collective farms and the implementation of other policies, the economy of Irkutsk's farms has declined, agricultural land reclamation and urban expansion have occurred, the area of cultivated land has decreased, and the population distribution has scattered [34]. The implementation of the "one-hectare land policy" intensified the degree of development in suburban areas, resulting in a reduction in woodland and grass land. Although the impact of natural conditions on LUCC was not significant within a short period of time, its impact was obvious.

In the context of the "Belt and Road" initiative, as the key region for the construction of the China-Mongolia-Russia Economic Corridor, the West Bank of Lake Baikal will become a focus for future development. The acceleration of population agglomeration and urbanization will inevitably have more dramatic impacts on local land use/coverage, which in turn will affect the structure and function of regional ecosystems. Managing the relationship between regional development and nature conservation is particularly important. This concept advocates the "Green Belt and Road" initiative, strengthening land management and control and preventing disorderly development of regional land.

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