Land Use Evolution and Simulation Prediction of Pyongyang Municipality in North Korea from 2000 to 2020

Qinchen Zhang¹,², Pingyu Zhang² and Dongyan Wang¹

¹ College of Earth Sciences, Jilin University, Changchun 130061, China
² Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, China

Abstract: Using Global Land30 standard product as data source, combined with CA-Markov model to quantitatively study the land use evolution of Pyongyang municipality in North Korea from 2000 to 2010 and simulate the land use situation of the region in 2020, the research found: (1) From 2000 to 2010, the area of forest land and bare land in Pyongyang was greatly reduced, and the cultivated land, grassland, water body and artificial surface increased to varying degrees, and the expansion of cultivated land area was the most significant. (2) In the first decade of 21st Century, the comprehensive utilization of land use in Pyongyang increased, the information entropy declined weakly, and the land use system remained in a stable and orderly state. (3) In 2020, cultivated land in Pyongyang is still the main type of land use, but the area will be significantly reduced, and the artificial surface will continue to expand, becoming the main land area for area transfer. (4) The land use change in Pyongyang is mainly driven by the three aspects of consumer demand, economic benefits and government decision-making. With the development of society, the influence of economic interests will become more and more prominent.

1. Introduction

Land use change is an important manifestation of material and energy interaction between human beings and the global environment [1]. It occurs at any time and space scale, affecting not only the geographical distribution pattern of terrestrial ecosystems and its productivity, but also objectively reflecting the changes in the earth's biochemical cycle, the structure and function of ecosystems, and the supply of products and services, and also reproducing the temporal and spatial surface of the land [2]. Therefore, land use change has always been the core field of regional system research on human-land relationship [3]. With the rapid development of social economy, the speed and scale of land use change has changed greatly. It is a hot issue to study the temporal and spatial changes of land use and predict its future speed and direction. By analyzing the characteristics of land use change, reconstructing past and predicting future land use status, we can assess the impact of various factors on land use development, reveal the interaction mechanism of the complex system of human-land relationship, and provide decision-making for regional sustainable development [4-6].

Pyongyang is the capital of the Democratic People's Republic of Korea. It is located at the junction of the Pyongyang plains and hills in the lower reaches of the Datong River. The east, west and north are undulating hills. Pyongyang has a long history and has been the political, economic and cultural center of the northern part of the Korean peninsula since ancient times. After the Korean War, the industry developed rapidly and has become the industrial center of the country. Pyongyang is also a modern city with a beautiful scenery. The urban construction area accounts for 20%, and the remaining 80% is green land for parks and so on. It is one of the cities with the largest proportion of green areas in the
world. In the 21st century, North Korean leader Kim Jong Il proposed ‘building a strong and powerful country in accordance with the requirements of the new era’. The face of Pyongyang has also changed, and the pace of construction has accelerated markedly. It has become one of the regions where the human system in the Korean Peninsula and even the entire Northeast Asian region is more intense. This paper takes the entire regional perspective of geography research and the entire Pyongyang administrative scope (Pyongyang municipality*) as the research object, through the analysis of land use structure, degree and system change from 2000 to 2010 and the simulation prediction of land use status in 2020. It is intended to reveal the characteristics of land use evolution and the future development trends in typical urban areas under the special social system, and to explore the driving mechanism behind land use change. This study is helpful to deepen the understanding of land use in Pyongyang. It is of great significance to understand the status quo of North Korea’s national land control and its impact on the resources and environment of Northeast Asia.

* The scope of the Pyongyang municipality is based on the newly adjusted administrative boundaries around 2010, with specific reference to the North Korean map of the North Korean Map Publishing House in 2015.

2. Data and methodology

2.1 Data source
This study is based on the world's first 30m resolution global surface coverage product, the GlobeLand30-based data source, including products for the two base years of 2000 and 2010. The data adopts WGS-84 coordinate system, UTM projection, 6° banding, and the surface coverage types are divided into ten categories such as cultivated land and forest land [7]. The product has high spatial resolution and precision. Compared with the 1000m and 300m resolution products in Europe and the United States, the spatial resolution of the surface coverage product has been improved by one to two orders of magnitude. According to third-party verification, the classification accuracy is 83%. At present, the research application based on GlobeLand30 has been widely carried out. It has been proved that the data can not only meet the application needs of scientific research in land resources management, environment, agriculture, urbanization, etc., but also provide basic geographic data support for global change and Earth system model research.

2.2 Land use dynamic simulation
Land use process modeling and simulation is an important tool to explore land use drive mechanisms, support urban planning and policy development, and assess the impact of land use on the ecological environment. At present, the dynamic simulation model of land use change can be divided into two categories: retrospective macro model and forward-looking micro model [8]. The retrospective macro model focuses on the macroscopic model of land use temporal and spatial change process, and quantifies its driving factors based on land use temporal and spatial data. The mechanism of action explores the characteristics and laws of changes in its temporal and spatial scales, including geographic weighted regression, logistic regression, Markov prediction, and System Dynamics (SD). The forward-looking micro-model focuses on the interaction mechanism between micro-factors such as land mass, population and environment, and formulates the type transition rules between the plots and the influence function of the driving factors, by analyzing the relationship between the plot unit and the driving factor [8]. The microscopic effect is obtained as a simulation result of land use change on a macroscopic whole, represented by Multi-Agent System (MAS) and Cellular Automata (CA). This paper uses the CA-Markov model integrated in IDRISI software to simulate the land use status of Pyongyang municipality in 2020 with reference to the data of 2000 and 2010. The model has both Markov and cellular automata (CA). The advantage of the macro-top-down and micro-bottom-up coupling modeling method can not only express the overall evolution mode of land-use space-time process, but also quantify the micro-interaction between the block unit and the driving factor. It has a
good predictive effect on the spatial and temporal changes of land use, especially in the mesoscale basins and cities, and is therefore widely used [9-11].

2.3 Analysis of land use change

2.3.1 Land use change rate
Through the area tabulation in ARCGIS 10.4, the area transfer of various regions from 2000 to 2010 was counted, and the extent of land use change was analyzed. From the change of the area of a single land type and the change of the total land use quantity, the rate of land use change is measured [12], and the speed of structural change is analyzed.

\[
V_{t,i} = \frac{u_{bi} - u_{ai}}{u_{ai}} \times 100\%
\]

(1)

\[
V_t = \frac{\sum_{i=1}^{n} |u_{bi} - u_{ai}|}{2\sum_{i=1}^{n} u_{ai}} \times 100\%
\]

(2)

Where: \(V_{t,i}\) is the rate of change of land use type \(i\) in the study area; \(V_t\) is the overall rate of change of all land use types; \(u_{ai}\) is the area of land type \(i\) in the starting year \(a\); \(u_{bi}\) is the area of its ending year \(b\); \(t\) is the number of years from start to end; \(n\) is the number of all land types in the area.

2.3.2 Comprehensive Index of Land Use Level
By classifying the land use types of the four ideal states and assigning values to their own categories, four classification indexes of land use levels are obtained (Table 1). Since the four types in reality are mixed in the same area, each occupying a different proportion of the area, and making local contributions to the extent of local land use, according to their own weight [13-15]. Therefore, the comprehensive quantitative index of land use degree is based on mathematical synthesis (Equation 3), forming a continuous distribution of comprehensive index, the value of which comprehensively reflects the degree of land use in a certain area.

**Table 1.** Land use degree classification value table

| category       | unused land level | natural land level | agricultural land level | town level               |
|----------------|-------------------|--------------------|-------------------------|--------------------------|
| land use type  | unutilized or hard to use | forest, grass, water | cultivated land, garden | towns, residential areas, industrial and mining land, transportation land |
| graded index   | 1                 | 2                  | 3                       | 4                        |

\[
L_a = 100 \times \sum_{i=1}^{n} A_i \times C_i
\]

(3)

Where: \(L_a\) represents the comprehensive index of land use degree, \(A_i\) represents the grade index of land use degree of the \(i\)-th grade, and \(C_i\) is the percentage of the graded area of the land use degree of the \(i\)-th grade.

2.3.3 Land use information entropy
Information entropy is based on the concept of information theory used to measure the amount of information and uncertainty of the system [16]. The information entropy value of the land use structure can be used to reflect the order degree of the land use system in a region [17, 18]. Generally speaking, the larger the information entropy value, the lower the degree of order of the land use system, and vice versa.

\[
H = -\sum_{i=1}^{n} P_i \ln P_i
\]

(4)

Where: \(H\) is the information entropy, \(P_i\) is the ratio of the area of the \(i\)-th land-use type to the total area of the area, and \(n\) is the number of all land types in the area.
3. Results and analysis

3.1 Temporal and spatial variation characteristics

During the period from 2000 to 2010, the area of forest land and bare land in the Pyongyang municipality was greatly reduced (Table 2). Among them, the forest land decreased by nearly 30% to 119.14 km², and the bare land decreased by nearly 70%, but the absolute amount was only 1.21 km². Correspondingly, the area of cultivated land, grassland, water body and artificial surface has been significantly expanded. In terms of magnitude, the grassland area increased by up to 37.91%, the artificial surface was 10.79%, and the cultivated land and water body were again 5.85% and 3.97%. However, from the perspective of changing areas, the arable land expansion reached 69.8 km², the grassland and artificial surface were 29.8 and 18.39 km², respectively, while the water body area growth was only 2.37 km². From the perspective of structural changes, the conversion of forest land-cultivated land, forest land-grassland, cultivated land-artificial surface, bare land-water body is most obvious (Table 3). In space, woodland-cultivated land, woodland-grass mainly occurs in the northern and eastern hilly areas near Pyongyang. In order to ensure a stable food supply in the capital, large-scale deforestation and land reclamation have occurred in these areas, and the regional ecology has gradually deteriorated. Cultivated land-artificial surface occurred mostly in the south of the urban area and along the Datong River, mainly due to population growth and urbanization development. Artificial land expansion has encroached on a large number of urban suburbs. The change of bare land-water body is mainly affected by climatic factors. Relevant research shows that the average annual precipitation of North Korea has increased since 2000, which turns most of the bare beaches into rivers and lakes. A part of. In addition, the conversion of forest land-artificial surface in Pyongyang city is also very obvious. It can be seen that the urban construction of Pyongyang is accelerating and the building density of urban areas is increasing.

Table 2. Changes in the area of different land use types from 2000 to 2010

| Index                      | cultivated land | forest land | grassland | water body | artificial surface | bare land |
|----------------------------|-----------------|-------------|-----------|------------|-------------------|-----------|
| area in 2000 (km²)         | 1193.48         | 403.52      | 78.60     | 59.51      | 170.47            | 1.73      |
| area in 2010(km²)          | 1263.28         | 284.38      | 108.40    | 61.87      | 188.86            | 0.52      |
| single rate of change(%)   | 5.85            | -29.53      | 37.91     | 3.97       | 10.79             | -69.94    |
| comprehensive rate of change(%) | 6.31           |             |           |            |                   |           |

Table 3. Land use type area transfer matrix from 2000 to 2010

| Category                        | cultivated land | forest land | grassland | water body | artificial surface | bare land | transfer out |
|---------------------------------|-----------------|-------------|-----------|------------|-------------------|-----------|--------------|
| cultivated land                 | 116532.72       | 113.85      | 160.11    | 499.41     | 2041.29           | 0.36      | 2815.02      |
| forest land                     | 8302.05         | 28094.13    | 3179.61   | 95.49      | 681.03            | 0.00      | 12258.18     |
| grassland                       | 151.02          | 208.44      | 7459.11   | 30.15      | 10.98             | 0.00      | 400.59       |
| water body                      | 511.83          | 18.99       | 5370.48   | 31.05      | 0.36              | 0.36      | 580.23       |
| artificial surface              | 828.90          | 2.61        | 23.04     | 71.01      | 16121.34          | 0.00      | 925.56       |
| bare land                       | 1.17            | 0.00        | 0.00      | 120.87     | 0.00              | 51.30     | 122.04       |
| transfer in                     | 9794.97         | 343.89      | 3380.76   | 816.93     | 2764.35           | 0.72      | 17101.62     |
| net transfer                   | 6979.95         | -11914.29   | 2980.17   | 236.70     | 1838.79           | -121.32   |              |
The land use degree index formula is used to calculate the comprehensive land use degree of Pyongyang municipality from 2000 to 2010. The comprehensive index for 2000 and 2010 was 280.36 and 286.01, respectively, and increased by 5.65 in 10 years (Table 4). The expansion of land use indicates that Pyongyang is in the development stage, the urbanization process is gradually accelerating, and the role between human and land systems will become more intense. According to the calculation of land use information entropy formula, the information entropy of the land system in 2000 was 1.08, and in 2010 it was 1.06, a decrease of 0.02, and the change was very weak. It can be seen that the land use situation in Pyongyang is still in an orderly use range. For the system, there is no obvious imbalance in the conversion between land types.

Table 4. Land use comprehensive degree and information entropy

| Index                 | 2000   | 2010   | difference |
|-----------------------|--------|--------|------------|
| land use degree       | 280.36 | 286.01 | 5.65       |
| information entropy   | 1.08   | 1.06   | -0.02      |
3.2 Simulation and prediction analysis

The land use change probability transfer matrix of Pyongyang municipality from 2000 to 2010 was obtained by means of the CA-Markov module in IDRISI software, and the distribution of land use in Pyongyang municipality in 2020 was predicted by 10a (Fig. 3).

According to the forecast results, the area of cultivated land, forest land and grassland will decrease to varying degrees in 2010-2020 (Table 5). The reduction of cultivated land is most obvious to reach 121.95hm², but it is still the main type of regional land use, accounting for 66.17% of the total area. The reduction of woodland was 48.78hm², and the area ratio fell to 14.89%. The artificial surface is the main type of area growth, which has expanded by 183.96hm² in 10 years, and the proportion of the total area has increased to 10%. In addition, there is a weak transition between the water body and the bare land, and the area remains basically stable.

Comparing the land use change in Pyongyang municipality from 2000 to 2010 and 2010-2020, it can be found that the cultivated land and grassland gradually change from the early expansion to the attenuation, and the cultivated land will replace the forest land as the main type of net transfer, and the artificial surface will become the region. The main type of net transfer into the area. Changes in water and bare land area will gradually become weaker and remain at a dynamic level of stability. From the perspective of structural transformation, the cultivated land-artificial surface will surpass the forest land-cultivated land, and the forest land-grass becomes the most important feature of regional land use change. To a certain extent, this indicates that in the future, in the Pyongyang region, urbanization expansion will replace the traditional agricultural cultivation as the main way of interaction between human and land systems.

Table 5. Statistics of land use type area in 2020

| Land use category | Cultivated land | Forest land | Grassland | Water body | Artificial surface | Bare land | Total |
|-------------------|-----------------|-------------|-----------|------------|-------------------|-----------|-------|
| Area (hm²)        | 126232.47       | 28396.89    | 10828.89  | 6188.22    | 19069.83          | 51.93     | 190768.23 |
| Proportion (%)    | 66.17           | 14.89       | 5.68      | 3.24       | 10.00             | 0.03      | 100.00 |
| Change* (hm²)     | -121.95         | -48.78      | -13.23    | 0.27       | 183.96            | -0.27     | 0     |

*The amount of change here refers to the status comparison with 2010

Figure 3. Simulation of land use distribution in Pyongyang municipality by 2020
4. Discussion
From the historical analysis of human society development, consumer demand, economic interests and rational decision-making are three humanistic driving forces that affect land use change at the present stage and in the future [3]. Since the 21st century, the transformation of land use types in Pyongyang has also been affected by the synergy of the three driving forces.

One of the core of consumer demand is food, and land is always the most important carrier for humans to access food. When food supplies are in short supply, it is the only option to survive without breaking new land to meet basic food needs. Since the early 1990s, North Korea has been facing a food shortage and has experienced a ‘great famine’. Opening up new arable land and expanding planting area have become the most direct way to alleviate the contradiction between the supply and demand of the grain in the capital. The increase in arable land area at the expense of forest land has become a distinct feature of land use change in Pyongyang from 2000 to 2010. On the other hand, as the capital of North Korea, the country's population, industry and capital gathering places, economic interests also have an impact on land use in Pyongyang. The industrial structure succession and the urban-rural settlement change centered on the maximization of the economic benefits of land use are the two main driving forces, resulting in the adjustment of land use in various industries within the city and the expansion of marginal urban space. The proportion of construction land in Pyongyang's jurisdiction has been rising, and as the future food supply improvement and consumer demand tend to weaken, it will become the main form of regional land use transformation.

In addition, government decisions are also important factors affecting land use change in Pyongyang. On the one hand, Pyongyang has always been a model for North Korea to ‘build a strong country in accordance with the requirements of the new era’. The three generations of North Korean leaders pay special attention to the development and construction of the capital region, with the intention of building Pyongyang into a prosperous socialist modern city. On the other hand, North Korea pays special attention to the protection of the ecological environment in the management and development of land planning, and puts forward five principles for the construction of cities, industrial and mining, etc.: 1. It is not allowed to invade farmland; 2. The size of the city should not be too large, mainly in small and medium-sized cities; 3. According to natural conditions and local characteristics; 4. Construction should be combined with national vision planning; 5. Prevent environmental pollution and protect the ecological environment. Therefore, Pyongyang's urbanization development is generally in an orderly state. Although the construction land will inevitably encroach on cultivated land, forest land and grassland, it has not caused obvious ecological and environmental problems until now.

5. Conclusion
The essay quantitatively analyzes the land use change from 2000 to 2010 in the Pyongyang municipality of North Korea and simulates the land use status in 2020. The results show that the forest land in Pyongyang has decreased significantly from 2000 to 2010, and the cultivated land area has increased the most. Obviously, the degree of land use has increased, and the role between human and land systems has become more intense, but it still belongs to the scope of orderly utilization. The area of cultivated land will gradually decline from 2010 to 2020. Instead, the artificial surface will expand. Urbanization will become the main driving force for regional land use transformation. On the macro level, land use change in Pyongyang is mainly driven by food consumption, economic benefits and government decision-making. In the future, the gradual improvement of the food supply situation in North Korea and the acceleration of the pace of economic construction will inevitably make the driving role of economic interests on land use change more and more significant.

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