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Dynamic Simulation of Land use with CLUE-S Model and Change Rate of Land-Sea Gradient

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Abstract: The land use data in Qingdao, Yantai and Weihai, Shandong Province, China in 1995, 2005, 2009 and 2014 were interpreted from the RS images of Landsat 5 TM and Landsat 8 OLI to analyze the process of land use change in the study area in recent 20 years, and the spatial distribution of land use under three different scenarios in 2020 was predicted and simulated with the change rate of land-sea gradient and the promoted CLUE-S model. The results revealed that the change of land use types in the study area in recent 20 years was significant, the farmland was reduced in large area and shifted to construction land and woodland, the enlargement of construction land was particularly significant in the coastwise zone 0~10km to coastline, and that of woodland occurred mainly in the hilly zones 20~30 km to coastline. The GM(1,1) model was used to predict the demanded land areas, the bivariate logistic regression model was used to calculate the interrelations among the land use types and 10 kinds of driving factors at spatial scale of 450m×450m, the CLUE-S model was used to simulate the spatial distribution of land use types in 2014, and the effect was verified with the interpretation of images in 2014. The Kappa index was increased from 0.78 to 0.83 after the change rate of land-sea gradient was increased as one of the driving factors, and the accuracy simulated with the model was effectively improved. On which the spatial distribution of land use under three different scenarios including the natural growth, ecological conservation and economic development in the study area in 2020 was simulated, and the results revealed that the difference of spatial distribution was significant.

Keywords: *land use; CLUE-S; change rate of land-sea gradient*

1. Introduction

The coastal region of the peninsula is a zone most sensitive to land-sea interaction and human activities, and human activities accelerate the change of natural resources and environment in the peninsula region [1-4]. The process of LUCC (land use/cover change), driving mechanism and environmental effects are the core and frontier research subjects of LUCC [5-9]. The change processes and environmental effects in different regions in the peninsula have their own characteristics due to their different geographical location, exploitation and utilization level, function division, etc. The Shandong Peninsula is consisted of the low mountains and hills and denudated plains developed under the long-term geologic rise and denudation, its coastline is irregular, and the land-sea interaction is violent [10-12]. The various natural and human diving factors are complicated and diversiform due to the sea level rise caused by climate change, population growth, industrial development, shortage of freshwater resources, saltwater intrusion, seabed groundwater drainage, seawater pollution near offshore, etc. Especially the land use change is significant under the disturbance of human activities.

The difficulty of researching the driving mechanism is increased due to the diversity and correlation of driving factors and their complexity to the spatiotemporal process of regional LUCC, which need to be lucubrated based on the local conditions [13-14]. The highly complicated driving mechanism is depended on the higher-quality data of driving factors and the analysis methods of driving mechanism. At the stage of quantitative analysis and analysis with empirical statistical and evaluation model, neither can the action mechanism between driving forces and LUCC be comprehensively understood from the mechanism, nor can the action mechanism of LUCC be simulated from the action mechanism. The driving mechanism and land use change are quite different due to the spatiotemporal difference and environmental heterogeneity, and their studies are gradually shifted from the quantitative methods to the model methods [15-16].

The CLUE-S (Conversion of Land Use and Its Effects at Small Region Extent) model was developed for the spatial simulation of land use change at medium and small scales, it can be used to quantitatively sum up the relationships between the evolution of various land use types and the various natural and human factors, and to research the driving mechanism, developing trend and effects of land use [17-18], and it is also an international frontier modeling approach for researching land use change and its affecting extent [19-20]. Recently, the model was used by the many scholars one after another to carry out the dynamic simulation and the situational analysis of land use change in some drainage basins, cities and towns [21-24].

Verburg used the CLUE-S model to simulate the change of land use pattern in Europe [25]. Overmars used it to simulate the change of land use pattern in the Cagayan Valley on Luzon, the Philippines [26-27]. Orekan, et al used it to carry out a case study in the Bight of Beninto simulate and research the land degradation in West Africa [28]. Peng Jian used it to simulate and predict LUCC in the typical drainage basins under 4 kinds of scenarios in the ecological-frail areas and karst regions [29]. Many scholars probed how to regulate and improve the parameters in the model based on the local conditions so as to achieve the optimal simulation results. In this paper, the RS and GIS means and the CLUE-S driving force model were used to quantitatively research the dynamic mechanism and its evolution trend in exploitation, construction, development and change process at regional scale in the Shandong Peninsula. Based on the regional conditions along the coastal zone of the peninsula, the driving factors of land-sea gradient change probability were used to quantitatively research the effects of human activities on regional development and evolution of land use in the peninsula. The relationship between the diversity of land use and the comprehensive sustainable development capability in coastal region was specified, and the scientific bases could be provided for further lucubrating the human-land interaction in coastal region.

2. Materials and Methods

The study area (119°31′~122°43′E ,35°35′~38°24′N) is located in the east Shandong Peninsula and consisted of Qingdao, Weihai and Yantai cities (Figure 1), it faces the Bohai Sea on the north and borders on the Yellow Sea on the east and south, and its terrain is relatively low. The study area is a coastal region with active economic development, relatively dense population, and high level of industrialization and urbanization in Shandong Province. The effects of human activities on development and change of the peninsula are significant after the long-term exploitation and utilization. The situation of land use and land cover is not only the foundation and safeguard of social and economic development in coastal region, but also affects the regional environment and ecosystem in land, debouchures and coastal regions.

The land use data were interpreted from RS images. The RS data of the Landsat4 and Landsat5 TM(Thematic mapper) and Landsat8 OLI (Operational Land Imager) from the Computer Network Information Center of Chinese Academy of Sciences（http://www.gscloud.cn）were taken as the image data. Four images were needed to cover the study area, and they were cut and matched based on the regional boundaries of the peninsula in 2014 to derive the data in 1995(from Landsat4), 2005(from Landsat5), 2009(from Landsat5) and 2014(from Landsat8). The surface reflectance, vegetation index and DEM data (30 m) were regarded as the classification features to develop the decision tree classification model under ENVI software, and the spatial distribution information of land use types in the 4 years was derived. The data were classified and processed by referring the historical land use data, field survey results, statistical data and written records, and the accuracy of deriving the classification information was improved. The "Land Classification" of the Ministry of Land and Resources in 2001 was referred in the land classification system, the specific circumstance of the study area and the study scale were considered, and 5 land use types including farmland, construction land, waters, woodland and unused land were finally confirmed.

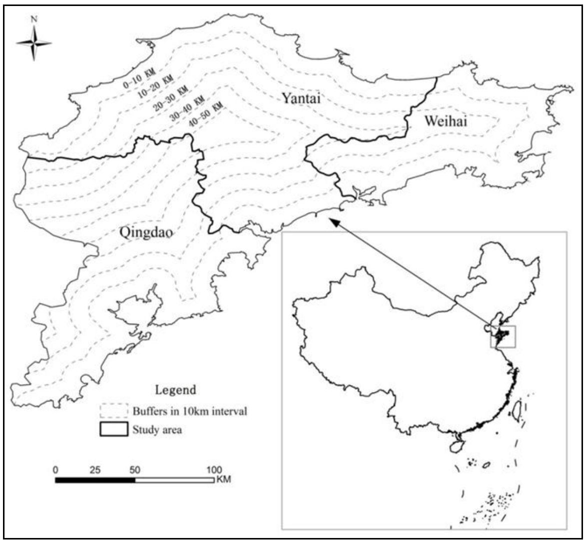

Figure 1 *Location of study area*

The CLUE-S model was used to predict and simulate land use, and it included mainly two parts, i.e. the non-spatial analysis module and spatial analysis module. The non-spatial analysis module was used to calculate the demanded land areas through the GM(1,1) model [30], in the model the discrete series was used to develop a differential equation, the discrete values were all the continuous variables and derived from calculation, and the data were processed with the developed differential equation. In this study, the prediction and simulation were carried out based on considering three scenarios, i.e. the natural growth, ecological conservation and economic development, the land demand plans under the three scenarios were regarded as the demand files to input into the CLUE-S model for the allocation of spatial pattern and the spatial simulation; the spatial analysis module was used to analyze the spatial suitability of land use under the driving of all the driving factors, the analysis was based on the probability and statistics, and the shift of land use types was depended on the probability of land use types at a certain spatial position. The spatial features of land use were calculated with the logistic regression, they were the spatial distribution probabilities of land use types,and the contribution rates of driving factors to land use change were analyzed [17-18]. The binary logistic regression calculation equation can be expressed as

$$log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots\cdots + \beta_n X_{ni} \qquad (1)$$

Where, P_i is the possible probability of land use type i in a spatial grid, X_{1i}~X_{ni} are the n alternative driving factors related to land use type i, β value is the explanatory variable coefficient of the regression equation, and the higher the β value is, the higher the relevancy will be.

In geographical study, many scholars realize the importance of scale [31]. If there is a relevancy at a certain scale, it cannot be determined whether there is a relevancy after the scale is changed. It is crucial to select a scale in studying LUCC. Only by analyzing and researching LUCC at different scales can its internal regularity be accurately seized. Six scales, i.e. 150m×150m, 300m×300m, 450m×450m, 600m×600m, 900m×900m and 1500m×1500m, were selected in this study, the logistic regression analyses between land use types and driving factors at each scale were carried out, then the simulated results were verified with the ROC (receiver operating characteristic) curve, and the optimal simulation scale suitable for the study area was selected based on the ROC value. According to the historical situation and the restriction policies of the change of different land used types in the study area, the shift rules and flexibility among different land use types were designed. The shift flexibility of a certain land use type with low stability and easy shift to other land use types, such as unused land, was close to 1, and that with high use degree and high stability, such as construction land, was close to 0.

According to the local conditions in the peninsula, the change probability of land-sea gradient was taken as a driving factor except the 9 driving forces including elevation, slope, exposure, and distance to main railway, distance to main highway, distance to Main River, distance to county town, and distance to prefecture town and distance to coastline. In which the DEM data were used to derive the values of elevation, slope and exposure through surface analysis; the Euclidean distance analysis was used to derive the values of distance to main railway, distance to main highway, distance to main river, distance to county town, distance to prefecture town and distance to coastline; the change probability of land-sea gradient was assignedand rasterized to be used as a driving factor in the model after the land use data in the 4 years were derived from the interpretation of overlay analysis, the whole study area was divided into 6 gradients every 10 km in zonal width from coastline to inland to calculate the changed parts of land use types, and the shift probability of each land use type at each gradient was derived through statistical analysis.

The CLUE-S model was used to carry out the spatial allocation of land use types according to the total probability based on analyzing the suitable probability of spatial distribution of land use types, shift rules of land use types, and areas of various demanded land use types. Many times of iteration were needed to achieve the spatial allocation. Accuracy of the final results was verified with Kappa index, and the equation can be expressed as

$$\mathrm{Kappa} = (P_o - P_c)/(P_p - P_c) \qquad (2)$$

Where, P_o is the accuracy proportion of the simulation, P_c the expectation of accuracy proportion under stochastic situation, and P_p the accuracy proportion of the simulation under the ideal situation. The Kappa index is between 0 and 1, and the higher the Kappa index is, the higher the accuracy of simulation will be.

3. Analysis

3.1 Prediction of Demanded Land Areas

The statistical results of the interpreted data of land use in 1995, 2005, 2009 and 2024 were used as the basic data (Table 1), and the values of demanded land areas from 2005 to 2014 were interpolated. Based on the data of land use types in 2014, the GM(1,1) model was used to simulate the land use data in the study area during the period of 2015-2020, and the data were used as the sequential data of demanded land areas under natural growth. On which the data of demanded land areas under considering the ecological conservation and economic development in 2020 were calculated based on the factors of ecological conservation and economic development and the restriction of policies including the “Overall Planning of Land Use in Shandong Province (the years of 2006-2020). The predicted data of demanded land areas under three scenarios in the study are shown in Table 2.

Table1: *Area of land use type interpreted by images in four periods (unit: ha.)*

Time	Farmland	Construction land	Water bodies	Forest land	Unused land
1995	2491771	172293	122162	246431	10321
2005	2356680	266085	145763	261255	13195
2009	2199863	409748	133434	284650	15283
2014	2112675	461244	127501	325011	16548

Table2: *Demanded land areas under three scenarios in 2020 by GM (1, 1) (unit: ha.)*

Three scenarios	Farmland	Construction land	Water bodies	Forest land	Unused land
Ecological conservation	2013688	484123	120213	410802	14152
Economic development	1963270	599617	112883	353995	13214
Natural growth	1998243	527191	119862	384025	13657

The effects of policies, laws, regulations, etc. on the demand of land use under natural growth were not significant, and the data of demanded land areas were derived from the prediction with GM(1,1) model; it was requested that the areas of two kinds of ecological lands (i.e. woodland and waters) under the scenario of ecological and environmental conservation must be ensured, and the shift of farmland and unused land should be intensified. The proportion of woodland area in Qingdao, Yantai and Weihai, as the coastal tourist cities, will be reached to 13.5% of the total land area in 2020; under the driving of economic development, it was considered that the area of construction land will be rapidly enlarged, the shift from farmland and unused land to construction land will be sped up, and some of the woodland and coastal waters will be possibly occupied by construction land. Approval of the "Development Planning of Blue Economic Zone in the Shandong Peninsula" in 2011 marked that the construction of blue economic zone will become as the principal direction of regional development in the future, and it was predicted that the area of construction land in the Shandong Peninsula in 2020 will be enlarged by about 30% based on the construction land area of 461244 ha in 2014.

3.2 Logistic Regression Analysis

RS interpretation was used to extract the information of land use, five land use types, i.e. the farmland, construction land, waters, woodland and unused land, were saved as the individual files of land use types, the value of each land use type was assigned by 1, and the values of other land use types were assigned by 0. According to the 6 simulation scales, the land use files and driving force files under each scale were converted into the ASCII file format, and then they were converted into the single record files and inputted into the SPSS 20.0 software to carry out the logistic regression analyses of all the land use types and driving factors at 6 simulation scales. The results revealed that the ROC values of construction land, waters and woodland reached their maximums at scale of 450m×450m, the difference of ROC values of farmland and unused land was not significant at all the scales, so the scale of 450m×450m was regarded as the optimal simulation scale. Before the driving factor of change probability of land-sea gradient was used, the ROC values of the five land use types were 0.61, 0.73, 0.75, 0.75 and 0.62, after that they were 0.69, 0.73, 0.78, 0.81 and 0.67, respectively, which revealed that the change probability of land-sea gradient could be used to significantly improve the accuracy of regression analysis, and also revealed that the good interpretation results of spatial distribution of land use types could be achieved by selecting the 10 driving factors. The β values in the logistic regression analyses are shown as Table 3.

Table 3: *The β Value of Land Use Types after Logistic Regression in 2005*

Factors	farmland	Construction land	Water bodies	Forest land	Unused land
Elevation	-0.00252209	-0.00872566	-0.00870360	0.00758680	-
Slope	-0.01602482	-0.01401035	-0.02289474	0.04894875	-
Aspect	0.00072560	-	-0.00068465	-0.00093414	-
Distance to main railway	0.00000955	-0.00000851	-0.00000300	-	-
Distance to main highway	-0.00000899	-0.00000480	0.00000659	0.00002259	-
Distance to main river	0.00000543	0.00000624	-0.00003633	-0.00000435	0.00002236
Distance to county town	0.00001596	-0.00006336	0.00002536	-	-
Distance to prefecture town	0.00000530	-0.00000131	0.00000881	-0.00002327	0.00001874
Distance to coastline	0.00003982	-0.00001471	-0.00006079	-0.00001679	-0.00000772
Change probability of land-sea gradient	0.00080086	-0.00093565	-0.00078841	-	-
Constant	-0.41107687	0.00788311	-1.83626018	-1.76890283	-6.93976925

3.3 Simulation and verification of CLUE-S model

The CLUE-S model was used to simulate the land use situation in 2014 by taking 2005 as the starting year, and the land use results interpreted from the RS data in 2014 were used to verify the simulation effects. Before the driving factor of change probability of land-sea gradient was used, the grids of correct simulation in 2014 were 124128 and occupied 82.57% of the total grids (150325). So P_o =0.8257, there were 5 land use types in the study area, P_c=1/5, P_p=1, and it was derived from equation (2) that the Kappa index was 0.7822; after the driving factor of change probability of land-sea gradient was used, the grids of correct simulation in 2014 were 130012 and occupied 86.49% of the total grids, P_o=0.8649, the derived Kappa index was 0.8311, the simulated result was higher than 0.8, and the accuracy was improved to a certain extent. These revealed that the land use change in the study area could be simulated well with the CLUE-S model and the change probability of land-sea gradient. Figure 2 shows the contrast of the simulated and interpreted results of land use types in the study area in 2014.

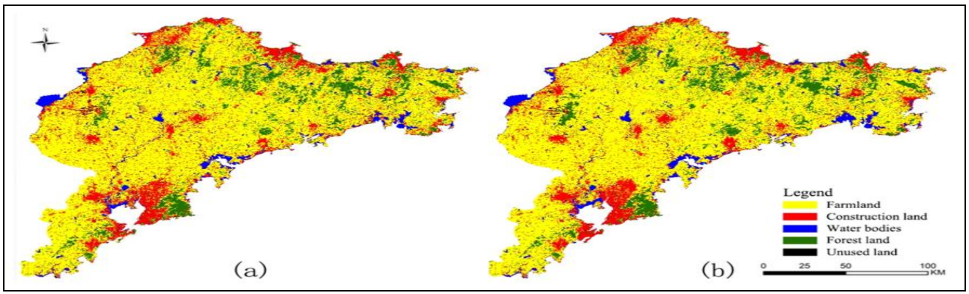

Figure 2 *Land Use maps in 2014: (a) Simulation map and (b) Interpretation map*

4. Results and Conclusions

4.1 Features of Land Use Change in the Shandong Peninsula

During the period of 1995-2014, the change of farmland and construction land was significant in the study area, the proportions of farmland in 1995, 2005, 2009 and 2014 were 81.89%, 77.45%, 72.29% and 69.43%, and the area and proportion of farmland were reduced by 379873 ha. and 15.25%, respectively. The area of construction land was rapidly enlarged, its proportions in 1995, 2005, 2009 and 2014 were 5.66%, 8.74%, 13.47%and 15.16%, and the construction land was enlarged by 167.71%. The sharply-reduced farmland was mostly shifted to construction land, and then to woodland. Construction land was expanded from the residential areas outward in the county and prefecture towns, especially in the coastal region. The area of woodland was slightly enlarged mainly in the regions with high elevation, and the forest coverage rate in the ecological and tourist towns in the coastal region was increased year by year. The coastlines were expanded toward sea, and the natural coastlines were changed into the artificial coastlines, thus the waters before was shifted into construction land.

The closer to the coastal region was, the lower the proportion of farmland would be. In 2005, for example, the proportion of farmland was 51.55% in the zone of 0-10 km in zonal width to the coastline, and it was as high as 88.78% in the zone of 50-60 km to the coastline; human activities were active, the economic development was rapid, and the proportion of construction land was high. The proportions of construction land in the zones 50-60 and 0-10 km to the coastline in 2014 were 6.38% and 26.21% respectively. Coastal cities, towns and ports were the supports of regional economic development and very important for the development in the study area. Waters were mainly distributed in the zone of 0-10 km in zonal width, they were formed from seawater and fish breeding farms, and the areas of inland rivers, lakes and ponds were small. Woodland was mainly distributed in the hilly regions with high elevation, the proportion of woodland in the zone 0-30 km in zonal width to the coastline was high in three years, and the area of woodland was enlarged with the time in all the zones.

4.2 Prediction and simulation of spatial distribution of land use in the shandong peninsula

The data in 2014 were taken as the basic data, the demanded land areas predicted under the three scenarios in 2020 in Table 2 were separately edited as the demand files to be inputted into the model, some of other parameters were adjusted, the spatial distribution of land use in the study area in 2020 were simulated, and the maps of land use under three scenarios were finally generated (Figure 3).

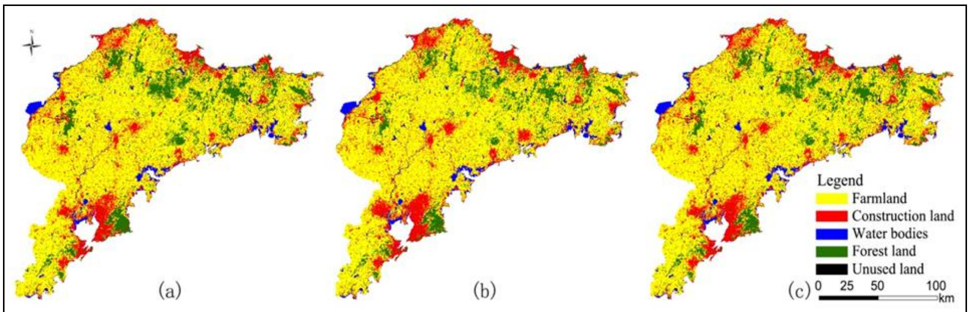

Figure 3 *Simulation maps of land use in 2020: (a) Natural growth scenario, (b) Ecological conservation scenario and (c) Economic development scenario*

The areas of farmland under the three scenarios were reduced, those of construction land and woodland were enlarged, and those of waters and unused land were basically stable with slight fluctuation: (1) Under the scenario of natural growth, the change rates and trends of all the land use types were basically maintained during the period from 2005 to 2014, the area of construction land was rapidly enlarged, that of woodland was also enlarged, that of farmland was continuously reduced, some of the farmland was shifted to construction land and woodland, waters were shifted to construction land, and the shifting of land use types occurred mainly in the marginal zone of towns, farmland-woodland ecotone and coastal area; (2) Under the scenario of ecological conservation, the area of woodland was rapidly enlarged mainly in the peripheral regions of the previous woodland, the enlargement of construction land was slowed down and lower than that during the period from 2005 to 2014, and the area of waters was slightly enlarged; (3) Under the scenario of economic development, the area of construction land was rapidly enlarged, the enlargement was higher than that during the period from 2005 to 2014, it in 2020 will be enlarged by about 35% compared with that in 2014, the area of woodland was slightly enlarged, that of farmland was sharply reduced, and the coastline was continuously expanded toward sea.

5. Discussion

In this study, the CLUE-S model was used to predict and simulate the change of land use types in the study area. After the driving factor of change probability of land-sea gradient was used, the simulation accuracy was effectively improved. Three scenarios of land use change in the future, i.e. the ecological conservation, economic development and natural growth, were designed, which revealed that there will be a certain difference in spatial distribution of land use types in 2020 for the presupposed solution under different scenarios. Along with the gradual construction of the Blue Economic Zone in the Shandong Peninsula, it was planned to build up the Blue Economic Zone with the optimized industrial structure and the harmonious human-nature relations, the ecological conservation will be emphasized, and the capability of sustainable development will be enhanced. Which will be advantageous for intensifying the cooperation in the Circum-Bohai Sea Region and the Yangtze River Delta Area, and also for further optimizing the overall development pattern in the coastal regions of China.

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