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Original Research

Land Use Changes and its Driving Factors in a Coastal Zone

Xuncheng Fan[1], Lili Zhao[1], Dongjin He[2]*

[1]College of Urban and Rural Construction, Shaoyang University, Shaoyang, China
[2]Forestry College, Fujian Agriculture and Forestry University, Fuzhou, China

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Abstract

Three-fifths of the world's population lives in coastal zones. The rapid increase of the population in the zone is bound to have a significant impact on the ecological environment, thus affecting economic sustainable development. Therefore, a coastal zone was regarded as the study area, and we studied the land use changes and its driving factors in the zone. The study had an important guiding significance for the scientific management and sustainable development of land in zones. Firstly, object-oriented classification was used as the classification method of land use. Secondly, the dynamic degree of land use and canonical correlation analysis were used to study the land use changes and its driving factors. The results showed that forestland and grassland, and cultivated land were the main types of land use in the study area over the study period. The area of forestland, grassland and aquaculture increased while the area of cultivated land decreased. The area of aquaculture and unused land has dramatically changed over the study period. Population was the main driving factor for the areal change of construction land, water and unused land. The main driving factors of aquaculture were population and primary industry. Population and policy were the main driving factors of cultivated land. Policy was the main driving factor causing the change of forestland and grassland. Consequently, policy, population and primary industry were the main drivers of land use changes in the coastal zone.

Keywords: dynamic degree, canonical correlation analysis, Ningde, RS, GIS

Introduction

Land is a natural complex that includes geology, geomorphology, climate, hydrology, soil, vegetation and other natural elements [1-2]. Land use means that human beings manage and treat land, adopting a series of biological and technological means according to natural characteristics of land and economic purposes during the long term [3-4]. Land use changes not only change the structure of the Earth's surface, but also affect the ecosystem and humans. Therefore, the International Geosphere-Biosphere Program (IGBP) and the International Human Dimensions Program on Global Environmental Change (IHDP) jointly proposed a scientific research program about land use changes and regarded this program as a core of global change research [5]. The study of driving factors is an important part of land use change research [6-7]. It has an outstanding practical significance for the accurate prediction for the future of land use changes and rational planning of regional land, and environment protection to identify the driving factors.

*e-mail: 1525972790@qq.com

The coastal zone refers to the region of interaction between land and sea [8-9]. It not only is affected by natural factors, but also by human activities. Therefore, the balance in the ecosystem of the coastal zone is easily broken. The area of the global coastal zone is less than 20% of the earth's surface. However,3/5 of the world's population lives in coastal zones [10]. In this study, the population in the coastal zone of Ningde City accounted for 68% of the total population of Ningde by the end of 2014[11]. In addition, the primary productivity of coastal zone accounts for a quarter of the world's primary productivity, and 95% of fishing activity is carried out in coastal ecosystems [12]. Therefore, coastal zones are one of the most promising areas for human beings, and are also an extremely fragile and sensitive region. Study of land use changes in a coastal zone provided an important theoretical support for the sustainable development of a coastal zone.

The coastal zone of Ningde, the study area, is located in the middle of the coastline of China's mainland. There are more than 600 kinds of aquatic resources in this zone. The impact of human activities on the coastal zone has become increasingly serious with economic development, population growth, and urbanization. The existing research about this region mainly focused on the landscape changes of the wetland in a coastal zone [13], the distribution characteristics of heavy metals in different wetland types [14], the phenotypic plasticity of invasive species (Spartina alterniflora) [15], and ecological security of the zone [16]. There is alack of research on land use changes and its driving factors in the coastal zone. Therefore, land use changes and its driving factors in the zone were studied using a dynamic degree of land use and canonical correlation analysis under support of RS and GIS. This study provided an important case for land management and policy formulation in a coastal zone.

Materials and Methods

Choice and Overview of Study Area

At present, the explanation of coastal zone is diverse. Geomorphologists believe that a coastal zone should be the intertidal zone between the high and low tides [17]. Some planners believe that part of the land in a coastal zone should not be bound, and the part of the sea should be extended to the continental shelf [18]. However, the administrative region (Jiaocheng, Fuan, Fuding, Xiapu) was regarded as the study area (Fig. 1). The main reason is that these regions directly contact the sea. Other reasons are that socio-economic factors were easily obtained from the statistical yearbook,which is measured in the administrative region.

The coastal zone of Ningde belongs to Fujian Province of China, which is located in the middle of the Yangtze River Delta, Pearl River Delta and Taiwan. The terrain is mainly hilly and mountainous. It belongs to the mid-subtropical maritime monsoon climate. The land area of the coastal zone is 6253 km^2. The sea area is 44,600 km^2, accounting for 35.63% of the total marine fishery area of the province. The coastline (excluding islands) is 943.2 km long, accounting for 28.35% of the total coastline of the province. The zone is rich in aquatic resources and has more than 600 kinds of marine life. It is rich in large yellow croaker, prawn, grouper, dioxin and sword. The artificial breeding and

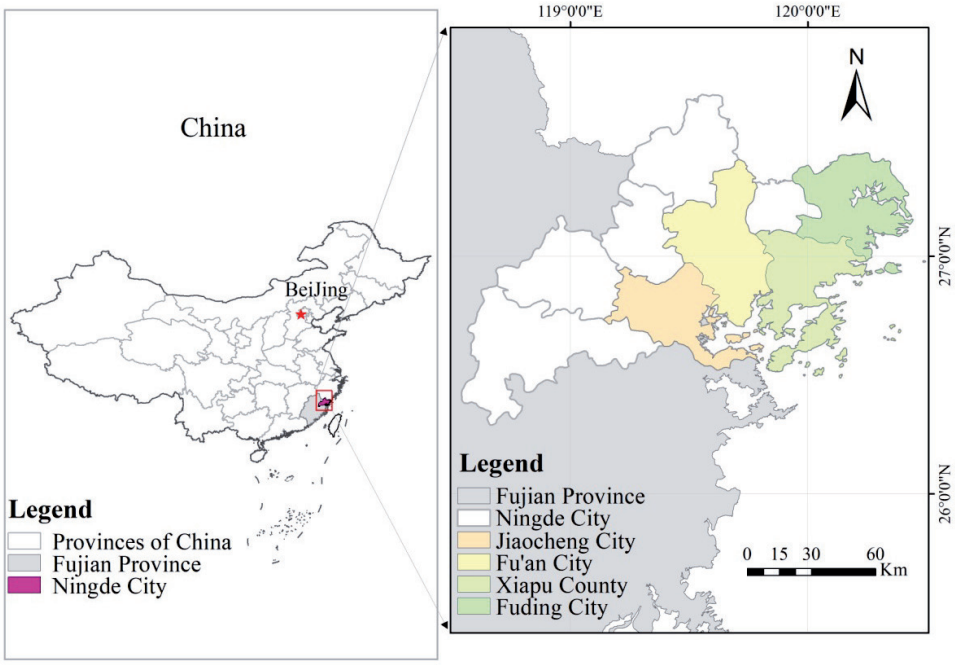

Fig. 1. Map of study area.

Table 1. Source and description of the remote sensing data.

Source	Shooting time	Description
Landsat-5 TM	2000-05	The cloud coverage of these images was less than 10%. The four scenes were required to completely cover the entire study area. Their track numbers were 119/42, 119/41, 118/41, and 118/42, respectively.
Landsat-5 TM	2009-06	
Landsat-8 OLI	2014-12	

seedling technology of large yellow croakers in the zone has reached the international leading level. At the end of 2014, the resident population and GDP of the coastal zone were 2.30 million and 137.60 billion yuan respectively.

Source and Process of Data

The remote sensing data, including Landsat-5 TM (2000 and 2009) and Landsat-8 OLI (2014) (Table1), were obtained from the Geospatial Data Cloud (http://www.gscloud.cn/). In addition, other study materials include the administrative zoning maps obtained by the geographical information monitoring cloud platform (http://www.dsac.cn/) and the Ningde statistical yearbook from 2000 to 2014 [11,19-20].

These remote sensing images had undergone the correction of ground control point geometry and DEM terrain before being downloaded. Therefore, the processing of remote sensing data in this study was to do color synthesis, mosaic, clip and object-oriented classification using ENVI 5.2. Types of land use were divided into six categories: forestland and grassland, cultivated land, water, aquaculture, construction land, and unused land. In this study, remote sensing images from Landsat-5 TM and Landsat-8 OLI were processed using 4, 3, and 2 bands and 5, 4, and 3 bands for color synthesis respectively. Finally, the maps of land use classification were obtained using ENVI 5.2 (Fig. 2).

250 samples for each type of land use were selected to achieve better classification results. Field investigations and interactive verification using Google Earth were carried out. After field verification, the classification accuracy of the remote sensing images fromthe three periods was 89.30%, 94.50%, and 92.50% respectively, which can meet the requirements of this study.

Dynamic Degree of Land Use

The land use dynamic degree reflects dynamic change of a specific land use type during the study period [21]. The mathematical model is as follows:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \quad (1)$$

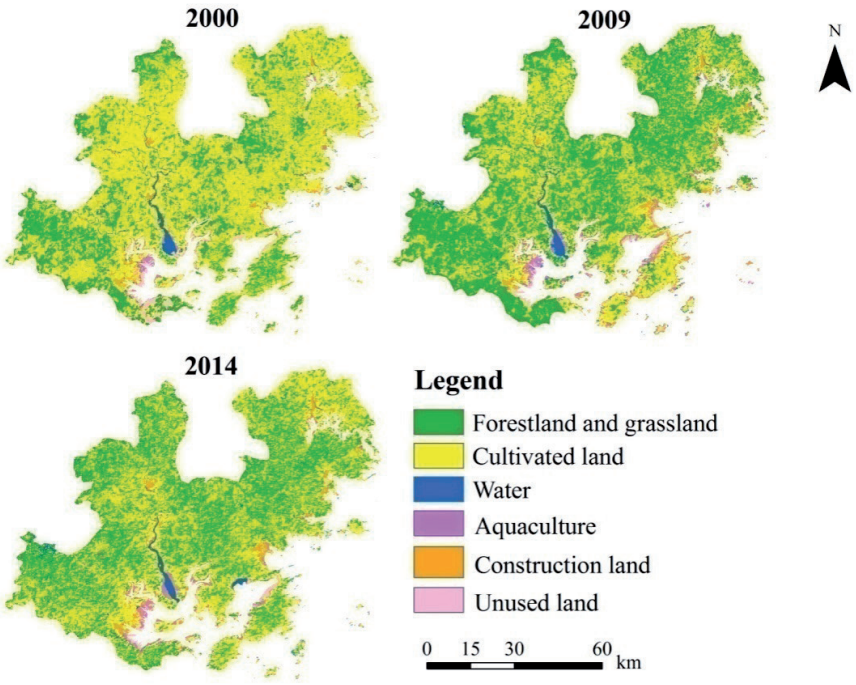

Fig. 2.Classification of land use types.

…where K is a value of dynamic degree of a specific land type; U_a and U_b represent the area of a specific land type at the beginning and end, respectively; and T indicates the length of study, and its unit is a.

Canonical Correlation Analysis

Canonical correlation analysis is a multivariate statistical analysis method that reflects the overall correlation between the two sets of indicators using the correlation between pairs of integrated variables. For example, U_1 and V_1 are the linear combination of each variable in the two variable groups respectively. The two integrated variables U_1 and V_1 are extracted from the two sets of variables respectively in order to grasp the correlation between the two sets of indicators. Finally, the correlation between the two integrated variables is used to reflect the overall correlation between the two sets of indicators [22-23]. Land use changes and its driving factors can be quantitatively analyzed and simulated using the method. Therefore, it has been applied to study driving factors of land use changes by many scholars [24-25].

The socio-economic factors were used in principal component analysis. In the shorter period (14 years in this paper), the influence of natural factors on land use changes was not obvious. By contrast, the socio-economic factors had a significant impact on land use changes in the shorter period [26]. The coastal zone in Ningde is located in the middle of the Yangtze River Delta, the Pearl River Delta and Taiwan. The socio-economic factors formed by the economy, population and urbanization had a greater impact on land use changes. Therefore, the socio-economic factors excluding natural factors were used to study the driving factors in the coastal zone.

Socio-economic factors were obtained using the Ningde Statistical Yearbooks from 2000, 2009 and 2014 [11,19-20]. Finally, 18 factors that were easy to be quantified and had a strong correlation with land use changes were selected. They included population, economy, consumption, technology and social awareness (Table 2). For canonical correlation analysis,these 18 factors were regarded as explanatory variables, and the areas of all the land use types obtained by remote sensing images were regarded as target variables.

However, multi-collinearity analysis was performed before using a canonical correlation analysis. Since these 18 explanatory variables might have strong correlation, multi-collinearity analysis was used to find the factors that can best represent the explanatory variables to improve the efficiency of the operation. Therefore, SPSS20.0 was used to perform multi-collinear analysis. From Table 3, total population (X_2), urban population (X_3), population density (X_4), rural population (X_5), primary industry (X_7), local fiscal revenue (X_{12}), and natural population growth rate (X_{18}) passed a significance test with a significance level

Table 2. Selection of explanatory and target variables.

Explanatory variable (Socio-economic factor, X)			Target variable (Area of land use types, Y)	
Population	X_1	Household registration	Y_1	Cultivated land
	X_2	Total population	Y_2	Construction land
	X_3	Urban population	Y_3	Water
	X_4	Population density	Y_4	Forestland and grassland
	X_5	Rural population	Y_5	Aquaculture
Economy	X_6	GDP	Y_6	Unused land
	X_7	Primary industry		
	X_8	Secondary industry		
	X_9	Tertiary Industry		
	X_{10}	Industrial output		
	X_{11}	Gross agricultural output value		
	X_{12}	Local fiscal revenue		
	X_{13}	Local fiscal expenditure		
Technology	X_{14}	Fixed assets investment		
Consumption	X_{15}	Total retail sales of social consumer goods		
	X_{16}	Urban and rural residents' savings balance		
	X_{17}	Average annual salary of all employees		
Social awareness	X_{18}	Natural population growth rate		

Table 3. Results of multi-collinearity analysis.

Target variable	Explanatory variable	Standard regression coefficient	t	Sig.
Y_1	X_7	-0.550	-9.973	0.000
	X_2	1.407	25.529	0.000
Y_2	X_3	0.942	10.082	0.000
Y_3	X_2	1.128	14.344	0.000
	X_{12}	-0.358	-4.271	0.001
	X_{18}	0.160	2.304	0.042
Y_4	X_5	0.971	14.672	0.000
Y_5	X_5	0.993	12.021	0.000
	X_4	-0.232	-2.808	0.016
Y_6	X_3	1.322	5.061	0.000
	X_4	-0.532	-4.173	0.002
	X_5	-0.678	-2.554	0.027

Table 4. Result of the canonical correlation coefficients.

Group	Canonical correlation coefficients	Wilk's	Chi-SQ	DF	Sig.
1	0.999	0.000	138.463	42.000	0.000
2	0.989	0.000	61.612	30.000	0.001
3	0.956	0.007	35.083	20.000	0.020
4	0.897	0.077	17.965	12.000	0.117
5	0.774	0.393	6.543	6.000	0.365
6	0.144	0.979	0.146	2.000	0.930

of <0.05. Therefore, canonical correlation analysis was performed using only the above seven variables.

After the canonical correlation analysis was operated, the results were tested using a canonical correlation coefficient. From Table 4, the correlation coefficients of the first three groups were greater with a value of 0.999, 0.989, and 0.956, respectively. Their significance probability value (Sig.) were all less than 0.05, indicating that the first three groups of variables represented most of the original indicators, and also clearly and fully explained the corresponding variables. Finally, the three groups of variables were analyzed in this study.

Results

Area of Land Use

The areas of six kinds of land use types from 2000, 2009, and 2014 were obtained using ArcGIS10.1. From Table 5, forestland and grassland, and cultivated land accounted for more than 87% of the total area over 14 years. The area of forestland, grassland and aquaculture increased by 1047.23 km^2 and 60.80 km^2, respectively. By contrast, the remaining land use types showed a decreasing trend. Specifically, the area of cultivated land decreased by 959.45 km^2 during the study period.

Dynamic Degree of Land Use

From Table 6, the absolute value of aquaculture dynamic degree was the greatest, with a value of 5.70%/a, indicating that aquaculture had the fastest change in area over 14 years. The absolute value of unused land was 4.71%/a, indicating that the change of unused land was faster than other land use types except aquaculture. The value of aquaculture reached 12.14%/a from 2000 to 2009, while the value was only -2.82%/a from 2009 to 2014. This indicated that the area of aquaculture grew more rapidly from 2000 to 2009.

Driving Factors of Land Use Changes

The canonical loadings were obtained after the operation of canonical correlation analysis. From Table 7, the cultivated land, water area and construction land in target variables of the first group were extracted. The value of the canonical loadings in the three land use types were -0.978, -0.945, and -0.939, respectively.

Table 5. Areas of six kinds of land use types (km^2).

Land use types	2000	2009	2014	Changing value over the 14 years (km^2)
Unused land	119.11	64.30	40.63	-78.48
Construction land	219.82	247.70	211.63	-8.19
Forestland and grassland	1669.84	2892.25	2717.07	1047.23
Aquaculture	76.24	159.57	137.04	60.80
Water	277.25	332.44	215.34	-61.91
Cultivated land	3890.47	2556.47	2931.02	-959.45
Total	6252.73	6252.73	6252.73	-

Table 6. Dynamic degree of land use types (%/a).

Land use types	2000-2009	2009-2014	2000-2014
Unused land	-5.11	-7.36	-4.71
Construction land	1.41	-2.91	-0.27
Forestland and grassland	8.13	-1.21	4.48
Aquaculture	12.14	-2.82	5.70
Water	2.21	-7.04	-1.59
Cultivated land	-3.81	2.93	-1.76

In the explanatory variable group of the first group, total population and urban population were extracted due to the value of -0.992 and -0.991, respectively. It can be seen that there was a strong correlation between the change of cultivated land, construction land and water area from Y group, and the total population and urban population from X group.

From the second group, aquaculture from Y group and primary industry from X group were extracted based on the value of -0.525 and -0.582. This indicated that the aquaculture was positively correlated with the primary industry. From the third group, unused land with a value of 0.474 and natural population growth rate with a value of -0.683 were extracted, indicating that the changes of unused land were negatively correlated with the natural population growth rate.

Discussion

The area of forestland and grassland increased, while the area of cultivated land decreased over the study period. This is mainly because forests in Ningde were used as a commodity under the supervision of the policy from the government. Increasing the area of forestland was regarded as a way to improve the local economy. In addition, cultivated land located in inappropriate areas was transformed into forestland under the supervision of the policy. Another reason for the decrease of cultivated land was the dramatic increase of the aquaculture area over the study period. The population of the coastal zone increased from 2.08 million in 2000 to 2.30 million in 2014. The people who live in seaside prefer to eat seafood. The increased population led to the increase in demand for seafood. Therefore, more cultivated land was transferred into the aquaculture.

The result of the canonical correlation analysis showed that there was a strong correlation between cultivated land, construction land, waters and unused land from Y group and the total population, urban population and natural population growth rate from X group. This indicated an increase in the population, resulting in the increasing demand for food, housing, drinking water, and the occupation of unused land. Consequently, the population is an important driving factor for the change of cultivated land, construction land, water and unused land. Wuet al. [27] studied the driving factors of land use change in the coastal zone

Table 7. Results of canonical loadings of the canonical correlation analysis.

Canonical variables	Name of variables	Canonical loadings					
		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Target variable Y							
Y_1	Cultivated land	-0.978	0.156	0.103	0.038	-0.035	0.070
Y_2	Construction land	-0.939	-0.132	0.045	0.181	-0.21	-0.147
Y_3	Water	-0.945	0.018	-0.225	0.22	-0.075	-0.049
Y_4	Forestland and grassland	-0.895	-0.401	-0.138	0.011	0.073	-0.112
Y_5	Aquaculture	-0.822	-0.525	-0.084	0.163	-0.006	0.126
Y_6	Unused land	-0.61	0.12	0.474	0.532	0.317	-0.072
Explanatory variable X							
X_2	Total population	-0.992	-0.123	-0.029	-0.016	0.01	0.014
X_3	Urban population	-0.991	-0.017	0.08	-0.002	-0.044	0.09
X_4	Population density	-0.177	0.096	-0.386	-0.78	-0.12	0.305
X_5	Rural population	-0.897	-0.374	-0.193	-0.084	-0.09	-0.011
X_7	Primary industry	-0.762	-0.582	-0.235	-0.099	0.088	-0.042
X_{12}	Local fiscal revenue	-0.511	-0.382	0.011	-0.696	0.092	-0.165
X_{18}	Natural population growth rate	-0.018	-0.165	-0.683	-0.209	0.205	0.251

of Fujian Province, China from 2005 to 2015 under the support of RS and GIS, and found that population, social wealth, and technology were the main drivers in the zone. Han et al. [28] studied the driving factors in the coastal zone of the United States during 50 years. They found that population, economy and policy had the most significant impact on land use changes in the zone.Wang et al.[29] studied the driving factors in the coastal zone of Jiangsu province, China, and found that population growth, government policies and the economy were the main driving factors in the zone. In summary, the study results of other researchers also once again proved that population was one of the factors affecting land use changes in a coastal zone.

Conclusions

Forestland, grassland, and cultivated land occupied more than 87% of the study area. The area of forestland, grassland, and aquaculture increased, while the area of cultivated land decreased over the 14 years. The change of aquaculture area was the most dramatic during the 14 years, especially between 2000 and 2009. The area of unused land had the fastest decrease over the study period.

Policy was the driving factor for the change of the forestland, grassland, and cultivated land. The population and natural population growth rate were the driving factors for the change of land use. Population and primary industry were the drivers of change in aquaculture. In summarize, policy, population, and primary industry were the main drivers of land use changes in the coastal zone.

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Conflict of Interest

The authors declare no conflict of interest.

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