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Analysis of Characteristics of Spatio-temporal Evolution of Land Use in Inhabited Islands of Pearl River Estuary

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Abstract Under the support of the remote sensing and geographical information system (GIS) techniques, we acquire the land use data in 1990 and 2008 regarding 6 inhabited islands, namely Longxue Island, Hengmen Island, Weiyuan Island, Qi'ao Island, Hengqin Island and Gaolan Island in Pearl River Estuary. By using dynamic degree of land use, land use change intensity, relative change rate and other indicators, we conduct quantitative description, and thus quantitatively and qualitatively analyse characteristics of temporal evolution and law of spatial pattern change concerning land use of each island. The study indicates that in the period 1990 -2008, the area of construction land and water in 6 islands increased, while the area of agricultural land and unused land increased in some islands and decreased in others. The land use change shows spatial disparity; the holistic land use change degree in Hengmen Island is higher than that of other islands; the dynamic degree of land use, intensity of land use, and relative change rate differ in different islands.

Key words Land use change, Remote sensing, Spatio-temporal evolution, Pearl River Estuary, Inhabited islands, China

With in-depth study of global environmental change, the research of land use and land cover change (LUCC) is considered as a critical and urgent research problem. And especially the land use and land cover change research program formulated and implemented by International Geosphere-Biosphere Program and International Human Dimensions Program on Global Change[1] made the research on land use and land cover change become a core component and hot spot of research of global environmental change[2]. Through accumulation and researches over the past ten years, the research of land use change gradually develops into a subject exploring global change and human sustainable development, under the guidance of geographic science theory, taking remote sensing and Geographic Information System as technical support. In the research field of land use and land cover change, China's scholars launch a number of researches, whose research fields are mainly focused on analysis of land use change and driving factors[3-5], impact of land use change on the ecological environment and regional climate[6-9], relationship between land use, land use change and vegetation succession[10], and dynamic simulation and prediction of land use and cover change[11-12].

However, the research on island land use and land cover change is relatively weak in China. With continuous and rapid economic growth in the ocean, the land use of island is in a process of constant adjustment. Beyond all dispute, there is significant impact of land use change on regional economic development and changes in the marine environment.

This paper uses 6 inhabited islands near Pearl River Estuary in Guangdong Province (Longxue Island, Hengmen Island, Weiyuan Island, Qi'ao Island, Hengqin Island and Gaolan Island) as main research objects. Combining use of satellite remote sensing survey and field investigation, according to land use classification system suitable for classification ability of sensors with regional characteristics, we acquire land use data in 1990 and 2008, and analyse land use change of island over the past decade.

1 Data source and research method

1.1 Data source Longxue Island, Hengmen Island, Weiyuan Island, Hengqin Island, Qi'ao Island and Gaolan Island are the islands in Pearl River Estuary with large development scale and sharp land use change. This paper conducts land use change analysis on the basis of the remote sensing and geographical information system (GIS) techniques. Research data are from two groups of remote sensing images of Landsat TM in 1990 and 2008. Taking the exact coordinates of ground control points measured on-site as image for geometric correction and taking photos, video and control point record sheets obtained on-site as basis, we establish interpretation mark base of image, and acquire land use data in two different periods by visual method for interpretation. To facilitate the analysis of land use change in the study area, according to the classification standard of land use in *Island Investigating Technical Specifications*[13], we divide the study area into 8 land use

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types as follows: farmland, garden plot , woodland, residential area and mining land, public facility land, water surface for aquaculture, other water surfaces, tidal flat and unused land.

Based on RS (ERDAS) and GIS (ArcGIS) software platform, we obtain island land use in 1990 (Table 1), island land use in 2008 (Table 2), and distribution of land use type in two corresponding periods (Fig. 1). And we use field survey data to verify land use in 2008, making it as much as possible reflect the recent actual land use.

Table 1 Land use information in 1990 of 6 inhabited islands in Pearl River Estuary km²

Name of island	Land use type									Total area
	Farmland	Garden plot	Woodland	Residential area and mining land	Public facility land	Water surface for aquaculture	Other water surfaces	Tidal flat	Unused land	
Longxue Island	–	5.40	0.90	0.04	–	5.23	1.12	–	–	12.68
Hengmen Island	0.70	3.12	0.64	0.10	–	1.01	–	–	1.79	7.35
Weiyuan Island	3.42	2.34	6.62	2.94	–	1.40	0.23	0.05	–	17.00
Hengqin Island	–	15.76	32.83	0.94	–	2.32	1.22	–	0.22	53.28
Qi'ao Island	–	1.21	12.19	0.42	0.24	3.05	0.06	–	0.77	17.93
Gaolan Island	0.62	–	32.98	0.15	–	–	0.04	0.10	0.38	34.27

Table 2 Land use information in 2008 of 6 inhabited islands in Pearl River Estuary km²

Name of island	Land use type									Total area
	Farmland	Garden plot	Woodland	Residential area and mining land	Public facility land	Water surface for aquaculture	Other water surfaces	Tidal flat	Unused land	
Longxue Island	–	10.17	0.36	2.75	–	18.20	2.65	–	1.54	35.67
Hengmen Island	–	15.47	0.80	1.03	0.01	2.28	–	–	0.17	19.76
Weiyuan Island	0.92	0.76	5.58	4.00	1.09	3.91	1.95	0.05	1.42	19.67
Hengqin Island	1.06	5.53	35.44	1.11	2.60	20.75	9.17	–	8.61	84.28
Qi'ao Island	–	0.58	11.35	0.90	0.40	7.54	–	0.27	0.59	21.63
Gaolan Island	0.35	–	31.23	1.28	0.57	0.33	0.65	–	3.19	37.61

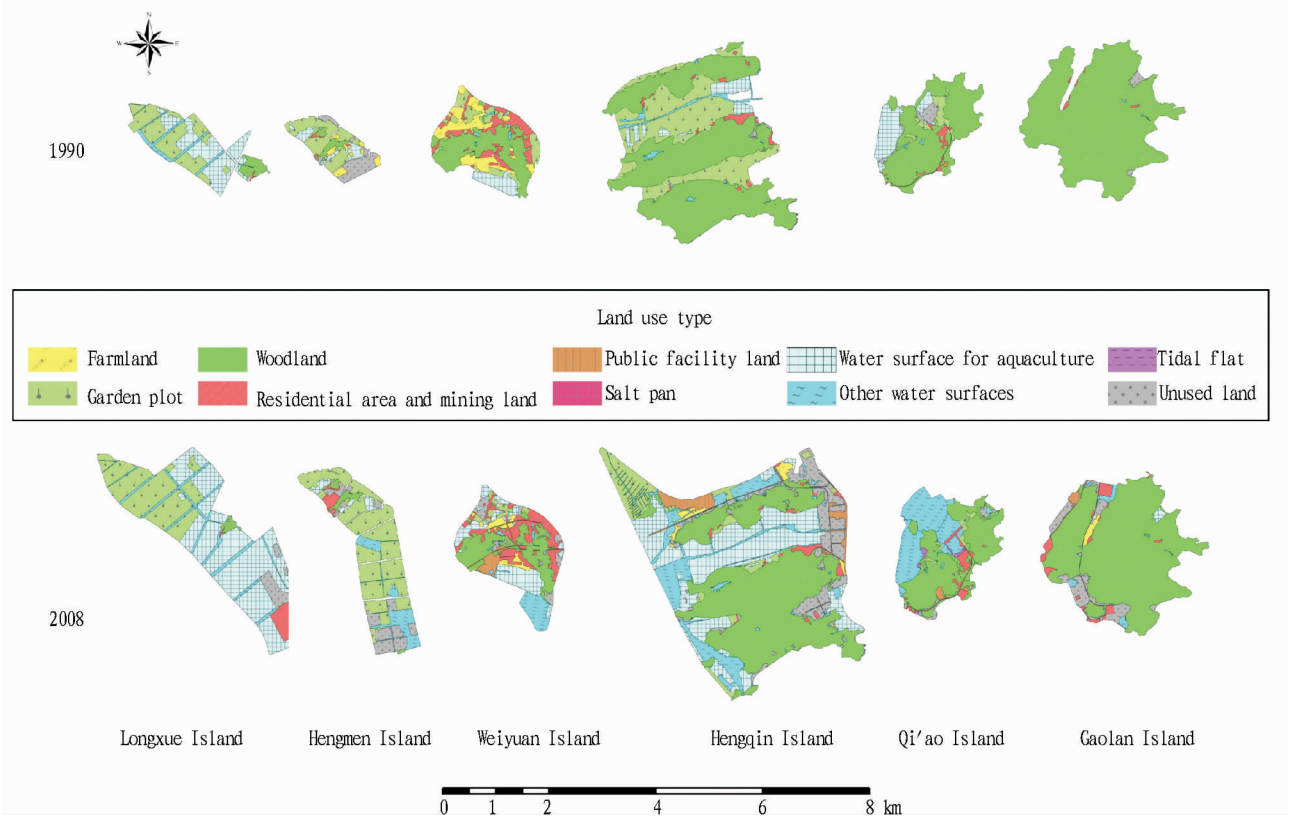

Fig. 1 Remote sensing classification of land use in 6 inhabited islands of Pearl River Estuary

1.2 Research method

1.2.1 Simple dynamic degree of land use (K)[14]. The dynamic degree is to measure the ratio of patch number regarding the single land type and total number of patches in the region in

a particular period, and the calculation principle is as follows:

$$K=\frac{LU_{t_2}-LU_{t_1}}{LU_{t_1}}\times\frac{1}{t_2-t_1}\times 100\% \quad (1)$$

In formula (1), t_1 and t_2 are the starting year and ending year of research on land use change respectively; LU_{t_1} and LU_{t_2} are the amount of certain land use type in corresponding year.

1.2.2 Comprehensive dynamic degree of land use(LC)[14]

$$LC=\frac{\sum_{i=1}^{n=1}|\Delta LU_{i-j}|}{2\sum_{i=1}^{n}LU_i}\times\frac{1}{t_2-t_1}\times 100\% \quad (2)$$

In formula (2), t_1 and t_2 are the starting year and ending year of research on land use change respectively; LU_i is the area of land-use-type i in the starting time; ΔLU_{i-j} is the area of non-land-use-type i converted from land-use-type i.

1.2.3 Intensity of land use change(I)[14]. The intensity of land use change is to measure the ratio of change area of single land use type to total land use area in the study area in a particular period (increase positive and decrease negative), and the calculation principle is as follows:

$$I=\frac{LU_{t_2}-LU_{t_1}}{TLUA}\times\frac{1}{t_2-t_1}\times 100\% \quad (3)$$

In formula (3), $TLUA$ is the total land area in the study unit, and the meaning of the other indicators is the same as (1).

1.2.4 Relative change rate of land use(R)[14].

$$R=\left|\frac{LU_{t_2}}{LU_{t_1}}\right|\Big/\left|\frac{TLU_{t_2}}{TLU_{t_1}}\right| \quad (4)$$

In formula (4), TLU_{t_1} and TLU_{t_2} are the area of certain land use type in the starting research year and the ending research year in the study area respectively. If $R>1$, it proves that in the study area, the change rate of this land use type is higher than that of whole region.

2 Results and analysis

2.1 Temporal evolution analysis According to the above formula, we calculate dynamic change degree, change intensity and relative change rate of land use in the 6 inhabited islands respectively (Table 3,4,5).

Table 3 Dynamic degree of land use in 6 inhabited islands of Pearl River Estuary %

Simple dynamic degree	Simple dynamic degree									Comprehensive dynamic degree
	Farmland	Garden plot	Woodland	Residential area and mining land	Public facility land	Water surface for aquaculture	Other water surfaces	Tidal flat	Unused land	
Longxue Island	0	0.77	0	3.85	0	2.88	6.15	0	0	3.85
Hengmen Island	−7.69	23.08	7.69	3.85	0	−7.69	0	0	−5.49	12.65
Weiyuan Island	0.96	−2.56	12.31	0.45	15.38	84.62	1.92	0	0	2.86
Hengqin Island	0	5.77	11.54	1.10	0	20.51	19.58	0	32.97	3.85
Qi'ao Island	0	2.67	16.00	1.11	6.67	−6.67	20	0	6.67	3.29
Gaolan Island	0	0	26.67	10.67	0	0	13.33	−6.67	17.78	3.34

Table 4 Intensity of land use change in six inhabited islands of Pearl River Estuary %

Name of island	Farmland	Garden plot	Woodland	Residential area and mining land	Public facility land	Water surface for aquaculture	Other water surfaces	Tidal flat	Unused land
Longxue Island	0	1.03	−0.12	0.58	0	2.80	0.33	0	0.33
Hengmen Island	−0.27	4.81	0.06	0.36	0	0.49	0	0	−0.63
Weiyuan Island	−0.98	−0.62	−0.41	0.42	0.43	0.98	0.67	0	0.56
Hengqin Island	0.10	−0.93	0.24	0.02	0.24	1.68	0.73	0	0.77
Qi'ao Island	0	−0.19	−0.26	0.15	0.05	1.39	−0.02	0.08	−0.06
Gaolan Island	−0.05	0	−0.31	0.20	0.10	0.06	0.11	−0.02	0.50

Table 5 Relative change rate of land use in 6 inhabited islands of Pearl River Estuary

Name of island	Farmland	Garden plot	Woodland	Residential area and mining land	Public facility land	Water surface for aquaculture	Other water surfaces	Tidal flat	Unused land
Longxue Island	0	0.58	2.48	0.02	0	0.39	0.76	0	0
Hengmen Island	0	0.81	1.60	0.14	0	0	0	0	2.97
Weiyuan Island	4.21	2.06	3.09	0.78	0	4.31	0.15	1.00	0
Hengqin Island	0	4.99	2.32	0.97	0	0.41	0.47	0	0.14
Qi'ao Island	0	2.93	3.65	0.54	1.19	0	0	0	2.61
Gaolan Island	1.77	0	5.28	0.31	0	0	0.18	0	0.44

2.1.1 Longxue Island. In Longxue Island, amid area of all land types, there is the sharpest decline in the area of woodland and there is the greatest increase in area of water surface for aquaculture. The intensity change is 2.88% −0.12%. The patch number of 4 types of land increases and the patch number of other 5 types of land is basically unchanged. The dynamic degree of other water surfaces is the greatest, up to 6.15%, and the comprehensive dynamic degree of whole island is up to 3.85%. In this island, only the change rate of woodland is higher than land change rate of whole island, and the change rate of other land types is lower than land change rate of whole island.

In the period 1990 −2008, in Longxue Island, the newly-added area through reclamation of land from the sea was 22.99 km^2. The area of garden plot increased by 4.77 km^2, mainly through reclamation of land from the sea, followed by the con-

version of water surface for aquaculture; the area of woodland decreased by 0.54 km^2, which was mainly converted into water surface for aquaculture; the area of water surface for aquaculture increased by 12.97 km^2, mainly through reclamation of land from the sea. And transformation of land use type in Longxue Island from 1990 to 2003 can be seen in Fig.2.

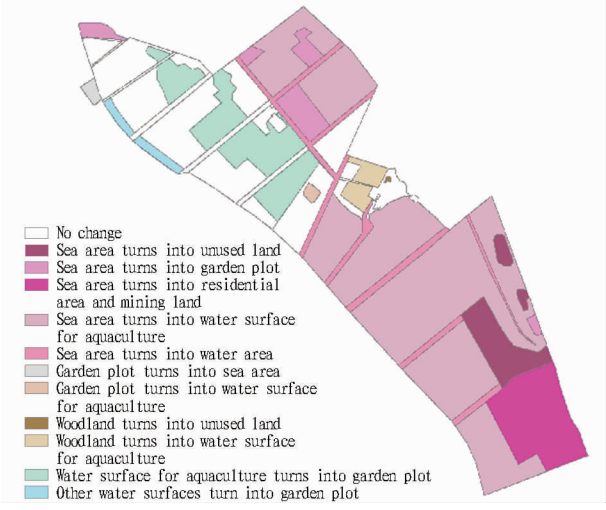

Fig.2 Transformation of land use type in Longxue Island from 1990 to 2008

2.1.2 Hengmen Island. There is the greatest decline in area of unused land in Hengmen Island, and there is the greatest increase in area of garden plot. The intensity change is −0.63% −4.81%. The patch number of 3 types of land increases, the patch number of 3 types of land decreases, and the patch number of the other 3 types of land is basically unchanged. The dynamic degree of change is −7.69% −23.08%, and the comprehensive dynamic degree of whole island is 12.65%. In this island, the change rate of woodland and unused land is higher than land change rate of whole island, and the change rate of other land types is lower than land change rate of whole island.

In the period 1990 −2008, in Hengmen Island, the newly-added area through reclamation of land from the sea was 12.41 km^2. The area of farmland decreased by 0.70 km^2, which was mainly transformed into garden plot and unused land; the area of garden plot increased by 12.35 km^2, mainly through reclamation of land from the sea; the area of unused land decreased by 1.62 km^2, which was mainly transformed into garden plot. Transformation of land use type in Hengmen Island from 1990 to 2003 can be seen in Fig.3.

2.1.3 Weiyuan Island. In Weiyuan Island, amid area of all land types, there is the sharpest decline in the area of farmland and there is the greatest increase in area of water surface for aquaculture. The intensity change is −0.98% −0.95%. In this island, only the patch number of garden plot decreases, and the patch number of other types of land increases. The dynamic degree is −2.56% −84.62%, and the comprehensive dynamic degree of whole island is 2.86%. The change rate of farmland, garden plot, woodland and water surface for aquaculture is higher than land change rate of whole island, and the change rate of other land types is lower than land change rate of whole island.

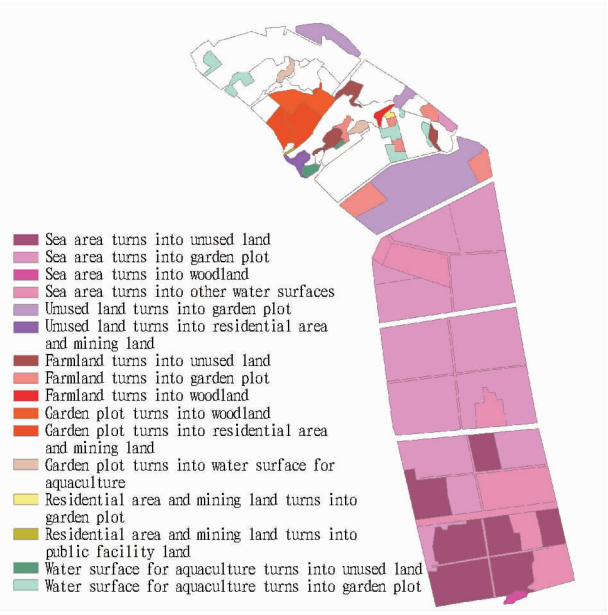

Fig.3 Transformation of land use type in Hengmen Island from 1990 to 2008

In the period 1990 −2008, in Weiyuan Island, the newly-added area through reclamation of land from the sea was 2.67 km^2. The area of farmland decreased by 2.5 km^2, which was transformed into water surface for aquaculture, followed by public facility land and residential area and mining land; the area of garden plot decreased by 1.58 km^2, which was transformed from water surface for aquaculture; the area of woodland decreased by 1.04 km^2, which was mainly transformed into residential area and mining land. Transformation of land use type in Weiyuan Island from 1990 to 2003 can be seen in Fig.4.

2.1.4 Hengqin Island. In Hengqin Island, amid area of all land types, there is the sharpest decline in the area of garden plot and there is the greatest increase in area of water surface for aquaculture. The change intensity is −0.93% −1.68%. The patch number of most types of land increases and the dynamic degree of unused land is the greatest, up to 32.91%. The comprehensive dynamic degree of whole island is 3.85%. From relative change rate, the change rate of garden plot and woodland is higher than land change rate of whole island. In the period 1990 −2008, in Hengqin Island, the newly-added area through reclamation of land from the sea was 22.99 km^2. The area of garden plot decreased by 10.23 km^2, which was mainly converted into water surface for aquaculture, followed by woodland and unused land; the area of water surface for aquaculture increased by 18.43 km^2, which was mainly converted from garden plot; the area of unused land increased by 8.39 km^2, mainly through reclamation of land from the sea. Transformation of land use type in Hengqin Island from 1990 to 2003 can be seen in Fig.5.

2.1.5 Qi'ao Island Qi'o. In Qi'ao Island, amid area of all land types, there is the sharpest decline in the area of woodland and there is the greatest increase in area of water surface for aquaculture. The change intensity is −0.26% −1.39%. In this island, only the patch number of water surface for aquaculture

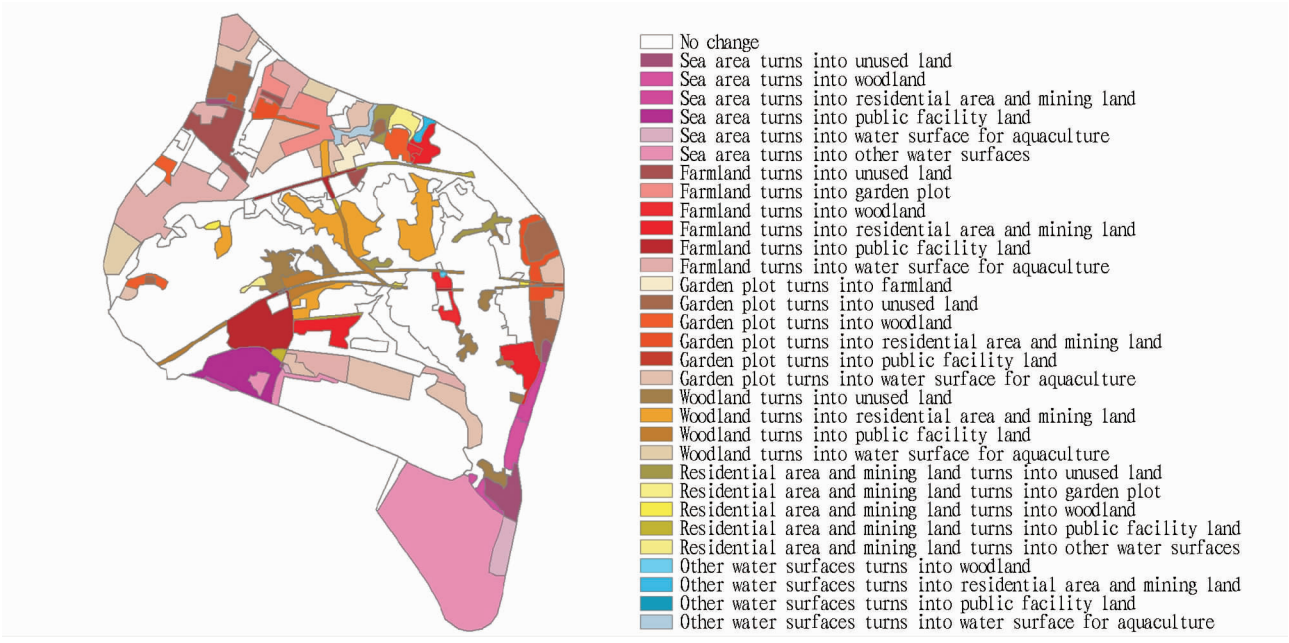

Fig. 4 Transformation of land use type in Weiyuan Island from 1990 to 2008

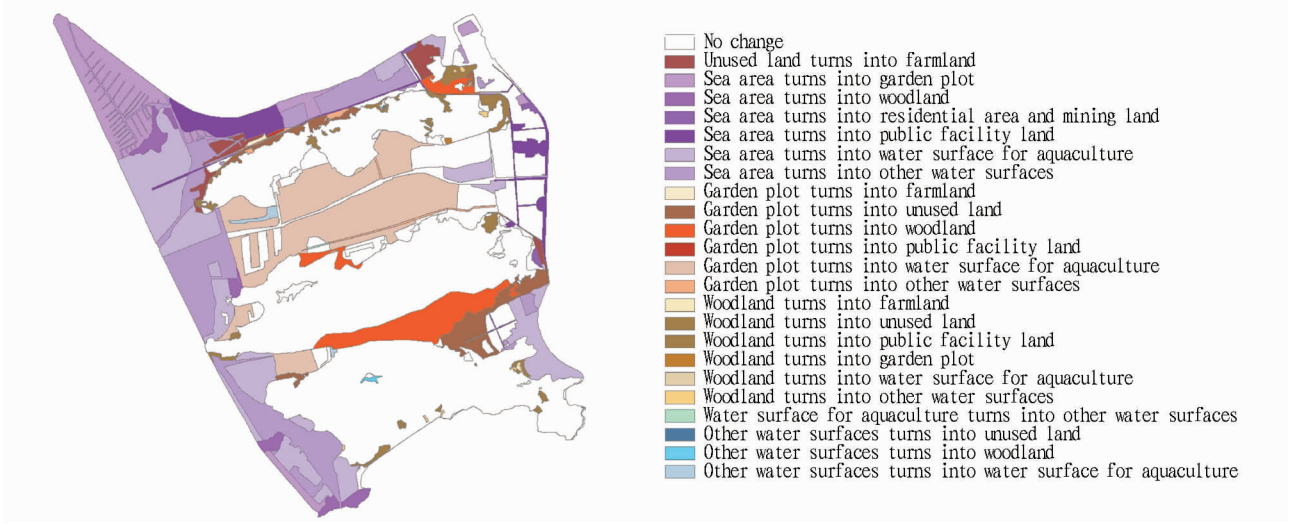

Fig. 5 Transformation of land use type in Hengqin Island from 1990 to 2008

decreases, the patch number of 6 types of land increases, and the patch number of 2 types of land is unchanged; the dynamic degree is −6.67% −20%, and the comprehensive dynamic degree of whole island is 3.29%. The change rate of garden plot, woodland, public facility land and unused land is higher than land change rate of whole island, and the change rate of other types of land is lower than land change rate of whole island.

In the period 1990 −2008, in Qi'ao Island, the newly-added area through reclamation of land from the sea was 3.7 km^2. The area of water surface for aquaculture increased by 4.49 km^2, mainly through reclamation of land from the sea; the area of woodland decreased by 0.84 km^2, which was mainly converted into unused land and residential area and mining land; the area of garden plot decreased by 0.63 km^2, which was mainly converted into water surface for aquaculture. Transformation of land use type in Qi'ao Island from 1990 to 2003 can be seen in Fig. 6.

2.1.6 Gaolan Island. In Gaolan Island, amid area of all land types, there is the sharpest decline in the area of woodland and there is the greatest increase in area of unused land. The change intensity is −0.31% −0.5%. In this island, only the patch number of tidal flat decreases and the patch number of other land types increases. The dynamic degree is −6.67% −26.67%. The change rate of farmland and woodland is higher than land change rate of whole island, and the change rate of other land types is lower than land change rate of whole island.

In the period 1990 −2008, in Gaolan Island, the newly-added area through reclamation of land from the sea was 3.34 km^2. The area of woodland decreased by 1.75 km^2, which was mainly converted into unused land and residential area and mining land. Transformation of land use type in Gaolan Island from

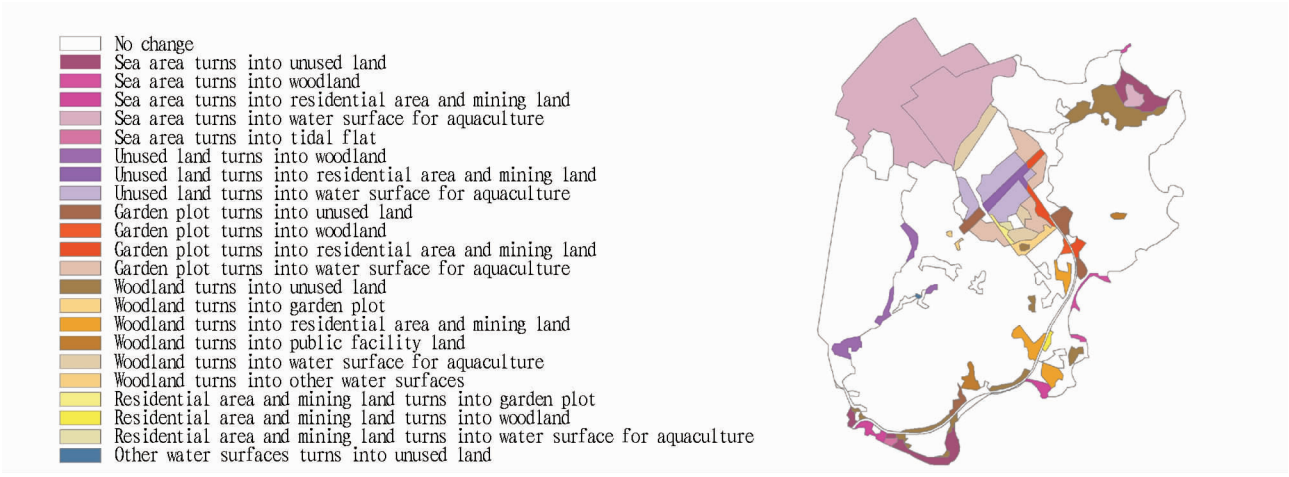

Fig. 6 Transformation of land use type in Qi'ao Island from 1990 to 2008

1990 to 2003 can be seen in Fig. 7.

2.2 Spatial difference analysis Land use type is divided into four categories: agricultural land (farmland, garden plot, woodland); construction land (residential area and mining land, public facility land); water area (water surface for aquaculture and other water surfaces), and unused land (tidal flat and unused land). On the basis of 4 types of land use, we draw the radar figure of 4 indicators regarding the 6 islands (land use dynamic degree, comprehensive dynamic degree, change intensity and relative change rate) (Fig. 8), and compare spatial differences of land use in all islands.

Fig. 8 (a) shows that the difference of simple dynamic degree of agricultural land, construction land and unused land in all islands is not significant, while there is obvious difference in simple dynamic degree of water area. The simple dynamic degree of water area in Weiyuan Island is 86.5%, significantly higher than that of other islands. It reflects that in terms of patch number, 4 types of land use in all islands change little. From comprehensive dynamic degree (Fig. 8 (b)), we know that the comprehensive dynamic degree of Hengmen Island is high, up to 12.65%, while the comprehensive dynamic degree of other islands is 3%. It reflects that the overall change degree of Hengmen Island is obviously higher than that of other islands. In terms of change intensity (Fig. 8 (c)), the change intensity of construction land and water area in all islands is positive value; the change intensity of agricultural land in Longxue Island and Hengmen Island is positive value, and the change intensity of agricultural land in other islands is negative value; the change intensity of unused land is negative value only in Hengmen Island, and the change intensity of unused land in other islands is positive value. It reflects that the area of construction land and water in all islands increases; the area of agricultural land in Longxue Island and Hengmen Island increases, and the area of agricultural land in other islands decreases; apart from Hengmen Island, the area of unused land in other islands increases. From relative change rate (Fig. 8 (d)), the relative change rate of agricultural land in all islands is bigger than 1, reflecting that the change rate of agricultural land in all islands is higher than the overall change rate of whole island; the relative change rate of construction land is bigger than 1 only in Qi'ao Island, and the relative change rate of construction land is smaller than 1 in other islands, reflecting that apart from Qi'ao Island, the change rate of construction land in other islands is lower than the overall change rate of whole island; the change rate of unused land in Hengmen Island and Qi'ao Island is bigger than 1, and the change rate of unused land in other islands is smaller than 1, reflecting that the change rate of unused land in Hengmen Island and Qi'ao Island is higher than the overall change rate of whole island, and the change rate of unused land in other islands is smaller than the overall change rate of whole island; the relative change rate of water area is bigger than 1 in Longxue Island and Weiyuan Island, reflecting the change rate of water area in Longxue Island and Weiyuan Island is higher than the overall change rate of whole island, and the change rate of water area in other islands is lower than the overall change rate of whole island.

2.3 Analysis of driving force of land use change The change of island land use type is related to the functional orientation of island in the regional economic development. We discuss the factors responsible for change of land use type in all islands.

According to *Regulatory Plan of Nansha Longxue Island Zoning (Port) in Guangzhou*, the function of Longxue Island is oriented as follows: focusing on export-based container transport, developing corresponding function of protective tariff, logistics and commerce, and based on port industry development, undertaking the transport of bulk cargo[15]. Longxue Island originally is established by enclosing river courses on the basis of 3 bedrock islands, with small area. From 2001, the port construction of Longxue Island is kicked off, and in southeastern waters of this island, a large area of water is enclosed. Through years of construction, aquaculture and transportation are developed vigorously in enclosing area.

Overall Planning of Eastern Coastal Areas in Zhongshan City clearly states that it takes Hengmen waterways as the axis, including part of the terrestrial ecology on both sides[16]. Therefore, the area of garden plot and woodland in Hengmen Island tends to increase.

The development orientation of Weiyuan Island is coastal tourism area. In light of change of land use type in Weiyuan Is-

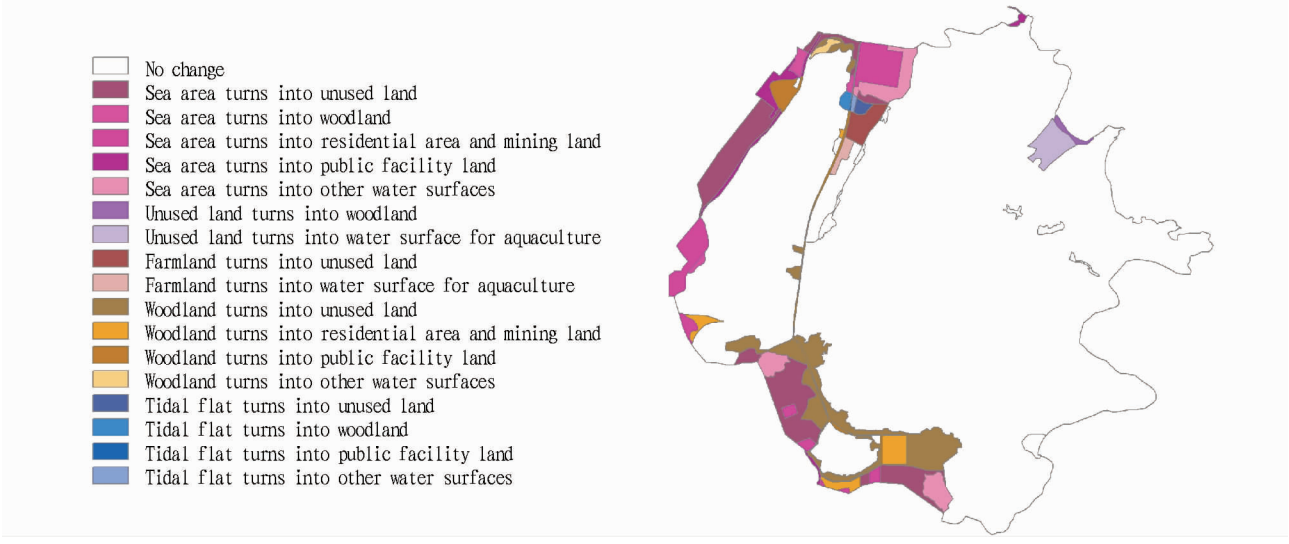

Fig. 7 Transformation of land use type in Gaolan Island from 1990 to 2008

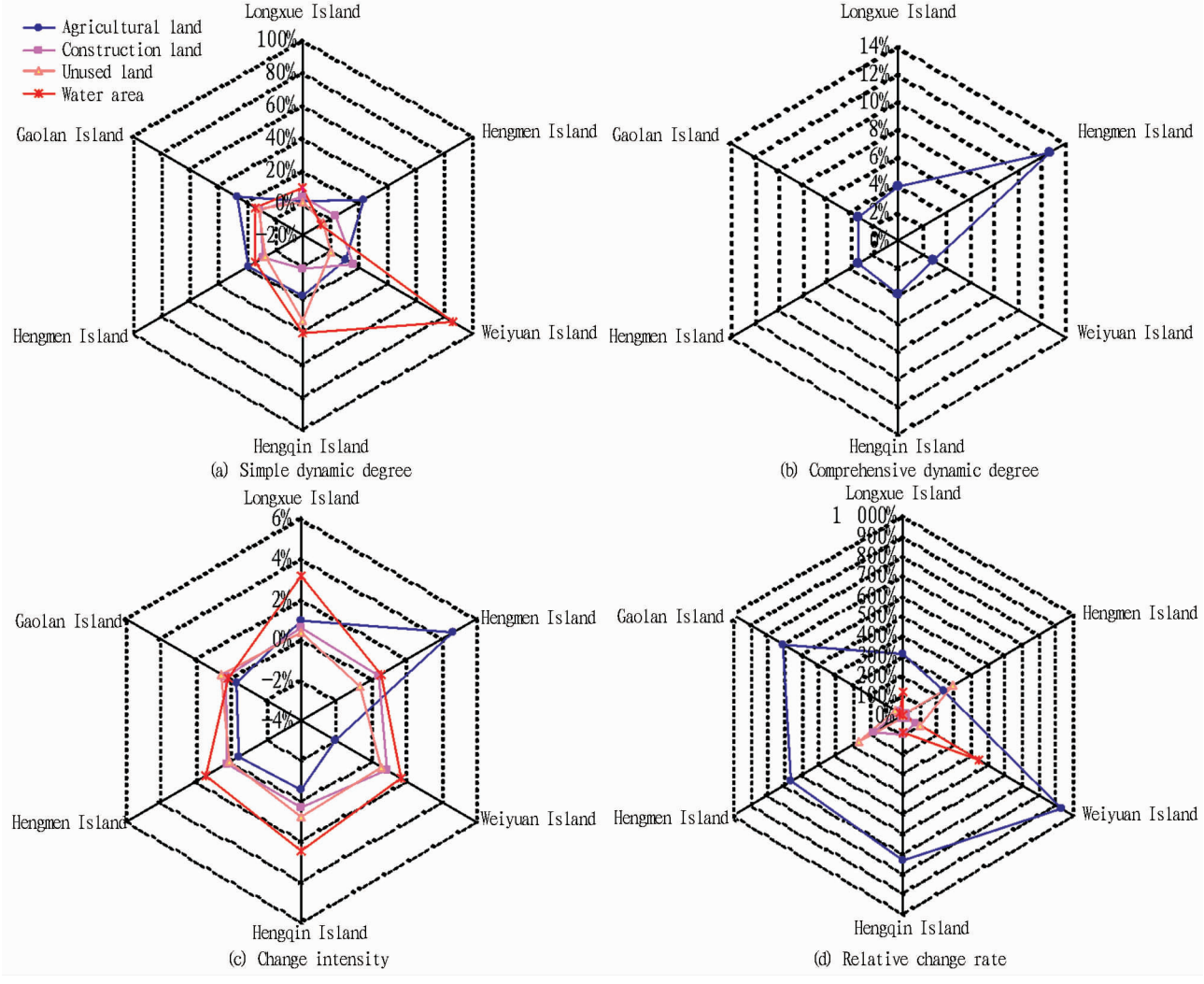

Fig. 8 Radar analysis result of four land use indicators in six inhabited islands of Pearl River Estuary

land, in the north and south of this island, it mainly develops aquaculture, and in the middle of the island, it uses ancient fort ruins to develop tourism. In the process of construction, considerable farmland is occupied.

According to *Overall Development Planning of Hengqin*, Hengqin Island is incorporated into Zhuhai Special Economic Zone, and its functional orientation is established as follows: under "one country, two systems", exploring new cooperative model of Guangdong, Hong Kong and Macau to develop demonstration zone[17]. The function of Hengqin Island develops comprehensively, the transformation of land use type is complex, and the overall trend is to develop aquaculture and the urbanization.

In *Zoning Planning Adjustment in Tangjiawan of Zhuhai City*, Qi'ao Island is required to be developed into green ecological island[18]. The change degree of land use type in Qi'ao Island is not big. The central plain of island is transformed into town; part of woodland is transformed into residential and industrial land; in the northwestern island, there is an area reclaimed from sea, which is mainly used for aquaculture.

In *Reform and Development Planning Outline of Pearl River Delta*, it clearly states that Gaolan industrial zone is required to be developed vigorously, into marine equipment manufacturing area and high-end leisure and travel business area[19]. As the main body of Gaolan Island is hills and low mountains, and narrow alluvial plain is distributed in the west of island, so Gaolan Island should use plains in the west of island to develop industrial warehousing and port cargo industry.

3 Conclusion and discussion

First, we compare the land area of 6 inhabited islands in Pearl River Estuary in 1990 and 2008, and the results show that the land area of island tends to increase incessantly, and the newly-added land is formed mainly through reclamation of land from the sea, primarily for aquaculture, followed by wharf or industrial development land.

Second, from change in land use type of whole island, the overall change degree of Hengmen Island is clearly higher than that of other islands. In the light of patch number of land use type, the patch number of land use type changes little; in the light of area of land use type, the construction land and water area increase in all islands; the area of agricultural land in Longxue Island and Hengmen Island increases, and the area of agricultural land in other islands dwindles; apart from Hengmen Island, the area of unused land in other islands increases. From the change rate of land use type, the change rate of agricultural land in all islands is high, and the change rate of construction land is low. The unused land and water area show spatial difference.

Third, affected by the current development of marine economy, preferential marine policy, population growth and other factors, the economic structure mode of island is changed substantially. Since the functional orientation of all islands in regional economic development is different, so the change of land use type is inconsistent. In general, the development of aquaculture and urbanization is the main trend of island development.

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