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Land Use and Land Cover Change in Guangzhou, China, from 1998 to 2003, Based on Landsat TM /ETM+ Imagery

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Abstract: Land use and land cover change is a major issue in global environment change, and is especially significant in rapidly developing regions in the world. With its economic development, population growth, and urbanization, Guangzhou, a major metropolitan in South China, have experienced a dramatic land use and land cover (LULC) change over the past 30 years. Fast LULC change have resulted in degradation of its ecosystems and affected adversely the environment. It is urgently needed to monitor its LULC changes and to analyses the consequences of these changes in order to provide information for policy-makers to support sustainable development. This study employed two Landsat TM/ETM+ images in the dry season to detect LULC patterns in 1998 and 2003, and to examine LULC changes during the period from 1998 to 2003. The type, rate, and pattern of the changes among five counties of Guangzhou Municipality were analyzed in details by post-classification method. LULC conversion matrix was produced for each county in order to explore and explain the urban expansion and cropland loss, the most significant types of LULC change. Land use conversion matrixes of five counties were discussed respectively in order to explore and explain the inherence of land use change. The results showed that urban expansion in these five counties kept an even rate of increase, while substantial amount of cropland vanished during the period. It is also noted that the conversion between cropland and orchard land was intensive. Forest land became the main source of new croplands.

Keywords: Land use and land cover change; Urban expansion; Cropland loss; Guangzhou; China; Landsat imagery.

1. Introduction

Land use and land cover (LULC) change is a major issue of global environment change. Scientific research community called for substantive study of land use changes during the 1972 Stockholm Conference on the Human Environment, and again 20 years later, at the 1992 United Nations Conference on Environment and Development (UNCED). At the same time, International Geosphere and Biosphere Programme (IGBP) and International Human Dimension Programme (IHDP) co-organized a working group to set up research agenda and promote research activity for LULC changes. The working group suggested three core subjects for LULC change research, such as situation assessment, modeling and projecting, and conceptual scaling. The ultimate goal of global change study was to assess the impacts under each possible scenario and suggest preventive actions. Equally important was the impact of these regional and global changes on society and environment. Lots of researchers found that LULC and its change had become a key to many diverse applications such as environment [8], forestry, hydrology [6], agriculture [26], geology and ecology [42]. These applications referred to urban expansion, cropland loss, water quality change, soil degradation, and so on. At the same time, in the past decade, a major international initiative to study land use change, the land use and LUCC (land use and land cover change) project, had gained great momentum in its efforts to understand driving forces of land use change (mainly through comparative case studies), developed diagnostic models of land use change, and produce regionally and globally integrated models [23, 28].

Historical changes in land use types such as urban expansion, cropland loss and forest cover were addressed in summary fashion. As Houghton (1994) [17] pointed out, the major reason of land use change was to increase the local capacity of lands to support the human enterprise. Yet, together with the "positive" changes – i.e., those that made land more productive- there were also unforeseen impacts that could reduce the ability of land to sustain the human enterprise. Today, localized changes around the world added up to massive impacts. Thus, it could be argued that even modest changes in land use had some unintended consequences. So it was necessary to discuss the impacts of land use change on society, environment and economy, especially economic growth in developing country such as India and China.

Satellite remote sensing had been widely applied on detecting LULC change [7, 40, 15, 24, 25, 48, 41, 42, 43, 44] especially urban expansion [39, 45, 34, 41, 42, 43, 44, 28], urban planning [49] and cropland loss [43, 27, 31]. Many change detection techniques, which was the process of identifying differences in the state of and object or phenomenon by observing it at different times [18, 38], were used in these studies, such as image differencing, vegetation index differencing, selective principal components analysis, direct multi-date classification, univariate image differencing, image rationing, change vector analysis and post-classification and so on [29, 38, 1]. At the same time, these were available in achieving different level of success in monitoring a variety of LULC changes [38, 9, 22, 23, 3, 13, 5, 21]. Among these methods, post-classification was a common-used method for detecting land use change and also was used in various areas successfully[38, 9, 22, 3, 5].

In past two decades, China's economy had experienced radical changes. With the rapid growth rates of economy, widespread land use had taken place, which was more serious in the coastal areas, such as Guangdong, Shanhai, Jiangsu and Zhejiang provinces of Southeastern China. As the economic center of Pearl River Delta and Guangdong, Guangzhou Municipality was one of the cities with the fastest economy development in China from 1978 to 2004. With the rapid economy growth, rampant urban land expansion and massive cropland loss had had severe environmental and social consequences [41, 43]. So there was an urgent need for studying land use change for sustainable development of this area.

The Pearl River Delta was one of three major economy corridors of China (the other two are *Beijing -Tianjin-Tangshan corridor and Yangtze Rive Delta Area*), many researchers paid their attentions to the land use change of this area. Among these studies, systematical and profound works were finished by Li, Yeh, Weng, Kaufmann and Seto mainly. Their researches discussed LULC changes of this area based on different point of views, and the time range of research was very wide, from 1978 to 1997 [26, 42, 44, 21, 35, 36]. Their studies were all based on the classification results of one scene image rather than the subset images, and took 5 years as a research cycle to discuss land use change. It was useful to analysis macroscopical structure of land use change by using large scale image, but many detail information of land use change maybe be lost to some extent. So, in order to get microcosmic land use information, subset images were introduced in this study. These subset images were not only helpful for improving the classification precision, but also helpful to understand the relationship between land use changes and related socioeconomic characteristics under GIS [43].

The primary objective of this paper was to quantify, and characterize county-level land use change of Guangzhou Municipality in past five years (1998-2003) using Landsat TM/ETM+ images, and to compare the urban expansion and cropland loss rates and locations among these five counties. These five counties had different types and intensities of land use, so it was expected that the trend of change would also differ in type and magnitude. At the same time, the economics of these five counties were not at the same level, so discussing the relationship between economic growth and cropland loss in these areas was vital.

2. Study area

The study area of this paper was Guangzhou Municipality in South China. Guangzhou is located in between 112°57'E to 114°3'E and 22°26'N to 23°56'N, which uses approximately 7434.4 km^2 (Guangdong's Statistical Bureau 2003) with a census population of 9.94 million in 2004. Guangzhou is the geometric center of the Pearl River Delta area, bounded by the Pearl River to the east and south, Zhongshan city and Foshan city to the west, Dongguan city and Huizhou city to the east and Qinyuan city to the north (Fig.1). Guangzhou was comprised of ten urban districts (Panyu, Huadu, Yuexiu, Dongshan, Haizhu, Liwan, Tianhe, Baiyun, Huangpu and Fangchun) and two subordinate county-level cities (Conghua, Zengcheng). Guangzhou is a political, economic, educational, cultural, as well as scientific and technological center of the Guangdong province and South China. Guangzhou is located in the piedmont and coastal plain physiographic regions, declining from the mountain areas in the north to sea level at the confluence of Pearl River in the south. The annual rainfall in this area was about 1689.3-1876.5mm. Being at the central location of the Pearl River Delta, Guangzhou was historically an intensive agriculture area embedded with a disk-pond system [41]. Agriculture and fishing were the two important human activities in Guangzhou Municipality, and leading planting crops are fruit and vegetable. Fig 1 showed the location of Guangzhou Municipality in the Pearl River Delta.

Figure1. Location of study area: Guangzhou Municipality and its main administrative districts.

3. Methodology

3.1 Data

In this study, two scenes of predominant cloud-free Landsat TM/ ETM+ images (WRS path 122, row 44) of the Guangzhou Municipality were acquired on December 22, 1998 (TM) and January 10, 2003 (ETM+) respectively. The resolutions of two imageries are 30 meters. These two scene images were obtained in the dry season (October to March) because the study area was located in the subtropical area (21^o- 23^oN), which was mostly cloudy during the rainy season (April to September). In this study, band1-band5 and band 7 of these two images were used as primary data to detect land use change of study area. Band1-5 and 7 of each image were stacked into single image with BIL format respectively. The stacked TM 1998 image was geo-coded to ETM+2003 image by “map to map” method and was re-sampled using a nearest neighbor algorithm with a first-order polynomial. The number of ground control points (GCPs) used for registration varies by image was about 52. The Root Mean Squared Error (RMSE) of the registration process was 0.49 pixels after verification calculation.

Other useful data included the co-registered vector administrative boundary and county level socioeconomic data. The administrative boundary data were generated by ArcView GIS 3.0 based on topography map (the scale is 1:1200000) of Guangzhou municipality, which were used as masks to get subset-images of each county. Due to the restructuring of Guangzhou, some of the boundaries had been re-delineated, so the restructured administrative boundaries data are used in this study to subset these two time remote sensing data. The socioeconomic data, mainly was Gross Domestic Product (GDP), were used to analysis the relationship between cropland loss and economic development. All GDP data were obtained from the Guangzhou's Statistical Yearbooks (from 1999 and 2004) officially published by local government.

3.2 Image classification and accuracy assessment

The maximum likelihood (ML) procedure was chosen as classification method because of its ready availability and the fact that it did not require an extended training process [30]. The ML was processed in ENVI™ 3.6. The training polygons were digitized on-screen based on terrain knowledge acquired during fieldwork and distributed throughout the study areas. The pixels in the polygons that were selected as representative of each class were plotted in spectral space and a visual check was made that all classes could be separated in at least one combination of bands.

The classification processes was as follows: (1) based on fieldwork and visual interpretation of each subset-image, a supervised classification was performed using ML algorithm; (2) 7 types land use were identified which included urban (URB), forest (FOR), cropland (CRO), orchard (ORC), water (WAT), dike-pond (DIK) and developing land (DEL). Among these land use types, URB means residential area which was one of prevalent land use types which were usually covered by group of buildings and its' accessories, in this study URB included old residential area and new residential area but don't include factory. FOR included low-density forest and high-density forest. CRO included rice land, dry land and vegetable land mostly. ORC included lichee, banana and some other land use types. On these land use types, lower trees were planed but higher trees like FOR. The DEL was a typical land use type in Pearl River Delta and other industrial areas in China, which was composed of a block of ground level land mainly from agricultural or non-construction land after primary developed.

Accuracy assessment was critical for a map generated from any remote sensing data. Many studies had focused on the proper sampling scheme and standard techniques for the assessment [16, 4]. The most common way to represent the accuracy is in the form of an error matrix which could be used as a starting point for a series of descriptive and analytical statistical analysis. Random sampling for accuracy assessment can be used to compare the results of change detection and the ground truth which can be obtained from aerial photos or field visit. An error matrix that indicates the concordance of the results of change detection and the ground truth could be constructed from the comparison. Many measurements had been proposed to improve the interpretation of the meaning of the error matrix. Among these methods, the Kappa coefficient is one of the most popular measures in addressing the difference between the actual agreement and chance agreement. The kappa was a discrete multi-variates technique used in accuracy assessment [4], and had many attractive features as an index of classification accuracy. In particular, it mad some compensation for chance agreement and a variance term could be calculated [33, 10, 12].

3.3 Post-classification change detection

In a variety of studies, the post-classification change detection method was found to be the most suitable for detecting land use change. In the post-classification technique, two images from different dates are independently classified [19, 38]. Accurate classification was imperative to insure precise change detection results [11]. Preliminary classification was performed on the 1998 and 2003 images. The classification of the 1998 and 2003 images with the highest overall accuracy were used in the change detection process. The classification images were combined to create a new change image classification, which indicated the changes “from” and “to” that took place. However, image classification and post-classification techniques are iterative and require further refinement into order to produce more accurate change detection results.

4. Results

4.1 LULC patterns in 1998 and 2003

The classification images of land use in 1998 and 2003 for five administrative areas in Guangzhou municipality are shown in Fig 2. The accuracy of the classified images was checked by a stratified random sampling method. Considering the fact that post-classification change detection technique may result inaccurate change detection as a result of misclassifications from different dates, the classification accuracy of each land type was tested (Table 1).

Table 1 The classification accuracy results of each land type.

Land type	URB	FOR	WAT	DIS	CRO	ORC	DEV
Classification accuracy of 1998	94.2%	86.4%	89.9%	76.5%	78.5%	72.6%	73.1%
Classification accuracy of 2003	96.2%	90.1%	89.7%	77.4%	85.2%	76.1%	74.9%

The process of classification accuracy test was as followed: 1) 2250 and 2370 samples which distributed into 7 land use classes were selected from 1998 and 2003 imageries respectively, these sampling data were collected from fieldwork and the published land use map; 2) after selecting samples from fieldwork, corresponding sites were checked in these two time classification images according to geographical coordinates; 3) and then, right classification land use type sites were picked and counted; 4) at last, account of these right sites was compared with that of samples in each kind of land use types. The overall accuracy of 1998 classification image was 89.61% and that of 2003 was 93.24%, and the Kappa was 0.79 and 0.86. Among these types of land use, urban land had highest classification accuracy; cropland and developing land had lowest classification accuracy.

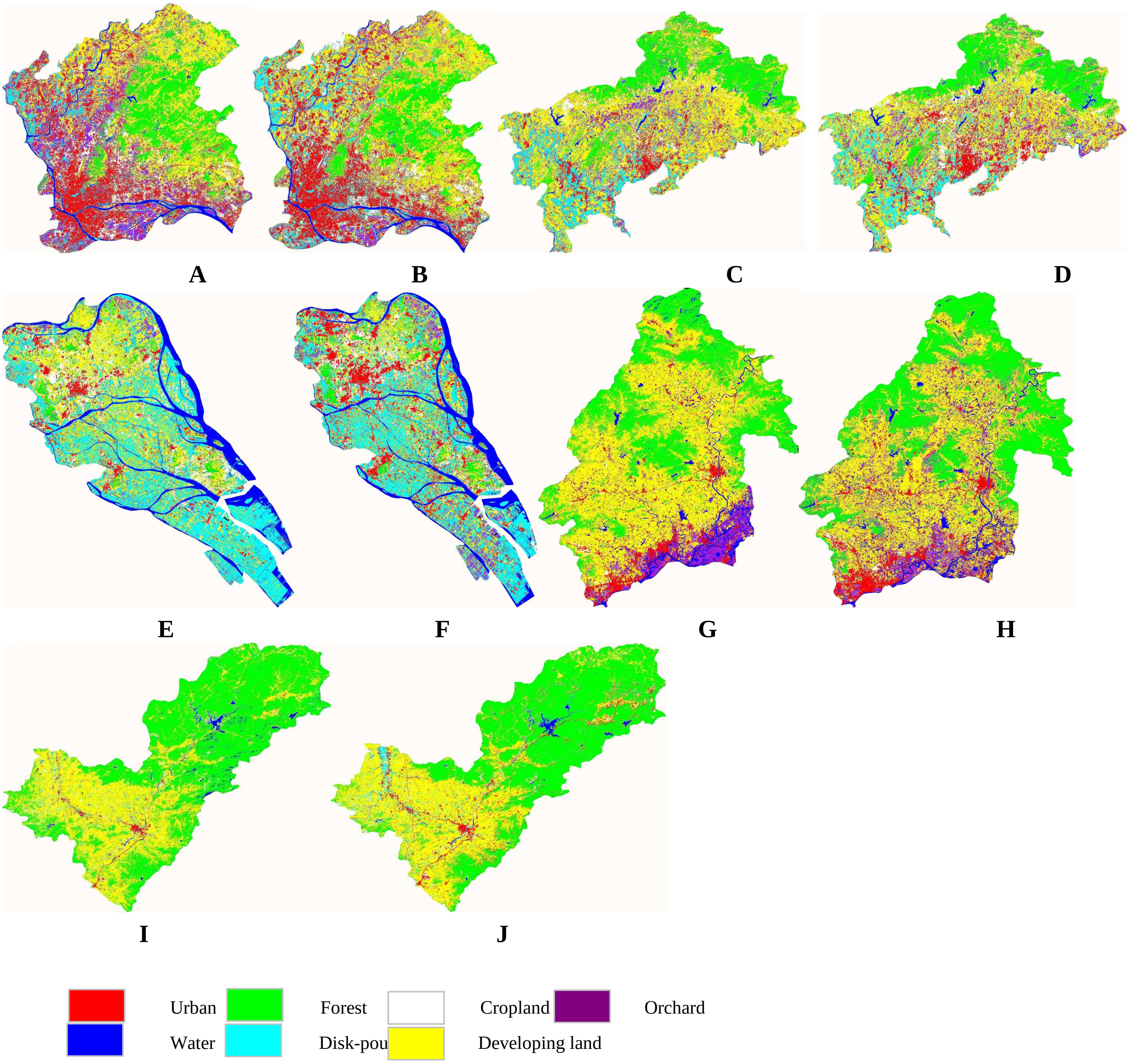

Figure 2. The classification images of land use in 1998 and 2003 for five administrative areas in Guangzhou (A: Guangzhou 1998; B: Guangzhou 2003; C: Huadu 1998; D: Huadu 2003; E: Conghua 1998; F: Conghua 2003; G: Zengcheng 1998; H: Zengcheng 2003; I: Panyu 1998; J: Panyu 2003).

4.2 LULC changes of five counties from 1998 to 2003

In order to obtain the information of land use conversion, post-classification was carried out in ENVI^{TM} 3.6 using classification images of 1998 and 2003. Classification image of 1998 which was defined "initial state" image and classification image of 2003 which was defined "final state" image were put into the post-classification procedure respectively. Through this program, conversion matrix of each county was got. The results are shown in Table 2 to Table6.

Guangzhou (Table 2) was the economic and culture center of the study area, of which urban was main land type which increased 1.04 km^2 with the rate of 0.08% during this five years. At the same time, cropland and dike-pond also increased rapidly, the increase area were 66.00 and 57.09 km^2 respectively. Other land types decreased in these five years. Urban of Huadu (Table 3) increased 49.43 km^2, and the rate reached 13.30%; the developing land increased 10.92 km^2, and the rate was about 3.18%; the orchard increase 36.81 km^2, and the rate was 5.74%. At the same time, lots of cropland deceased in this district. Conghua (Table 4) was a woody county, and the dominant type of land was forest. Although the area of urban was much smaller than other counties of Guangzhou, the change rate of urban was quite fast in these five years. The urban increased 64.02 km^2 and the increase rate were up to 41.10%. The developing land increased 132.11 Km^2 with the rate of 47.47%. The reason of urban and developing land had so fast increase area and rate was that Conghua was presently in the preliminary stage of economy developing. Zengcheng (Table5) was the biggest agriculture county in Guangzhou. Historically, lichee and bananas were dominant planting crops in this area. However, being closer to Guangzhou, Zengcheng's economy had got a great development in these five years. From Table 5, it could be found that the area of urban increased 24.43 km^2 with the rate of 4.38%; the area of developing land increased 4.43 km^2 with the rate of 3.53%; Cropland and orchard decreased 143.13 km^2 and 150.89 km^{2}with the rate of 3.17% and 4.68% respectively. The change rate of forest and dike-pond were in the extreme. The changing rate for forest was only 1.56% (from 486.74 km^2 to 524.72 km^2 with the changing area of 37.98km^2), and the changing rate for dike-pond was as larger as 16.44% (from 46.46 km^2 to 84.65 km^2 with the changing area of 38.19 km^2). Because of convenient transportation and beautiful surroundings, Panyu (Table6) was becoming a perfect residential area of Guangzhou. On the other side, a lot of dike-pond and paddy field were distributed in this county, so the land use changes of Panyu must be characterized with urban expansion and dike-pond and paddy field losses. Urban of Panyu increased 86.37 km^2 from 89.96 km^2 in 1998 to 176.33 km^2 in 2003, and the increased rate reached 19.20%. Comparing with other counties, urban increasing rate of Panyu was very faster. From 1998 to 2003, cropland of Panyu decreased 107.61 km^2, and the decreased rate reached 4.03%. The forest and orchard had demonstrated great changes: although the increased area of forest was 17.19 km^2 and orchard was 31.84 km^2. Their change rates were very faster, which reached 11.66% for forest, and 19.50% for orchard. Dike-pond decreased 22.59 km^2 in the five years from 252.14 km^2 to 2299.55 km^2. Because the radices of dike-pond were still very larger, the change rate of dike-pond was relatively smaller (only1.79%).

Table 2. Land use change matrix in Guangzhou from 1998 to 2003 (km^2).

	URB	FOR	CRO	ORC	WAT	DEL	DIK	1998
URB	151.12	0.86	36.64	13.06	1.34	**21.68**	**40.92**	265.76
FOR	1.33	127.15	**59.57**	8.93	0.01	2.36	1.36	201.14
CRO	**21.36**	**40.27**	234.40	**50.02**	0.44	**26.96**	**24.19**	398.09
ORC	**19.36**	7.91	**80.46**	41.71	0.44	13.72	**23.21**	186.98
WAT	1.67	1.20	2.05	1.07	26.01	0.71	10.15	42.96
DEL	**53.66**	1.37	28.82	8.25	0.74	30.82	21.43	145.20
DIK	18.14	1.82	21.95	11.79	4.00	6.76	43.94	108.52
2003	266.80	180.70	464.09	134.93	33.44	103.10	165.61	1348.65

Table 3. Land use change matrix in Huadu from 1998 to 2003 (km^2).

	URB	FOR	CRO	ORC	WAT	DEL	DIK	1998
URB	26.47	0.38	24.99	5.20	0.22	6.44	10.54	74.30
FOR	0.51	128.62	**29.92**	5.92	0.32	0.58	1.67	167.67
CRO	**72.88**	**227.24**	589.94	**116.46**	12.62	**53.245**	**152.44**	1225.17
ORC	7.88	15.69	**70.55**	17.76	0.20	4.21	11.66	128.12
WAT	0.85	0.13	2.17	0.67	6.28	0.90	2.94	14.11
DEL	6.11	2.78	34.34	8.00	0.20	9.96	7.55	68.63
DIK	**9.01**	3.21	**39.32**	11.32	3.14	4.21	52.00	122.61
2003	123.72	378.05	791.23	164.93	22.99	79.55	238.80	1799.26

Table 4. Land use change matrix in Conghua from 1998 to 2003 (km^2).

	URB	FOR	CRO	ORC	WAT	DEL	DIK	1998
URB	15.30	0.48	10.42		0.14	2.10	2.71	31.16
FOR	19.39	803.58	**144.24**		0.82	**99.36**	11.24	1079.74
CRO	**48.22**	**77.51**	513.56		1.88	38.43	**39.83**	719.59
ORC								
WAT	0.88	13.48	0.97		1.48	10.68	5.34	32.83
DEL	5.67	10.58	21.86		2.38	3.29	8.94	52.72
DIK	5.70	3.51	23.21		**16.69**	**187.78**	70.60	307.49
2003	95.18	910.09	714.64		23.39	341.64	138.66	2223.6

Table 5. Land use change matrix in Zengcheng from 1998 to 2003 (km^2).

	URB	FOR	CRO	ORC	WAT	DEL	DIK	1998
URB	54.32	4.17	28.79	9.17	1.54	2.91	10.80	111.78
FOR	4.66	368.31	**77.31**	28.51	0.20	4.62	2.58	486.74
CRO	**50.13**	**134.36**	570.49	**99.94**	2.00	15.38	**31.52**	904.02
ORC	13.18	6.61	**53.63**	35.41	0.47	2.04	9.83	121.31
WAT	2.38	8.55	6.20	1.65	13.09	0.53	10.69	43.28
DEL	6.12	1.15	11.68	0.98	0.39	3.19	1.50	25.02
DIK	5.38	0.65	12.62	5.92	3.36	0.75	17.68	46.46
2003	136.24	524.72	760.89	181.62	21.11	29.45	84.65	1738.68

Table 6. Land use change matrix in Panyu from1998 to 2003 (km^2).

	URB	FOR	CRO	ORC	WAT	DEL	DIK	1998
URB	47.88	1.28	20.75	1.63	0.34	10.21	7.81	89.96
FOR	0.78	17.91	5.99	2.13	0.01	1.41	1.27	29.49
CRO	**57.99**	**19.4**	303.47	**45.49**	0.60	**54.33**	**52.65**	534.18
ORC	1.78	3.53	14.9	9.05	0.03	1.75	1.61	32.66
WAT	1.63	0.09	0.86	0.05	113.86	21.70	1.99	141.61
DEL	**36.60**	0.94	28.19	1.30	0.24	7.69	37.34	112.36
DIK	29.53	3.52	**52.15**	4.79	**18.60**	**131.92**	11.14	252.14
2003	176.33	46.68	426.57	64.49	134.93	229.55	113.88	1192.43

In summary, from the analyses of these five conversion matrixes of land use, it could be found that: (1) urban expansion encroach a lot of cropland, orchard and development soil, mostly was cropland; (2) the areas of cropland transformed to other land were very excessive; and (3) Table2 - Table 6 had proved that the transformed area between cropland and orchard were tremendous. The commutative change extent between cropland and orchard was also very extensive. (4) Fig.3 contrasts several kinds land change rates of five counties.

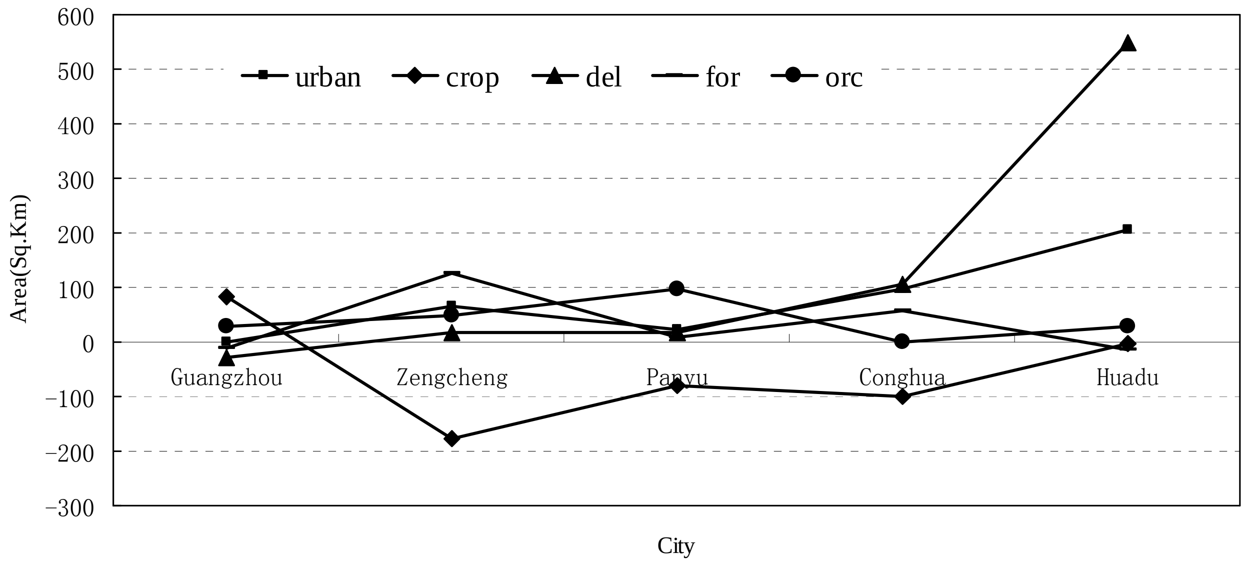

Figure 3. The changing rates of urban/built-up, cropland, developing/barren land, forest and orchard in five cities of Guangzhou.

It was very obvious that the urban expansion and developing land had same increase trend. That is to say that: when one county experience high urban expansion, lots of developing soil also appeared at the same time. (5) Cropland loss had higher negative correlation with other land use change. If the county had a higher cropland loss rate, the urban expansion rate, forest increase rate and developing land increase rate were also higher which implied that lots of cropland transformed to urban, forest, and developing land but these land types didn't transformed to cropland accordingly. (6) Because urban had a non-reversible natural attribute, so it was impossible to convert into other land types, the analysis also explained this point. (7) The high correlation between forest and cropland change was the accessorial evidence showing that the transform between cropland and forest was also intense.

4.3 Urban expansion of five counties in 1998-2003

Urban of these five counties had different increase areas and rates between 1998 and 2003 (Fig. 4, Fig.5 and Fig.6). Among these five counties, Panyu had the largest increase area which reached 86.37 km^2 and Guangzhou had the smallest increase area, only 1.04 km^2. At the same time, Guangzhou had the slowest annual increase rate (0.08%), but Panyu had very faster annual increase rate (19.20%). However, Conghua had the fastest annual increase rate 41.10% although its increase area was not larger. Huadu and Zengcheng were another two cities with higher increase areas and annual increase rates. The urban of Huadu increased 49.60 km^2 with annual rate 13.31% and Zengcheng increased 24.46 km^2 with annual rate 4.38%.

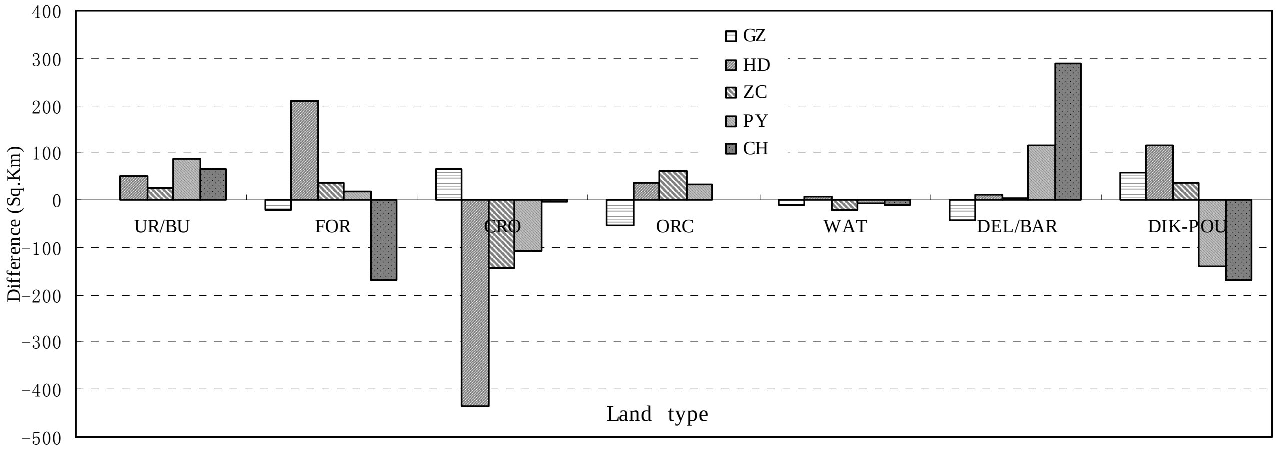

Figure 4. The land use change areas of five counties of Guangzhou Municipality from 1998 to 2003.

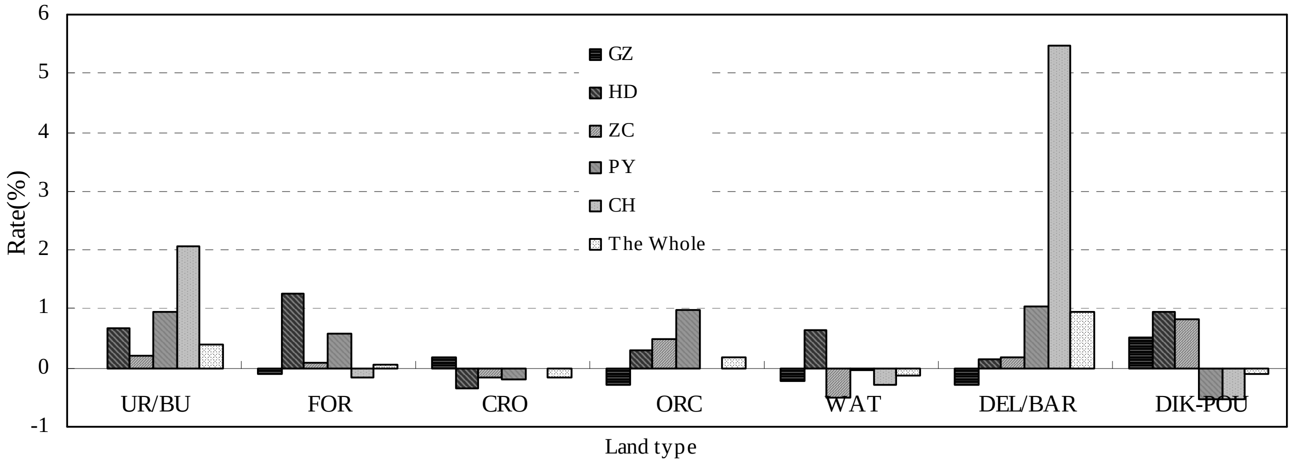

Figure 5. The annual change rates of land use in five cities and the whole Guangzhou Municipality.

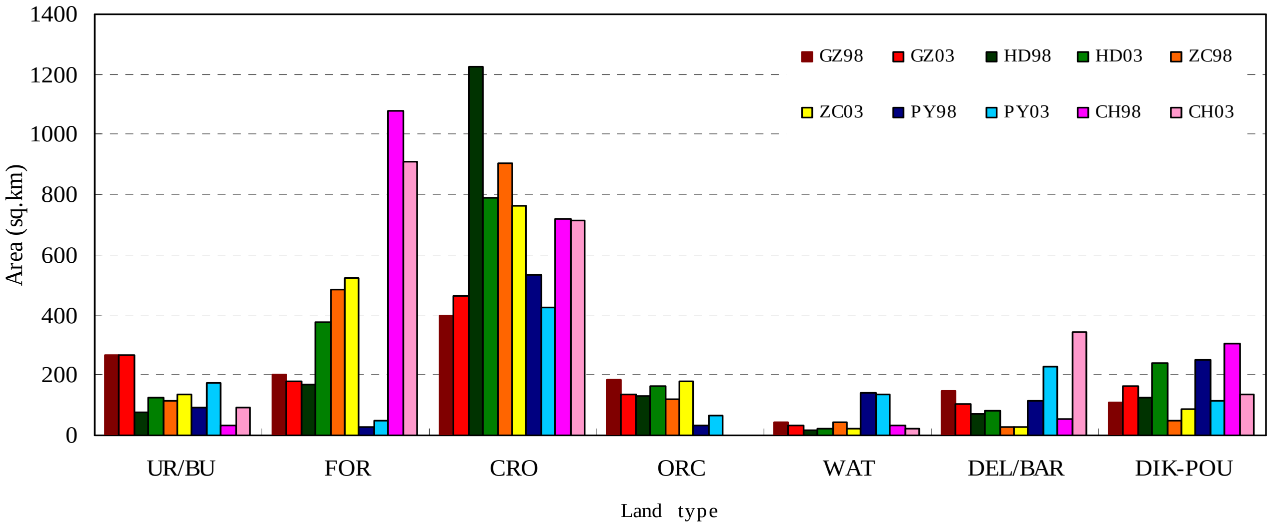

Figure 6. The land use areas of five counties. (Each kind of color column stands for a county, and each color column has two parts, which is the land use data of 1998 and 2003 from left to right).

During this period, because of the geographic location and convenient traffic of Panyu, the real estate industry of this district bloomed and a lot of residential areas were springing up rapidly in here. With the habitation function of Guangzhou was participated, Panyu was becoming the southern urban expansion center of Guangzhou Municipality step by step. Huadu and Zengcheng were northern and eastern centers of Guangzhou Municipality. Zengcheng's development was profited from the "agriculture-to-industry economy" reform which sparked the expansion of urban. Huadu was different from Panyu and Zengcheng, whose urban increase was depended on the establishing of the new airdrome (Baiyun international airport) and the implement of governmental policy for developing heavy industry like automobile manufacture and power plant. In Huadu, a climax of exploiture was coming ahead after merging into Guangzhou as an urban district since 2000. A lot of cropland, orchard, forest and dike-pond were converting into urban directly or changing into developing land initially and urban later.

The trend of other land types conversed to urban was similar in these five counties. Urban expansion caused the severe vanishing of cropland. The area of cropland transforming to urban in Guangzhou reached 21.36 km^2, 72.88 km^2 in Huadu, 48.22 km^2 in Conghua, 50.13 km^2 in Zengcheng, and 57.99 km^2 in Panyu. The area of urban growth of Guangzhou mostly comes from developing land, which reached 53.66 km^2; Conghua mainly comes from forest, which reached 19.39 km^2; Panyu comes from developing land and dike-pond, which were about 36.60 $km^2$and 29.53 km^2 respectively. Spatially, five counties' urban expansion radiated to the direction along road network based on their primary built-up area, the expanded urban areas usually occurred around roadside (Fig. 2). The road network around cities became the most important driver direction of urban expansion in these five cities.

4.4 Cropland loss of five counties in 1998-2003

We compared the increase area and rate of cropland losses in these five cities and found that the cropland loss was very severe from 1998 to 2003. The cropland loss phenomena had taken place almost in all counties but Guangzhou. The loss area of cropland was 143.13 km^2 in Zengcheng, 107.61 km^2 in Panyu, 433.95km^2 in Huadu and 4.96 km^2 in Conghua. The loss rate of cropland reached 3.17% in Zengcheng, 4.03% in Panyu, 7.08% in Huadu and 0.14% in Conghua.

According to Table 2 – Table6, a significant amount of cropland had been encroached by other kinds of land use types. Comparing with urban expansion properties in part 4.3, it was clear that the vanished cropland land converted into urban mostly. There exited two types of land use conversion: conversion from cropland to orchard and the conversion from cropland to urban and developing land. The change from cropland to orchard was the result of agricultural restructuring. Before 1998, the dominant type of land was cropland in Huadu, Zengcheng, Panyu and Conghua, and the planting were controlled strictly, so the changes between cropland and orchard were relatively determinate. But, with the economy developing, this simple agricultural pattern of land use was faced with great challenges from the market force. The economic benefit of orchard was higher than that of cropland, so under the economic driving, more and more peasants planted fruit not corns as before.

Although a lot of cropland had transformed to urban and developing land, other type of land use still transformed to it, such as forest. It was considered that the main component of cropland was forest.

Form 1998 to 2003, 59.57 Km^2 forest transformed to cropland in Guangzhou, and the areas in Huadu, Conghua, Zengcheng and Panyu are 29.92 km^2, 144.24 km^2, 77.31 km^2 and 5.99 km^2 respectively.

4.5 Urban expansion and cropland loss of Guangzhou Municipality in 1998-2003

Through discussing the urban expansion and cropland loss during this period in whole Guangzhou Municipality, it could be found that urban areas had increased 225.53 km^2 (from 572.95 km^2 in 1998 to 798.28 km^2 in 2003), while cropland areas had decreased 623.66 km^2 (from 3781.06 km^2 in 1998 to 3157.40 Km^2 in 2003) (Fig.4). The rates of urban expansion and cropland decreased were 7.86% and 3.30% respectively (Fig.5). According to the study of Li and Yeh (1998), the rates of urban expansion and cropland decreased were 7.19% and 7.23%, and Weng (2002) whose study indicated that the rates of urban expansion and cropland decreased were 5.96% and 6.04 respectively, it could be found that the urban expansion rate still keeps faster, while the rate of cropland decrease got slower.

The urban changes may be related to industrial development as well as population growth during this period, and the cropland change may be related to the policy of land use protecting of government since 1998. At the same time, the spatial process of urban expansion showed a close relationship with the distance from major roads and from the geometric center of a city, which indicates that the road was a most important drive to urban expansion (Fig. 2).

Developing land was defined as an area that has recently been bulldozed to make way for construction, and thus had a high contrast characteristic in remotely sensing images. Usually developing land was designed for building for industrial or urban usage by local government. In past two decades, developing land plays an important role in stimulating the local economy in Pearl River Delta area. So the area of developing land implied that one region had great potential for further developing. From 1998 to 2003, the area of developing land in whole Guangzhou had increased significantly, and the increasing area was 288.92 km^2 with the increasing rate of 18.78%. Considering the GDP growth of Guangzhou Municipality (Table 7), it could be found that the increasing trend of developing land had no change. With the GDP increasing, the area of developing land in whole Guangzhou was still becoming greater.

Table 7. The 5 years GDP and change rate of Guangzhou Municipality (Million Yuan).

Year	1997	1998	1999	2000	2001	2002	2003
GDP	164625.67	184160.52	205673.83	237591.29	271390.79	300147.6	349687.87
Rates of GDP growth		11.87%	11.68%	15.52%	15.79%	10.59%	16.51%

The spatial expansion process of developing land showed that it was transferring from Guangzhou and Panyu to Huadu and Zengcheng. During these five years, the developing land area of Huadu and Zengcheng expanded 15.90% and 17.70% respectively (Fig.5). The developing land area of Guangzhou decreased during this period (from 145.20 km^2 to 103.10 km^2 with the decreasing rate of 5.80%). Meanwhile, the developing land of Huadu increased from 42.32 km^2 to 68.63 km^2 with the increasing rate of 12.44%. The results indicated that the urban and economic center of Guangzhou was extending to the north and the east.

The loss of valuable cropland was very severe. The cropland area of whole Guangzhou decreased from 3781.06 km^2 in 1998 to 2040.22 km^2 in 2003, and the annual loss rate of cropland in the whole municipality reached 3.30%. Huadu had the higher loss rate, reaching 7.08%, Zengcheng had the loss rate of 3.17% and Conghua had lower loss rate (only 0.14%). The similar result was found in Dongguan between 1988 to 1993 by Yeh and Li (1999). Comparing with the result in Pearl River Delta in 1993-1998 by Yeh and Li (1999) and Weng (2002), the suburb county-level city Zengcheng and Conghua were still in process of rapid loss of cropland, while the cropland loss rate in city of Guangzhou had decreased a lot.

The reason of the cropland loss was that the income of cropland developed as industrial or urban land was of much higher profit for both farmers and local governments than that for cropland use. So many high quality croplands became industrial and urban used land gradually. It should be noted that the losses of cropland would promote the economy growth, but the land utilization efficiency were different in different cities. We analyzed the relations between the cropland loss and GDP growth using cropland loss rates of each county from 1998 to 2003 derived from classification images and GDP growth rates of each county in corresponding years published by the local governments. The results were expressed by the cropland consumption of per capital million Yuan (RMB) GDP growth and the ratio of cropland loss rate and GDP growth rate. It could be found from Table 8 that the results were different in these five cities. The cropland consumption was very high in some recent developed city like Huadu, Zengcheng and Panyu while it kept still lower in the under developing city like Conghua and very developed city like Guangzhou city. The cropland consumption reached 0.42269 km^2/million Yuan in Huadu, 0.02 km^2/million Yuan in Zengcheng and 0.01 km^2/million Yuan in Panyu respectively. However, it was only 0.001 km^2/million Yuan in Conghua and only 0.00000839 km^2/million Yuan in Guangzhou. For the whole municipality, it was about 0.004 km^2/million Yuan (Table 8 and Fig.7). The ratio of cropland loss rate and GDP growth rate demonstrated the similar trend. The cities with higher ratio indicate that their land utilization efficiencies were in lower stage, such as Huadu, Panyu and Zengcheng. However the cities with lower ratio indicate that their land utilization efficiencies were in higher stage, such as Guangzhou and Conghua (Table8 and Fig. 7).

It was well known, during the initial stages of China’s reformation and opening to the outside, the increasing of economy generally cost a lot of cropland and the cropland became a big engine of economic growth, particularly in the southeastern part of the country like Guangdong. But now, the analysis between the cropland loss and GDP growth in Guangzhou showed a significant phenomenon (Fig 8).

Table 8. The cropland losses of per capital Million Yuan.

Regions	Guangzhou	Zengcheng	Panyu	Conghua	Huadu	Whole Guangzhou
Cropland loss(km^2)	1.0377	143.13333	107.614	4.9563	433.95	689.653
Rate of cropland loss (%)	0.078	3.17	4.023	0.137	7.08	3.2988
GDP increase (Million Yuan)	123691.75	8575.83	18103.99	4889.74	10266.31	165227.35
Rate of GDP growth□□□	19.05	14.03	14.81	18.68	16.53	17.98
km^2/Million Yuan	0.00000839	0.01669	0.005944	0.001014	0.42269	0.00417
Ratio of growth rates	0.0041	0.0073	0.2259	0.2716	0.4283	0.1835

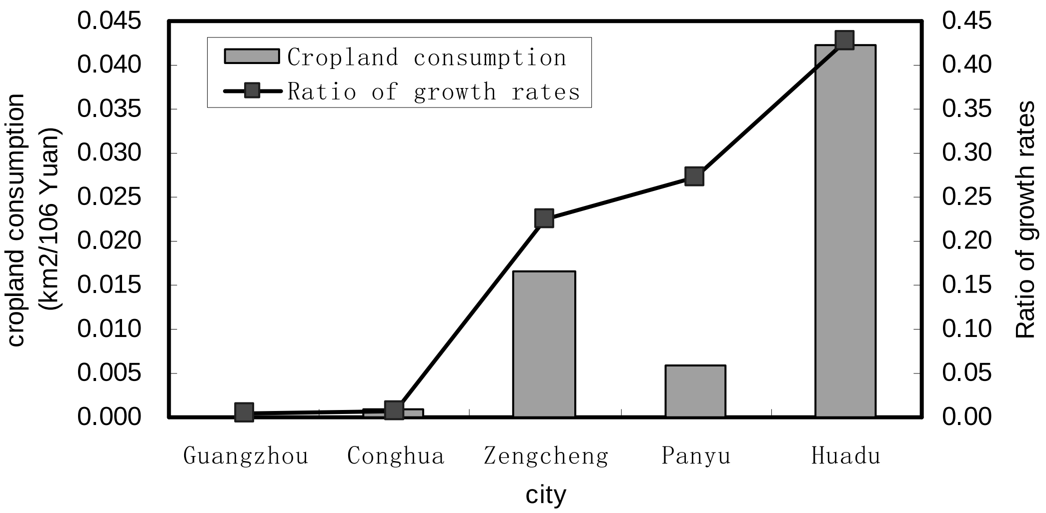

Figure 7. Comparison of the cropland consumption of per capital GDP growth and ratio of rates between cropland loss and GDP grow in Guangzhou.

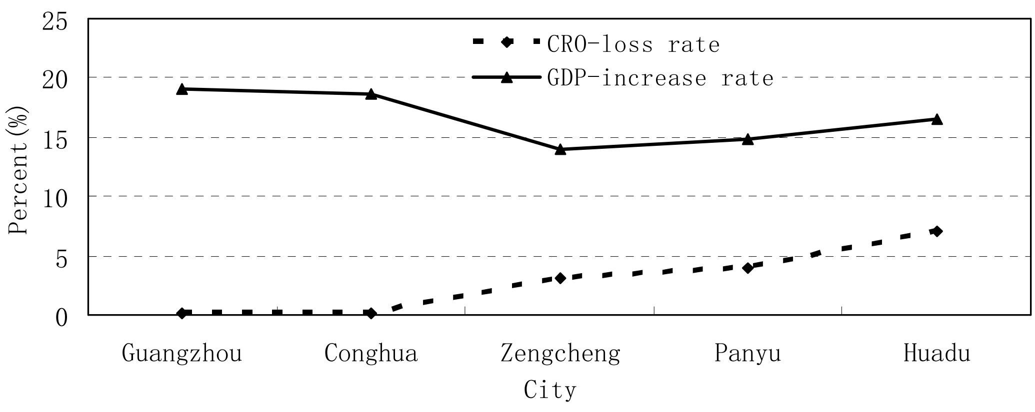

Figure 8. The relationship between cropland loss rate and GDP growth rate.

The result may imply that the pattern of economic increase in this region had moved on a new developing track. There were several possible reasons inducing these results: (1) in some regions like Guangzhou and Conghua, the tertiary industry such as tourism, service and information contribute greater percentage to the economy growth; (2) the successful transformation of industry structure from labor-intensive industry to technology-intensive industry; (3) registering and implement of strict land use control policy nationally and locally; (4) the rational land use planning and moderate urbanization strategy are adopting. However, for the lower land-use efficiency cities like Huadu, Panyu and Zengcheng, some political reasons should be noted, including the adjusting of administrative boundary like Panyu and Huadu's merging into Guangzhou in as an urban distract and urban's strategic expansion like Zengcheng' s extension to the south and west.

5. Conclusions

This paper analyzed the land use change of Guangzhou and its suburban areas from 1998 to 2003 by using remote sensing data and other assistant data, monitored the urban expansion and cropland loss, and discussed the relationships between land use changes and local economy development. The results of this study indicated that there had been important land use changes between 1998 and 2003 in the area of Guangzhou, with evidence of extensive degradation in cropland and farmland. This process may lead to a decline in soil fertility and compromise future agricultural productivity and ecosystem sustainability. In this work, county-level measurements of land use change in the extent of land use types and respective transitions had been presented, there were obvious urban expansions of these five cities from 1998 to 2003. The urban expansion speeded in Guangzhou is relatively slow while the cities around Guangzhou demonstrate higher urban expansion speed, such as Panyu, Zengcheng and Huadu. The city of Guangzhou mainly extended to the south, north and east in this period. Amounts of cropland vanished in the range of 1998-2003, but the decreasing rate for the whole Guangzhou was diminishing comparing with previous results in Dongguan and the Pearl River Delta. The "cropland to orchard" and "orchard to cropland" transforming was quite intense and common in this area. From 1998 to 2003, a lot of forest transformed to cropland, became the biggest compensation of cropland and slowed the loss rate of cropland to a certain extent. The road network and economic center city played important role in the process of urban expansion. The direction of road development was also the direction of urban development. At the same time, policy and environment were two important factors to affect the development of urban. Combining classification images of Landsat TM and ETM+ and socio-economic data were an effective way to research land use change dynamically (including monitoring the urban expansion and cropland vanishing and study the relationships between the land use change and local economy development). And found that the efficiencies of land use in these five counties were different and lower as a whole. The cropland loss and GDP growth in Guangzhou demonstrated the difference between these 5 counties and explained different cropland transform efficiency of these 5 counties in difference development stages, at the same time, the results implied the natural, social, managing and planning as well as political reasons.

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