

# Comparison of Urbanization and Its Eco-environmental Effects in Three Large Pearl River Delta Metropolises, China



Rongbo Xiao, Changguang Wu and Zhishan Li

**Abstract** Guangzhou, Shenzhen and Hong Kong are the three most representative large metropolises experiencing rapid urbanization in China. Through Landsat image interpretation, socio-economic and environmental monitoring data analysis, we constructed an index system for urbanization and eco-environmental quality assessment. We used this system to examine the urbanization process and evaluate the eco-environment quality changes in the three metropolises since 1980. Our goal was to provide a scientific understanding of green urban development in the Pearl River Delta and even in China. We found that the three metropolises are at different phases of urbanization. Hong Kong has the highest population density and the most intensive land use, followed by Shenzhen and Guangzhou. In terms of vegetation coverage, atmospheric environment quality, surface water environmental quality, and urban heat island effect, Guangzhou has the highest overall quality, followed by Hong Kong and Shenzhen. However, there are significant differences in ecological environment evolution for the metropolises, which are shaped by natural and geographical conditions, economic development pathways, and environmental protection policies.

**Keywords** Urbanization process · Eco-environmental effects  
Pearl River Delta region · Evaluation index system

---

R. Xiao (✉) · Z. Li

Guangdong Provincial Academy of Environmental Science, 335 Dongfeng Middle Road,  
Guangzhou 510045, Guangdong, China  
e-mail: [ecoxiaorb@163.com](mailto:ecoxiaorb@163.com)

R. Xiao

School of Environmental Science and Engineering, Guangdong University of Technology,  
Guangzhou 510045, Guangdong, China

C. Wu

Department of Landscape Architecture, College of Horticulture and Forest Science, Huazhong  
Agricultural University, Wuhan 430070, Hubei, China

© Springer Nature Switzerland AG 2019

X. Yang and S. Jiang (eds.), *Challenges Towards Ecological Sustainability in China*, [https://doi.org/10.1007/978-3-030-03484-9\\_7](https://doi.org/10.1007/978-3-030-03484-9_7)

# 1 Introduction

Since 1978 when the open-door policy initiated and economic reform began, China's urbanization has developed with a low starting point but a high speed driven by intensifying industrialization. From 1978 to 2013, the permanent urban population in China increased from 170 million to 730 million, and the urbanization rate increased from 17.9 to 53.7% with an average annual rate of 1.02% (Wu 2015). The number of cities also increased from 193 to 658 according to the 2014–2020 National New-Type Urbanization Plan. However, urbanization in China, problems such as loss of cultivated lands, decline of ecological quality and serious environmental pollution have emerged, which have restricted further development (Li et al. 2009). Therefore, how to maintain a good ecological quality in a rapid urbanization environment has become an important issue for China to promote the sustainable urban development.

There are obvious stage characteristics for urbanization and its eco-environmental influences, and the regional differences among cities may be due to the differences in the natural conditions, historical settings, location and policy orientations (Fang et al. 2016; Yang et al. 2017). To understand the eco-environmental effects of urbanization, it is necessary to conduct a comparative analysis of long-term changes in cities within a certain region. However, most of the existing studies largely focused on the overall impact (e.g., He and Zhuang 2006; Liu and Wang 2015; Fang and Ren 2017) or a single major city (Chang et al. 2012; Xie et al 2015), with few comparative studies considering different biophysical and socio-economic conditions. Such comparative studies can offer an important insight that can help urban planning and management.

Pearl River Delta has been the frontrunner in China's economic reform and the most representative region in terms of urban development in the country. Urbanization rate in this region has risen from 17.92% in 1978 to 82.72% in 2010. Meanwhile, the ecological environment has gradually degraded. In this study, we selected three most representative metropolises in the Pearl River Delta, namely, Guangzhou, Shenzhen and Hong Kong, as the study site to systematically analyze and evaluate the urbanization process and ecological environment quality since 1980, and discuss the influences of economic and social development models and urban management policies in order to provide a scientific understanding of the green urban development in the Pearl River Delta region and even in China.

## 2 Research Methods

### 2.1 Study Sites: *Guangzhou, Shenzhen and Hong Kong*

Guangzhou, the capital of Guangdong Province, is the largest city in southern China. Before the economic reform, the urban spatial structure of Guangzhou was relatively stable. It has experienced a rapid expansion in the 1980s and formed a huge agglomerate in the late 1990s (Xu 2004). With new “frog-leaping” development

zones continued to emerge in the periphery, Guangzhou has become a typical urban space expansion model of China (Su et al. 2005). Therefore, for studying on urbanization in the Pearl River delta, Guangzhou should be a good case to include.

Shenzhen is located at the eastern coast of Pearl River estuary. With the advantage as one “special economic zone” and its geographical location being adjacent to Hong Kong and Macao, Shenzhen has emerged from a small coastal fishing village to an international and modern metropolis since the city establishment in 1979. In 2004, Shenzhen completed the work changing all towns into sub-district offices and became the first and only megacity in China that does not include any rural area. Although Shenzhen is a megacity with a population of over 10 million, its physical size is rather small, and the land resources for construction are very scarce (Xie and Chen 2013). Shenzhen’s “concentrated” and “fast-paced” urban development can be viewed as a typical case of urbanization in the Pearl River Delta.

Located at the eastern side of the Pearl River estuary and being adjacent to Shenzhen to the north, Hong Kong Special Administrative Region has evolved from a colonial port trade city into an international shipping center, trade center and financial center since 1841. Its development and urban construction are subject to the great influence of Western and Eastern international political, economic and cultural changes, which are different from the economic and cultural systems in Guangzhou and Shenzhen. In addition, Hong Kong was already a highly urbanized area in the 1970s, and therefore its urbanization process in the latter period has been stabilized, which is also different from the rapid urbanization pattern in Guangzhou and Shenzhen. Studying Hong Kong, a highly urbanized and land-intensive international city, can provide valuable historical experience for transformation and upgrading of other cities in the Pearl River Delta region.

As the three major metropolises in the Pearl River Delta region (Fig. 1), Guangzhou, Shenzhen and Hong Kong are very different in urbanization process and economic development models, and face different challenges in balancing urban development and ecological environment maintenance. Therefore, a comparative analysis of Guangzhou, Shenzhen and Hong Kong over the past 30 years can help understand and analyze the eco-environmental effects of urbanization in the Pearl River Delta Region and provide a reference for sustainable development of urban areas in the Pearl River Delta and even in other parts of China.

## 2.2 Data

The data for this study was derived from diverse sources. Socio-economic data, such as population, economic, industrial structure, were collected from official website published data of Guangzhou Statistical Bureau (<http://www.gzstats.gov.cn/>), Shenzhen Statistical Bureau (<http://www.szstj.gov.cn/>) and Hong Kong Census and Statistics Department (<http://www.censtatd.gov.hk/>). Water environment, atmosphere environment and related Environmental quality data came from Guangzhou Environmental Quality Report (Guangzhou Environmental Protection

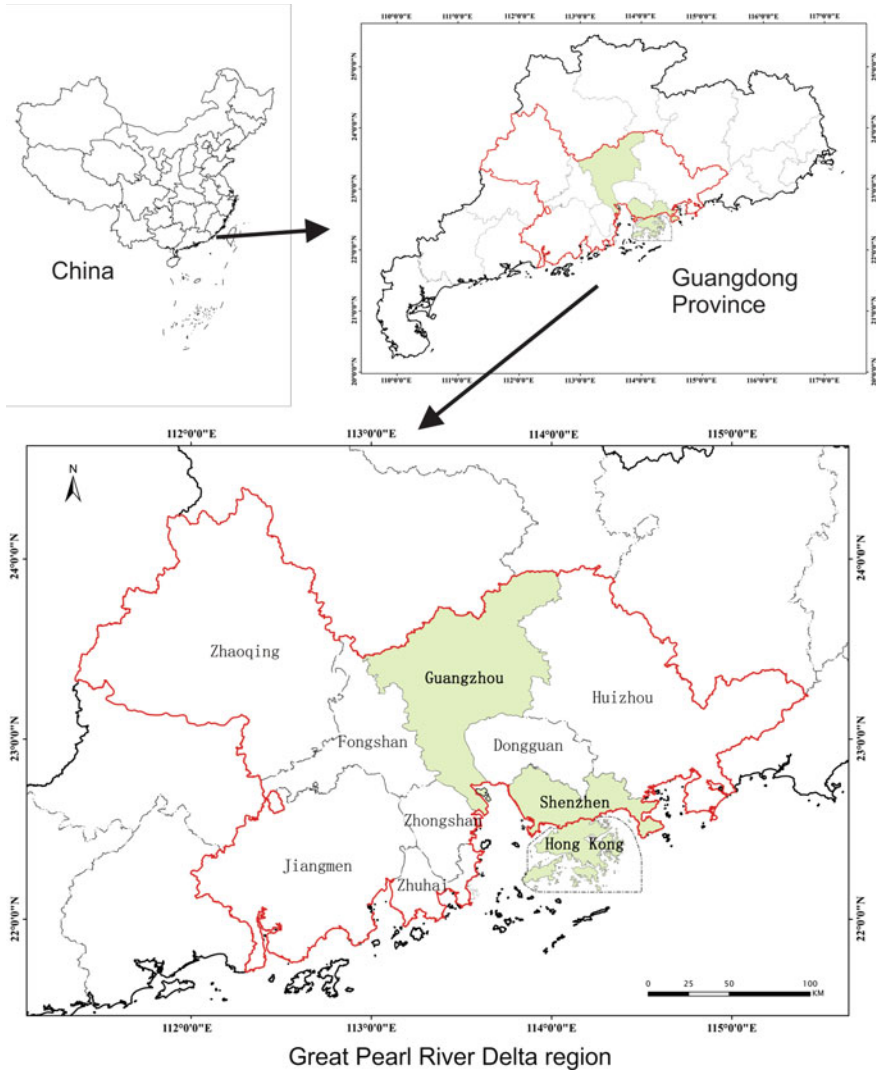


Fig. 1 Location of Guangzhou, Shenzhen, and Hong Kong

Bureau 2001–2011), Shenzhen Environmental Quality Report (Shenzhen Environmental Protection Bureau 2001–2011) and data published from the official websites of Hong Kong Environmental Protection Department (<http://www.epd.gov.hk/>).

Land-Use and Land-Cover Change (LUCC) data were derived from Landsat MSS (Multispectral Scanner)/TM (Thematic Mapper) images acquired in 1980, 1990, 2000, 2005, and 2010. Except Landsat MSS image data in 1980, all others were Landsat TM images. Object-oriented classification was conducted to derive land-use

maps with several different land-use types including built-up area, forest, grassland, farmland, wetland, and others (Xiao et al. 2017).

In order to quantitatively evaluate the heat island intensity, we used Urban Heat Island Ratio Index (URI) (Xu and Chen 2003). Temperature data were obtained from China 1 km monthly night time surface temperature synthetic MODIS products (TERRA), which were downloaded from the website of the Computer Network Information Center, Chinese Academy of Sciences (<http://www.gscloud.cn/>). We composed the average annual surface temperature data by monthly data.

$$URI = \frac{1}{100m} \sum_{i=1}^n w_i P_i$$

where, m is the temperature normalized rank index, i is the *i*th temperature level above which the heat island is above the low temperature region, n is the temperature level number above the low temperature region, w is the weight value, and *P<sub>i</sub>* is the percentage of the *i*th level. In this study, urban surface temperature rating is set at five levels, so m is 5; 5 and 4 levels are defined as the urban heat island range, so n is 2.

### 2.3 The Evaluation Index System

Considering the data availability, relevant research outcomes, and the actual situation in the Pearl River delta, we created an index system for urbanization and ecological environment quality evaluation in which the evaluation of urbanization levels includes three first-class indexes of land, population or economic urbanization, and the evaluation of ecological environment quality includes the proportion of natural vegetation coverage to urban area, biomass per unit area of forest, and the number of days with air quality above Grade II Standard, the proportion of rivers with case-III water and above, and heat island intensity (Table 1).

**Table 1** Urbanization and ecological environment evaluation index system

| Items                   | Evaluation indexes   |
|-------------------------|--|
| Urbanization indexes    | Proportion of built-up area to urban area (%)                              |
|                         | Population density of built-up area (person/km <sup>2</sup> )              |
|                         | Proportion of output value of secondary and tertiary industries to GDP (%) |
| Eco-environment indexes | Proportion of natural vegetation coverage to urban area (%)                |
|                         | Days with air quality above Grade II Standard (days)                       |
|                         | Proportion of rivers with case-III water and above (%)                     |
|                         | Heat island intensity  |

With equal weights, ecosystem quality index (EQI) uses the proportion of natural vegetation, biomass per unit area of forest, the proportion of the number of days with air quality reaching the standard, and the proportion of rivers with case-III water and above to establish the ecological quality index that is used to reflect ecological quality of urban agglomerations.

$$EQI_i = \sum_{j=1}^n w_j r_{ij}$$

where,  $EQI_i$  is the ecological quality index of the  $i$ th city, which is the relative weight of each index and the standardized value of each index of the  $i$ th city.

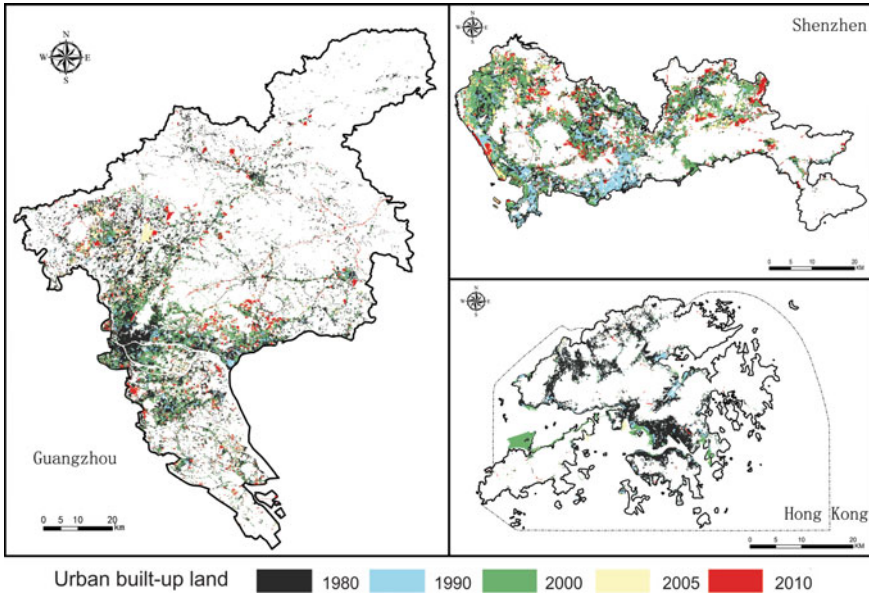
### 3 Results

#### 3.1 Urbanization Indexes from 1980 to 2010

##### 3.1.1 Land Urbanization

The change of built-up land can reflect the speed of urban expansion to a certain extent. The spatial expansion of urban built-up land in Guangzhou, Shenzhen and Hong Kong for the past 30 years mainly occurred between 1980 and 2000, with the most rapid expansion in 1990–2010 (Fig. 2). However, the patterns of urban spatial expansion are different for the three metropolises. Guangzhou mainly developed externally around the city center in circles, showing a trend of expansion from high density in the central area to medium and low density around circles of the outer area. The urban expansion in Shenzhen was concentrated on the built-up area in the Special Zone (including Nanshan, Futian, and Luohu districts), and gradually expanded and formed a multi-center axis-belt-cluster structure along mountains and water systems. Hong Kong changed little in the built-up land, which is mainly in a belt-like form along the coast, and discontinuous and shows an overall leap cluster expansion.

Based on the statistical data (see Table 2), the built-up land area in descending order was 1,492.08 km<sup>2</sup> in Guangzhou, 804.83 km<sup>2</sup> in Shenzhen and 229.88 km<sup>2</sup> in Hong Kong as of 2010. From 1980 to 2010, the annual growth of built-up land in Guangzhou, Shenzhen and Hong Kong was 26.76 km<sup>2</sup>, 18.64 km<sup>2</sup>, and 2.36 km<sup>2</sup>, respectively. From the perspective of land urbanization, Guangzhou and Shenzhen were in the stage of rapid urbanization, especially during 1990–2000 when the expansion of built-up land was the fastest with the annual growth rate of 45.09 km<sup>2</sup> and 32.11 km<sup>2</sup>, respectively. However, the land urbanization was basically stable in Hong Kong. In terms of land urbanization intensity, Shenzhen was the highest among the three metropolises, which was 42.61%, while the intensity in Guangzhou and Hong Kong was more or less identical, which was around 20%.



**Fig. 2** The spatial distribution of urban built-up land in Guangzhou, Shenzhen and Hong Kong from 1980 to 2010

### 3.1.2 Population Urbanization

From 1980 to 2010, the population of Guangzhou, Shenzhen and Hong Kong shows an increasing trend. However, the average annual growth of 330,000 people in Shenzhen is equivalent to the population of a typical medium-sized Chinese city, which is much larger than the rate of 100,000 in Guangzhou and 68,000 in Hong Kong each year (Fig. 3). As of 2010, the population size of permanent residents in the descending order was 10,372,000 in Shenzhen, 8,042,000 in Guangzhou, and 7,052,000 in Hong Kong. However, from the perspective of population urbanization intensity, Hong Kong was still the highest among the three cities, and its the population density of the built-up area remained at 30,000 persons/km<sup>2</sup> in the past 30 years. As of 2010, the population density of the built-up area in Hong Kong was 30,677 persons/km<sup>2</sup>, which is 2.4 times and 3.6 times that in Shenzhen (12,887 persons/km<sup>2</sup>) and in Guangzhou (5390 persons/km<sup>2</sup>), respectively.

### 3.1.3 Economic Urbanization

From 1980 to 2010, the GDP of the three cities shows an increasing trend, with an average annual growth of RMB35.636 billion in Guangzhou, RMB31.929 billion in Shenzhen, and RMB50.148 billion in Hong Kong (Table 3). As of 2010, the GDP in descending order was RMB1.548111 trillion in Hong Kong, RMB1.074828 trillion

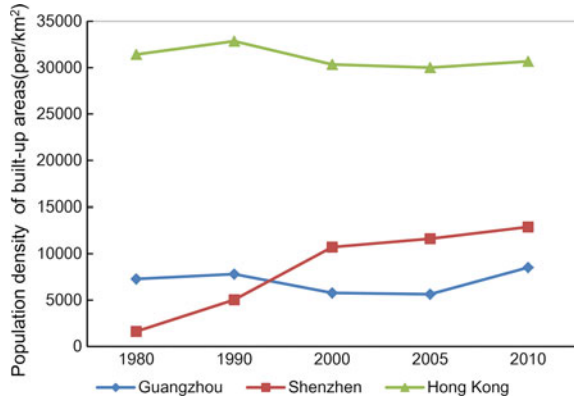
**Table 2** Summary of the urban built-up land growth in Guangzhou, Shenzhen and Hong Kong from 1980 to 2010

| Cities    | Indicators                                 | Year   |        |         |         |         |
|-----------|--|--------|--------|---------|---------|---------|
|           |  | 1980   | 1990   | 2000    | 2005    | 2010    |
| Guangzhou | Built-up land area (km <sup>2</sup> )      | 689.27 | 761.51 | 1212.37 | 1331.49 | 1492.08 |
|           | Average annual increase (km <sup>2</sup> ) | NA     | 7.22   | 45.09   | 23.82   | 32.12   |
|           | Percentage to urban area (%)               | 9.61   | 10.61  | 16.91   | 18.55   | 20.79   |
| Shenzhen  | Built-up land area (km <sup>2</sup> )      | 205.56 | 333.20 | 654.26  | 712.15  | 804.83  |
|           | Average annual increase (km <sup>2</sup> ) | NA     | 12.76  | 32.11   | 11.58   | 18.54   |
|           | Percentage to urban area (%)               | 10.88  | 17.64  | 34.64   | 37.70   | 42.61   |
| Hong Kong | Built-up land area (km <sup>2</sup> )      | 159.12 | 175.07 | 214.60  | 227.88  | 229.88  |
|           | Average annual increase (km <sup>2</sup> ) | NA     | 1.60   | 3.95    | 2.66    | 0.40    |
|           | Percentage to urban area (%)               | 14.40  | 15.84  | 19.42   | 20.62   | 20.80   |

in Guangzhou, and RMB 0.958151 trillion in Shenzhen. From the perspective of industrial structure, the economic urbanization intensity of the three cities was more or less the same, but there are some differences in the industrial structure proportion. The proportion of tertiary industry in Guangzhou exceeded that of the secondary industry in 1990, and the industrial structure showed a transition from “industrial economy” to “service economy”, and tertiary industry accounted for 61% of the total GDP in 2010. Shenzhen relied on its geographical advantages to actively undertake the development opportunity from relocation of Hong Kong’s manufacturing industry to Mainland. The secondary and tertiary industries in Shenzhen were balanced developing. In 2010, a new industrial system was formed, which was adaptive to the modern city central functions based mainly on high-tech and advanced manufactur-



**Fig. 3** Changes in the population density of the built-up area in Guangzhou, Shenzhen and Hong Kong from 1980 to 2010



ing industries supported by modern service industry. In the past 30 years, Hong Kong had been actively promoting industrial upgrading and rapidly developing modern service industries such as trade and logistics, financial services, professional services and tourism as its pillar industries, which accounted for 93% of GDP by 2010. Hong Kong is now a major service center in Asia and in the world.

### 3.1.4 Urbanization Stages

According to the three-stage theory of urban development (Fang et al. 2008), Guangzhou, Shenzhen and Hong Kong were at different stages of urbanization. Hong Kong was at the later stage of urbanization, while Guangzhou and Shenzhen had undergone the initial and mid-urbanization stages or the initial and accelerated development stage of urbanization since the 1980s and maintained a high rate of built-up area expansion (Table 4). In particular, the built-up area of Shenzhen expanded 3.9 times from the early 1980s to 2010, with the permanent population and GDP increasing by 31.4 times and 3548.5 times, respectively. This remarkable, rapid population and economic growth has been labeled as the “Shenzhen Speed”. However, in terms of land utilization, population density and GDP, Hong Kong had the highest level of land intensive use, followed by Shenzhen and Guangzhou. This may be attributed to the high proportion of hard-to-use land such as mountainous areas in Hong Kong and the efficient use of built-up land due to strict land management system in Hong Kong. Guangzhou and Shenzhen were at a period of rapid economic development. Although the population was highly concentrated, a large amount of land had been extensively used due to the imperfect land management system, and the population density was relatively small.

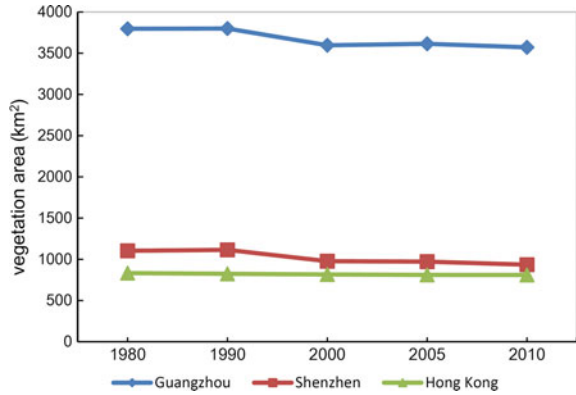
**Table 3** Summary of the output value proportions for secondary and tertiary industries in Guangzhou, Shenzhen and Hong Kong from 1980 to 2010

| Cities    | Indicators                             | Year   |         |          |          |          |
|-----------|--|--------|---------|----------|----------|----------|
|           |  | 1980   | 1990    | 2000     | 2005     | 2010     |
| Guangzhou | GDP (RMB100 million)                   | 57.55  | 319.60  | 2375.91  | 5154.23  | 10748.28 |
|           | Share of secondary industry to GDP (%) | 54.53  | 42.65   | 43.44    | 39.68    | 37.24    |
|           | Share of tertiary industry to GDP (%)  | 34.63  | 49.30   | 52.59    | 57.79    | 61.01    |
| Shenzhen  | GDP (RMB100 million)                   | 2.70   | 171.67  | 2187.45  | 4950.91  | 9581.51  |
|           | Share of secondary industry to GDP (%) | 26.05  | 44.81   | 49.65    | 53.37    | 47.21    |
|           | Share of tertiary industry to GDP (%)  | 45.07  | 51.09   | 49.64    | 46.43    | 52.72    |
| Hong Kong | GDP (RMB100 million)                   | 436.75 | 3678.83 | 14201.59 | 14869.68 | 15481.11 |
|           | Share of secondary industry to GDP (%) | 26.10  | 24.10   | 13.13    | 8.67     | 6.99     |
|           | Share of tertiary industry to GDP (%)  | 72.89  | 75.62   | 86.77    | 91.26    |          |

**Table 4** Comparison of the multiples of the expansion and population and economic growth for urban built-up areas in Guangzhou, Shenzhen, and Hong Kong from 1980 to 2010

| Cities    | Multiple of built-up land expansion | Multiple of resident population growth | Multiple of GDP growth |
|-----------|-------------------------------------|--|------------------------|
| Guangzhou | 2.2                                 | 1.6                                    | 188.3                  |
| Shenzhen  | 3.9                                 | 31.4                                   | 3548.5                 |
| Hong Kong | 1.4                                 | 1.4                                    | 35.5                   |

**Fig. 4** Vegetation area of Guangzhou, Shenzhen and Hong Kong from 1980 to 2010



### 3.2 Changes of Ecological Environment Quality from 2000 to 2010

#### 3.2.1 Vegetation Coverage

From the comparative analysis of vegetation coverage (Fig. 4), the natural vegetation area occupied by urban construction in descending order was 225 km<sup>2</sup> in Guangzhou, 169 km<sup>2</sup> in Shenzhen, and 20 km<sup>2</sup> in Hong Kong. Given a city’s total land area, the reduced area of natural vegetation accounted for only 2–3% in Guangzhou and Hong Kong and 9% in Shenzhen. Comparatively analyzing forest land landscape patterns (Table 5) shows that landscape heterogeneity and fragmentation in Guangzhou and Shenzhen were high and landscape diversity was obviously higher than that of Hong Kong. The spatial correlation of land use types in Hong Kong was higher than that of Guangzhou and Shenzhen, and the spatial connectivity of all kinds of land was higher, and land use landscape stability was better.

#### 3.2.2 Air Quality

The comparative analysis of sulfur dioxide and respirable particulate matter concentration in the air (Figs. 5 and 6) show that Guangzhou had the worst atmospheric quality, followed by Shenzhen and Hong Kong, but in general the atmospheric quality of the three cities from 2000 to 2010 tended to improve.

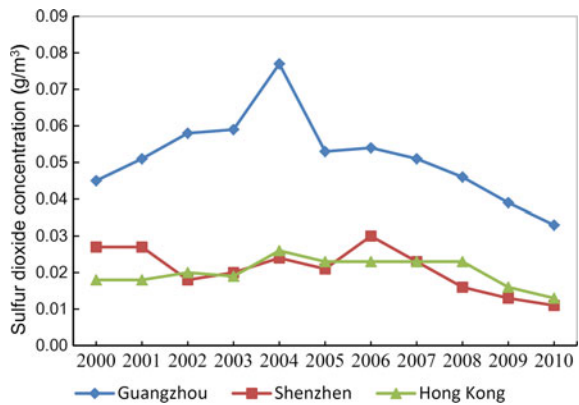
#### 3.2.3 Surface Water Quality

Our comparative analysis (Fig. 7) shows that the water quality of Hong Kong streams had always been at the optimal level with the minimum and maximum proportions of waters above case-III being 67 and 83% from 2000 to 2010. Guangzhou ranked

**Table 5** Forest landscape characteristic indices of Guangzhou, Shenzhen and Hong Kong from 1980 to 2010

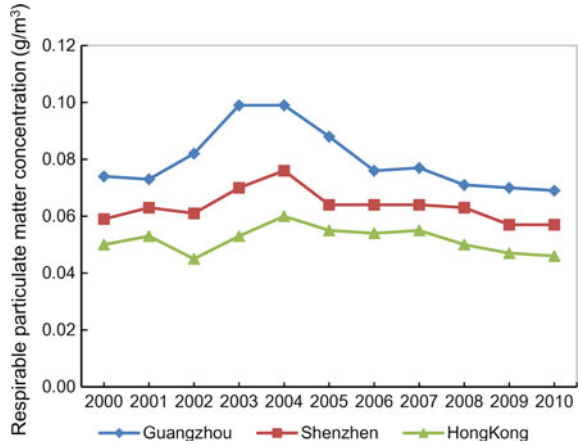
| Cities    | Years | Patch number<br>PN (pcs) | Mean patch<br>size<br>MPS<br>( $\text{hm}^2/\text{pcs}$ ) | Patch edge<br>density<br>PED ( $\text{m}/\text{hm}^2$ ) | Mean shape<br>index<br>MSI |
|-----------|-------|--------------------------|---|---|----------------------------|
| Guangzhou | 1980  | 10385                    | 24.22   | 32.96   | 1.57                       |
|           | 1990  | 10087                    | 24.93   | 32.74   | 1.57                       |
|           | 2000  | 7738                     | 29.66   | 28.42   | 1.60                       |
|           | 2005  | 7389                     | 31.19   | 27.98   | 1.61                       |
|           | 2010  | 7262                     | 30.98   | 27.14   | 1.60                       |
| Shenzhen  | 1980  | 3402                     | 22.38   | 36.36   | 1.51                       |
|           | 1990  | 3118                     | 24.71   | 36.52   | 1.54                       |
|           | 2000  | 2630                     | 23.83   | 30.52   | 1.60                       |
|           | 2005  | 2375                     | 26.14   | 29.29   | 1.61                       |
|           | 2010  | 2384                     | 24.46   | 27.90   | 1.60                       |
| Hong Kong | 1980  | 651                      | 126.81  | 23.47   | 1.47                       |
|           | 1990  | 772                      | 105.69  | 24.39   | 1.53                       |
|           | 2000  | 862                      | 93.61   | 24.66   | 1.53                       |
|           | 2005  | 854                      | 93.88   | 25.01   | 1.53                       |
|           | 2010  | 877                      | 91.31   | 25.40   | 1.53                       |

**Fig. 5** Sulfur dioxide concentration in the atmosphere of Guangzhou, Shenzhen and Hong Kong from 2000 to 2010

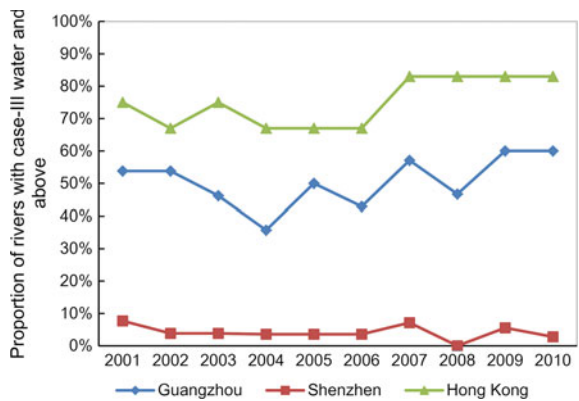


the second with 50% of waters above case-III for 6 years and 35.7% of the minimum proportion in 2004. The water quality of rivers in Shenzhen was the worst with less than 8% of waters above case-III, especially in 2008, and the water quality of rivers for the whole city didn't meet the case-III standard.

**Fig. 6** Respirable particulate matter concentration in the atmosphere of Guangzhou, Shenzhen and Hong Kong from 2000 to 2010



**Fig. 7** Proportion of rivers with case-III water and above in Guangzhou, Shenzhen and Hong Kong from 2000 to 2010



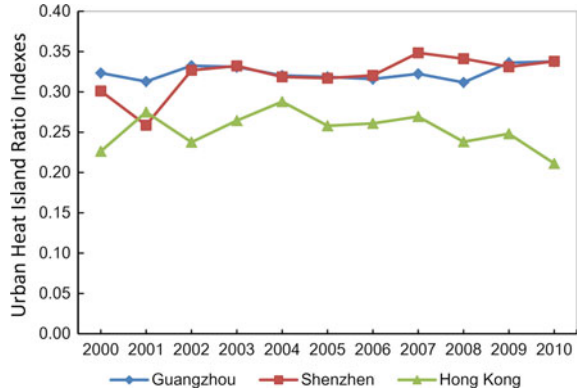
### 3.2.4 Urban Heat Island

Our comparatively analysis shows that urban heat island ratio indexes in the three cities fluctuated slightly from 2000 to 2010 without significant change (Fig. 8). The nighttime urban heat island intensity in Shenzhen was basically the same to that in Guangzhou, and the lowest was in Hong Kong.

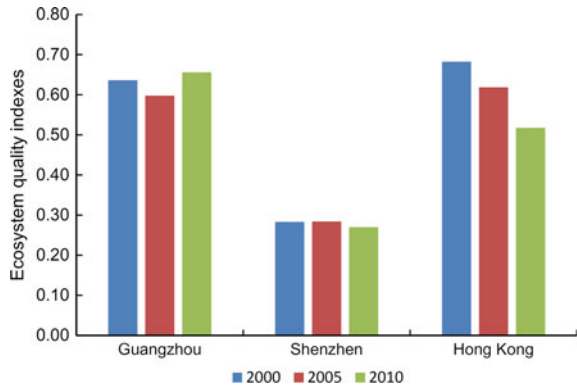
### 3.2.5 Ecological Quality

Our comparative analysis of the ecosystem quality index changes during 2000 to 2010 (Fig. 9) shows that Guangzhou ranked the first in the overall environmental quality, followed by Hong Kong and Shenzhen. During the period of 2000 to 2010, the overall quality of ecological environment in Guangzhou became better mainly due to the improved atmospheric and water environment quality. Although the atmospheric

**Fig. 8** Changes of Urban Heat Island Ratio Indexes in Guangzhou, Shenzhen and Hong Kong from 2000 to 2010



**Fig. 9** Ecosystem quality indexes in Guangzhou, Shenzhen and Hong Kong from 2000 to 2010



environment improved in Shenzhen, the water environment problem was serious and the proportion of natural vegetation invaded was higher, which brought about less change to the comprehensive index of ecological environment. The atmosphere and water environment in Hong Kong were stable but the comprehensive index of ecological environment dropped significantly due to the vegetation damage and the increasingly serious heat island problem.

## 4 Discussion and Conclusions

### 4.1 Discussion

The urban expansion and eco-environment consequences are mainly controlled by factors such as nature, society and economy. In this chapter, we analyzed the driving forces for urban expansion and its eco-environmental effects in Guangzhou,

Shenzhen, and Hong Kong from the aspects of natural and geographical conditions, economic growth models, and environmental protection policies.

#### **4.1.1 Natural and Geographical Conditions**

As the fundamental condition for urban land expansion, geographical settings largely determine the overall trend of urban expansion, affect the direction, speed, model and spatial form of urban growth, and sometimes even become the limit of urban form evolution. The urban built-up land in Guangzhou and Shenzhen tended to expand into the landform types conducive to land development, such as plains and hills, which are mainly characterized by high-speed, extensive and epitaxial land use patterns. The inefficient and poorly coordinated use of urban land was a major issue. On the other hand, Hong Kong has enforced a strict land management system. The high-density and high-intensity comprehensive utilization of land makes the construction area to be mainly concentrated on about one quarter of the land. Most of the suburban environment is preserved in order to protect nature and biodiversity. It becomes a typical example of an intensive and livable city in the world.

#### **4.1.2 Economic Growth Model**

Economic development is a major force driving and shaping the dynamic process of urbanization, and the most important factor affecting the quality of regional ecological environment. Both Guangzhou and Shenzhen adopted the economic growth model that “makes money from land” at the early stage of urbanization and at the expense of losing a large amount of agricultural production resources. This model of development was also a natural choice given the economic fundamentals and environmental conditions. At the accelerating urban development period, the economic development models began to change in the two cities. Guangzhou continued to follow the path of traditional industrialization development and promoted urbanization through “investment”. With limited land resources, Shenzhen tried hard to change its model of economic growth, taking the low-carbon development road and shifting to a low-carbon economy with low energy consumption, emission and pollution (Liu and Wang 2010). Hong Kong took the post-industrialization path in the 1980s and paid a great attention to improve land use efficiency in urban development. In a knowledge-intensive growth model with high technical content and highly added value, Hong Kong reduced consuming natural resources by in urbanization.

### 4.1.3 Environmental Protection Policies

The environmental problems presented in the rapid urbanization in Guangzhou and Shenzhen are characterized by accumulation, structure and compactness. Although the urban environmental quality has been improved by formulating a series of environmental protection policies, further improvement of the environmental quality has been under greater pressure as the rapid urbanization development stage, the large and continued increasing population of permanent residents and the continued increasing supply demand for land, energy and water resources will make the two cities to maintain large increases in pollutants. Hong Kong gradually established a set of sound environmental protection legal systems at 1950s so that the environmental governance in Hong Kong has achieved good results.

## 5 Conclusions

Guangzhou, Shenzhen and Hong Kong were at different stages of urbanization. Hong Kong was in the later stage of urbanization, while Guangzhou and Shenzhen had experienced the initial development stage and the accelerating development stage of urbanization since 1980s. In terms of the land use level, population density, and GDP, Hong Kong had the highest land intensive use level, followed by Shenzhen and Guangzhou. As for comprehensive vegetation coverage, atmospheric environment quality, surface water environmental quality and urban heat island effect, Guangzhou had the highest overall environmental quality, followed by Hong Kong and Shenzhen. From 2000 to 2010, Guangzhou generally became better in terms of its environmental quality due to the improved atmosphere and water quality. Although the atmospheric environment in Shenzhen improved, the comprehensive index didn't change much due to serious water environment problems. The atmospheric and water environment was stable in Hong Kong. However, the problems of vegetation deterioration and urban heat island became more and more serious, and thus comprehensive index dropped significantly. The evolution of urbanization and ecological environment quality in Guangzhou, Shenzhen, and Hong Kong has been controlled by natural and geographical conditions, economic growth models, and environmental protection policies.

**Acknowledgements** This work was supported by National Natural Science Foundation of China (#31470703).



## References

- Chang Q, LI S, Wang Y, Qiu Y (2012) Green landscape evolution and its driving factors in Shenzhen. *Acta Geogr Sin* 67(12):1611–1622
- Fang CL, Liu XL, Lin XQ (2008) Stages correction and regularity analysis of urbanization of China. *Arid Land Geogr* 31(4):512–523
- Fang CL, Ren YF (2017) Analysis of energy-based metabolic efficiency and environmental pressure on the local coupling and telecoupling between urbanization and the eco-environment in the Beijing-Tianjin-Hebei urban agglomeration. *Sci China Earth Sci* 60:1083–1097
- Fang CL, Wang Y, Fang JW et al (2016) A comprehensive assessment of urban vulnerability and its spatial differentiation in China. *Acta Geogr Sin* 26(2):153–170
- Guangzhou Environmental Protection Bureau (2001) Guangzhou Environmental Quality Report—1996–2000, Guangzhou Municipality, Guangdong Province
- Guangzhou Environmental Protection Bureau (2006) Guangzhou Environmental Quality Report—2001–2005, Guangzhou Municipality, Guangdong Province
- Guangzhou Environmental Protection Bureau (2011) Guangzhou Environmental Quality Report—2006–2010, Guangzhou Municipality, Guangdong Province
- He JF, Zhuang DF (2006) Analysis of the relationship between urban dynamic change pattern of the Yangtze River Delta and the regional eco-environment. *Geogr Res* 25(3):388–396
- Li SC, Zhao ZQ, Wang YL (2009) Urbanization process and effects of natural resource and environment in China: research trends and future directions. *Prog Geogr* 28(1):63–70
- Liu WL, Wang C (2010) Practice and patterns of low carbon city development. *China Popul Resour Environ* 20(4):17–22
- Liu YY, Wang SJ (2015) Coupling coordinative degree and interactive coercing relationship between urbanization and eco-environment in Pearl River Delta. *Hum Geogr* 3:64–71
- New national urbanization planning (2014–2020) from [http://ghs.ndrc.gov.cn/zttf/xxczhjs/ghzc/201605/t20160505\\_800839.html](http://ghs.ndrc.gov.cn/zttf/xxczhjs/ghzc/201605/t20160505_800839.html). 2016.05.05
- Shenzhen Environmental Protection Bureau (2001) Shenzhen Environmental Quality Report—1996–2000, Shenzhen Municipality, Guangdong Province
- Shenzhen Environmental Protection Bureau (2006) Shenzhen Environmental Quality Report—2001–2005, Guangzhou Municipality, Guangdong Province
- Shenzhen Environmental Protection Bureau (2011) Shenzhen Environmental Quality Report—2006–2010, Shenzhen Municipality, Guangdong Province
- Su JZ, Wen QQ, Guo HL (2005) The mechanism and adjustment of urban sprawl of Guangzhou. *J Geog Sci* 60(4):626–636
- Wu J (2015) A research on the development path of new urbanization based on low-carbon perspective. *Can Soc Sci* 11(3):309–313
- Xiao RB, Li ZS, Wu ZF et al (2017) Urbanization in the Pearl River Delta and its eco-environmental effects. Science Press, Beijing
- Xie DX, Cheng HQ (2013) Land problems and reflecting in highly urbanized areas: a case study of Shenzhen. *Green Econ (Chin)* 4:48–51
- Xie GD, Zhang B, Lu CX et al (2015) Rapid expansion of the metropolitan areas and impacts of resources and the environment. *Resour Sci* 37(6):1108–1114
- Xu HQ, Chen BQ (2003) An image processing technique for the study of urban heat island changes using different seasonal remote sensing data. *Remote Sens Technol Appl* 18(3):129–133
- Xu RS (2004) The history, current status and future of Guangzhou City. *Constr Dyn Guangzhou* 8:8–17
- Yang KC, Bi RC, Sun RH et al (2017) The spatio-temporal changes of urbanization in Beijing-Tianjin-Hebei region in Northern China. *Acta Ecol Sin* 37(12):3998–4007

**Dr. Rongbo Xiao** is the Chief Engineer of the Guangdong Provincial Academy of Environmental Science, China, and an Adjunct Professor at the Guangdong University of Technology. Xiao's research interests include urban and regional ecology and ecological planning and restoration. He has authored or co-authored 3 books and over 40 articles in these areas.

**Dr. Changguang Wu** is an Associate Professor at the Huazhong Agricultural University. His research interests include urban ecology, ecological health, green space efficiency, and climate adaptability. Wu has authored or co-authored multiple peer-reviewed articles in these areas.

**Zhishan Li** is an Engineer at the Guangdong Provincial Academy of Environmental Science, China. His major research area includes urban and regional ecology.