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Changing urban green spaces in Shanghai: trends, drivers and policy implications

Zhen Wu[a,1], Ruishan Chen[a,*], Michael E. Meadows[a,b,2], Dhritiraj Sengupta[a,3], Di Xu[c,4]

[a] Key Laboratory of Geographic Information Science, Ministry of Education, and School of Geographic Sciences, Institute of Eco-Chongming, East China Normal University, Shanghai, 200241, China
[b] Department of Environmental and Geographical Science, University of Cape Town, South Africa
[c] School of Environmental and Geographical Sciences, Shanghai Normal University, Shanghai, 201418, China

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ABSTRACT

Urban green spaces play a range of significant roles and have a positive influence on the quality of life in cities. Shanghai, a major economic and financial center in China, has set its goal to become a more ecologically integrated and livable city. The urban authorities envisage Shanghai as “a city in the forest, a forest in the city”. To achieve this greener future, the government has developed a series of policies to improve urban greening coverage. Based on land use and land cover data from 1980 to 2015, this paper analyzes temporal and spatial changes in urban green spaces in Shanghai, and explores the driving forces underlying the observed changes. Although the total urban green spaces in Shanghai declined from 1980 to 2015, different districts have different trends. Urban green spaces in the suburbs and the islands have declined, although, the city center increased its green spaces following several decades of decrease. Several factors have contributed to these changes, including population increase, conflicting government policies, real estate development, and rising demand for recreation space. Knowledge of the dynamics of urban green spaces in the city can assist in fostering an appropriate balance between urban development and environmental protection. To prevent environmental degradation and to plan a restoration pathway, cities should attempt to keep green spaces in mind during the development process and integrate the green spaces into urban planning. Understanding the dynamics of green spaces in Shanghai may offer insights for other cities in developing their own green spaces.

1. Introduction

Today, more than half of the global population lives in urban areas and, indeed, by 2030, it is expected that two out of every three people globally will reside in cities (UN Habitat, 2016). This will inevitably result in the ongoing expansion and/or densification of urbanized areas (Haaland and van den Bosch, 2015). The urbanization process has resulted in environmental degradation and the loss of global biodiversity (Seto et al., 2012), so the dynamics of urban green spaces have become an important topic in sustainable urban development discourse. Urban green space can be defined as any area within a city that is without buildings, may be natural or human-maintained, public or private and are complex and diverse components of the urban ecosystem (Wolch et al., 2014; Xu et al., 2011). The degradation or loss of these green spaces reduces the overall quality of urban ecosystems themselves (Fang et al., 2003) but also has direct impacts on human health and well-being (Tzoulas et al., 2007). Many inter-related problems arise from the fragmentation of urban green spaces, including augmentation

* Corresponding author. Present address: Key Laboratory of Geographic Information Science, Ministry of Education, and School of Geographic Sciences, Institute of Eco-Chongming, East China Normal University, Shanghai, 200241, China.

E-mail addresses: zhenwu013@gmail.com (Z. Wu), chenrsh04@gmail.com (R. Chen), michael.meadows@uct.ac.za (M.E. Meadows), dhritirajsen@gmail.com (D. Sengupta), xudicugb@gmail.com (D. Xu).

[1] Address: Key Laboratory of Geographic Information Science, Ministry of Education, and School of Geographic Sciences, East China Normal University, Shanghai 200241, China.

[2] Address: Department of Environmental and Geographical Science, University of Cape Town, South Africa. Key Laboratory of Geographic Information Science, Ministry of Education, and School of Geographic Sciences, East China Normal University, Shanghai 200241, China.

[3] Address: Key Laboratory of Geographic Information Science, Ministry of Education, and School of Geographic Sciences, East China Normal University, Shanghai 200241, China.

[4] Address: School of Environmental and Geographical Sciences, Shanghai Normal University, Shanghai 201418, China.

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of the urban heat island effect (Zhou et al., 2002), changes in the hydrological regime associated with the greater frequency and magnitude of urban flooding (Gupta and Nair, 2011), and deterioration in air quality (Santamouris, 2014). However, urban green space has emerged as one of the most important potential solutions to a variety of urban problems with a view to reinforcing the goal of sustainable development in cities (Yan, 2003). The roles of urban green spaces and their function and protection have thus become key topics of concern for city authorities in China (Anguluri and Narayanan, 2017; Liu et al., 2005; Zhao et al., 2013). A series of policies have been developed that are aimed at maintaining and, indeed, bringing more green areas into the city (Hernández-Moreno and Reyes-Paecke, 2018; Zhou and Wang, 2011), such as "Regulations of China on Urban Greening", "Shanghai Greening Regulations". The function of urban green spaces is emerging as a planning priority for decision makers and efforts have been made to identify and understand their dynamics (Baur et al., 2013; James et al., 2009).

Urban extension is the main cause of the reduction in urban green space (Nor et al., 2017), and has resulted in the transformation of green spaces into construction land. This process has been especially prominent in Asian and Australian cities, but is widely observed in cities globally (Haaland and van den Bosch, 2015). For example, so-called infill development resulted in a 5% reduction in green spaces in UK urban areas between 1975 and 2000 (Pauleit et al., 2005). The urban green spaces of Mashad city, the capital of Khorasan Razavi province of Iran, were significantly reduced during 1987–2006 (Rafiee et al., 2009), and they also decreased markedly in Greater Dhaka, Bangladesh, between 1975 and 2005 (Byomkesh et al., 2012). Elsewhere in China, green spaces in Beijing decreased by 47.05 km^2 annually between 1992 and 2004 as a result of extensive construction and the development of transportation infrastructure in both the city center and suburban districts, (Xu et al., 2011); similar trends are evident in Macau (Ye et al., 2018). The expansion of residential and commercial buildings has led to dramatic declines in urban green spaces in cities such as Hong Kong (Jim, 2005) and Kuala Lumpur (Akmar et al., 2011). In developing countries of Asia, rapid loss of urban green spaces has been shown in cities such as Hanoi, Vietnam (Uy and Nakagoshi, 2007) and Karachi, Pakistan (Qureshi et al., 2010).

Shanghai, one of the world's largest coastal megacities, has been experiencing rapid urbanization since the 1980s. There is clearly a need for the city to find approaches to more rational urban planning in the face of ongoing widespread construction, mitigating the negative impacts of, for example, the urban heat island effect and flood damage, ensuring better human health, and achieving sustainable development overall. Indeed, the government has recognized this need and has been striving to increase the area of urban green spaces in recent years. The Shanghai government has defined urban green spaces to include all woodlands, grasslands, garden plots, wetlands and cultivated lands (Xu et al., 2011) and has proposed that the proportion of green spaces (ecological land) in the city should, by 2020, exceed 50% of its land area, resulting in the need for an increase in urban green spaces of more than 60 km^2 (Shanghai Municipal Government (SMG, 2016a, 2016b). In order to assess the feasibility of the government achieving these ambitious goals, it is necessary to understand the temporal and spatial dynamics of green spaces in Shanghai.

In reviewing the situation, we try to identify the spatiotemporal pattern and trend of green spaces change in Shanghai. Here the city of Shanghai refers to the municipality and its administrative boundaries. The main aims of this paper are to document the changing spatial distribution of green spaces in Shanghai from 1980 to 2015 and to analyze the relationship between these changes, urbanization and green space planning policies. This aim is addressed through the following objectives in relation to the three major zones of the city, viz. city center, suburbs, and the islands:

- To understand the changes of Shanghai green spaces through spatial-temporal patterns and trends obtained from land use and land cover data.
- To detect the changing distribution and integrity of urban green spaces through various landscape indices for Shanghai.
- To identify the underlying driving forces of observed changes in urban green spaces.

2. Study area, data and methods

2.1. Study area

Shanghai (120°51′-122°12′E, 30°40′-31°53′N) is a coastal megacity located in eastern China, with an urban area of some 6340.5 km^2 (Shanghai Municipal Statistics Bureau (SMSB, 2018). From 1980 to 2015, Shanghai's urbanization rate, resident population, and per capita GDP have changed dramatically. The urbanization rate (ratio of urban population to total population) in Shanghai increased from 61.35% in 1980 to 87.6% in 2016, ranking first in China's cities (Shanghai Municipal Statistics Bureau (SMSB, 2018). The perceived economic attraction of urban development has resulted in substantial immigration and the resident population of Shanghai increased from 11.52 million in 1980 to 16.07 million in 2000 and, by 2015, it exceeded 24.15 million (Shanghai Urban Master Plan (2017–2035)). In addition, the per capita gross domestic product (GDP) has risen rapidly, from 3,855 CNY in 1985 to 18,942 CNY in 1995, reaching 103,041 CNY by 2015, nearly 27 times higher than in the 1980s (Shanghai Municipal Statistics Bureau (SMSB, 2018). Shanghai plays several key roles in being the country's main economic, financial, trade and shipping center. The urban area consists of 17 districts which can be divided into three zones, *viz*. the city center, the suburbs, and the islands. The city center has eight districts, *viz*. Jing'an, Changning, Xuhui, Huangpu, Hongkou, Yangpu, Zhabei and Putuo; the suburbs comprise eight districts as follows: Jiading, Baoshan, Pudong, Minhang, Qingpu, Songjiang, Jinshan and Fengxian; islands include Chongming, Changxing, and Hengsha island (Fig. 1).

2.2. Data and methods

This paper examines the temporal and spatial dynamics of changing urban green spaces in Shanghai, using high-resolution Landsat TM (Thematic Mapper) data for 1980, 1995, 2005 and Landsat OLI (Operational Land Imager) data for 2015. Land use data were classified based on images obtained from the Earth System Science Data Sharing Platform - Yangtze River Delta sub-platform of China's National Geospatial Data Sharing Center[5] for the years 1980, 1995 and 2005. The 2015 Landsat 8 OLI image was downloaded from the China Geospatial Data Cloud website.[6] After completing atmospheric correction, image fusion, stitching and visual interpretation, supervised classification was used to classify the land use and land cover into green spaces and non-green spaces. 100 pixels were randomly selected in GIS to validate the classified results; accuracy exceeded 95% for all the years. The scope of the data set is at prefecture-level throughout Shanghai at a resolution of 30 m. The resultant maps reflect the status of green spaces in Shanghai and their spatial distribution over the time period in question. The distribution was mapped using ArcGIS 10.0 software. NDVI (Normalized Difference Vegetation Index), downloaded from Google Earth Engine,[7] was used to examine changes in green spaces in Shanghai for 1986, 1992, 1996, 2000, 2005, 2010, 2015 as calculated from remote sensing images of Landsat 5 and Landsat 8 in summer (June, July, August).

[5] http://www.geodata.cn
[6] http://www.gscloud.cn/
[7] https://code.earthengine.google.com/4ca9a430f6b331-def89757e1863c2593

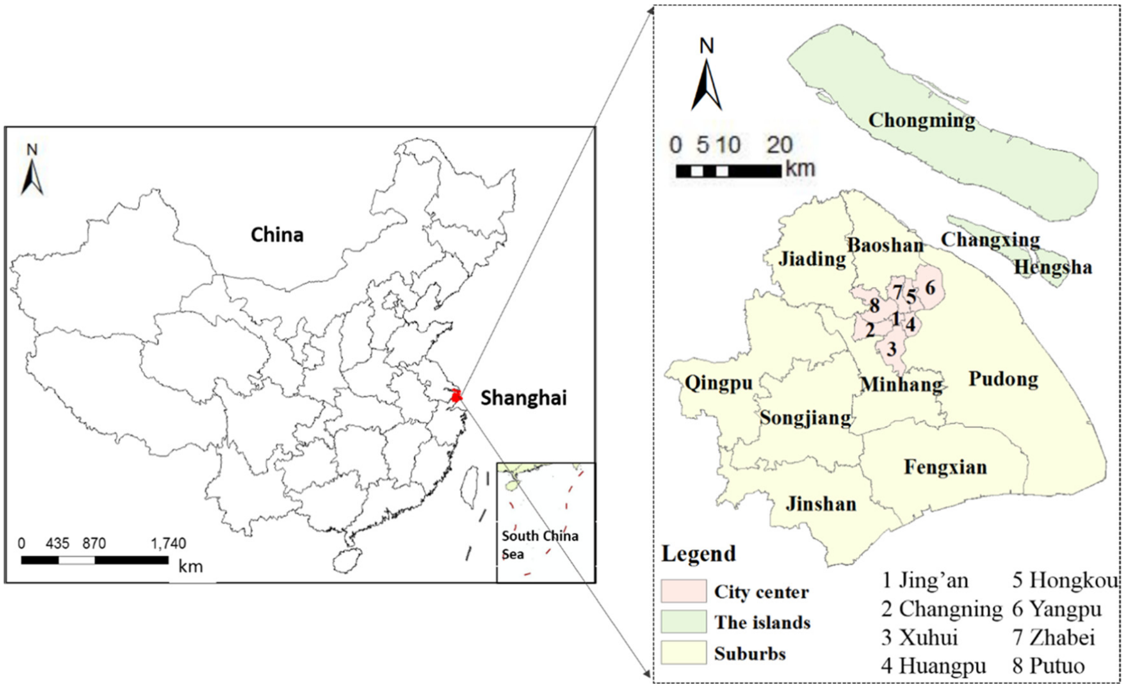

Fig. 1. Location of Shanghai.

Quantitative measures exist that can enrich the landscape pattern information and reflect aspects of its structure and spatial configuration (Huang et al., 2015; Yang et al., 2010; Cheung et al., 2016). This study employed several so-called landscape indices to describe the spatial structure of green spaces, including the ratio of green spaces (RGS) to total urban area, Patch Shape Index (PSI) and Mean Perimeter-Area Ratio (MPAR) (Liu and Chen, 2000; Xiao et al., 2015).

The ratio of green spaces (RGS) is a valuable indicator which expresses the percentage of all green spaces in the city as a percentage of total land area (Wu, 1990). The parameter was calculated as follows:

$$RGS = \frac{S_{Green\ area}}{S_{Land\ area}}$$

Where, RGS is ratio of green spaces, $S_{Green\ area}$ is the area of green spaces, $S_{Land\ area}$ is the total land area.

NDVI, which is dependent on the chlorophyll content of plants and facilitates monitoring of vegetation change, is used to indicate the plant growth condition and spatial distribution of vegetation density (Liu and Guo, 2009; Pettorelli et al., 2005). Calculated NDVI values lie between −1.0 and +1.0, the higher the value, the greater the vegetation coverage. NDVI index is defined as:

$$NDVI = \frac{DN_{NIR} - DN_R}{DN_{NIR} - DN_R}$$

Where, DN_{NIR} is the reflectance of the near-infrared wavelength band and DN_R is the reflectance of the red wavelength band.

The patch shape index (PSI) measures the complexity of a shape by calculating its degree of deviation from a circle or square of the same area. PSI was calculated as follows:

$$S_{PSI} = \frac{P}{2\sqrt{\pi A}}$$

Where, S_{PSI} is the patch shape index, P is the patch perimeter length, A is the total area of the patch (the area of green spaces).

A PSI value closer to 1.0 is achieved when patches are more regular (circular) in shape; the higher the value, the greater the difference between the shape of the patch and a circle and, therefore, the more irregular the shape (Liu and Chen, 2000). Lower PSI values result when patches have a more regular and simpler geometry, while higher values indicate more complex patch shapes (Liu, 2000).

Mean Perimeter-Area Ratio (MPAR) can be used to describe the complexity of green patches and is calculated as follows:

$$S_{MPAR} = \frac{P}{A}$$

Where, S_{MPAR} is the mean perimeter-area ratio, P is the patch perimeter length, and A is the area of the patch. The larger the value of S_{MPAR}, the more irregular the shape of the landscape patch is.

Changes in PSI and MPAR therefore reflect dynamics associated with the complexity of the shape of green spaces (He and Zhang, 2009).

Per capita green space was also calculated to reveal the nature of the relationship between population and green spaces in the city. The Shanghai Statistical Yearbook documents the number of recreational parks and their respective areas and both parameters were recorded for the period studied. Related policy and planning documents on urban green spaces since the 1980s in China and Shanghai were reviewed, and the evolution of urban green spaces policy was explored. The Shanghai urban master plans have been updated three times since the 1980s, including the versions of 1986–2000, 1999–2020 and 2017–2035; the contents of these documents that related to green spaces were extracted and analyzed.

3. Results

3.1. Changes in green spaces and RGS in Shanghai

3.1.1. Changes of urban green spaces in the whole city

The analysis of land use and land cover data indicate that Shanghai has experienced an overall decline in the area of green spaces ('green area') between 1980 and 2015. Total green area in Shanghai decreased from 5056.7 km^2 in 1980 to 3593.5 km^2 in 2015 (Fig. 2), a reduction of almost 30%. RGS decreased from 79.75% in 1980 to 56.68% in 2015, which shows that the proportional area of green spaces in Shanghai as a whole has declined.

3.1.2. Changes of urban green spaces in the city center of Shanghai

Green spaces in the Shanghai city center decreased from 30.9 km^2 in 1980 to 2.6 km^2 in 2005 but then increased to 26.1 km^2 to 2015. The

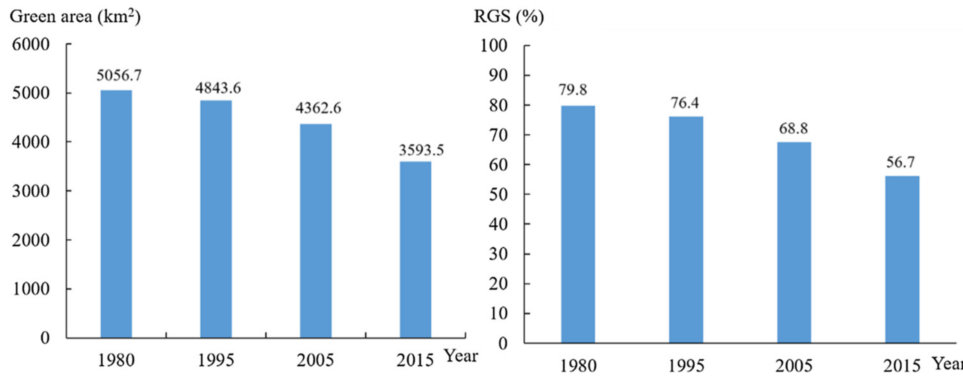

Fig. 2. Green area and RGS changes in Shanghai (entire city). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

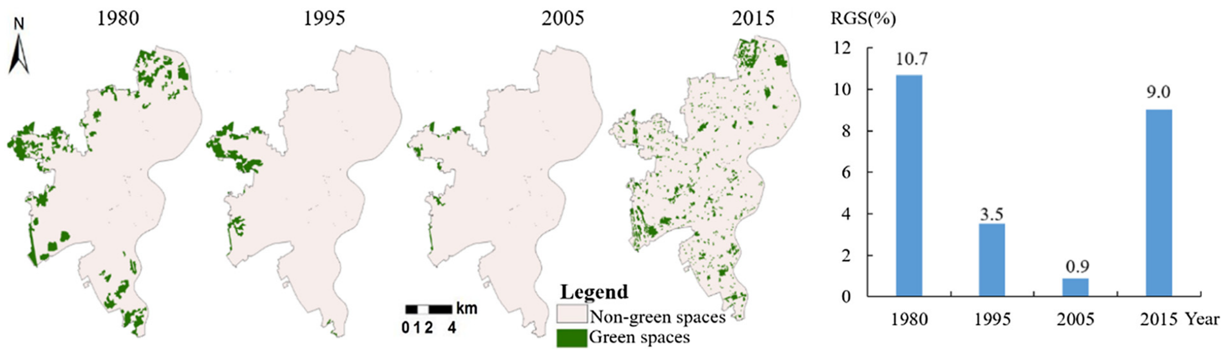

Fig. 3. Green spaces distribution and changes in RGS from 1980 to 2015 in the city center.

city center had the lowest RGS in 1980 (10.7%), declining further to 0.9% (2005), but then increased rapidly to 9.0% (2015) (Fig. 3).

3.1.3. Changes of urban green spaces in the suburbs of Shanghai

RGS in the suburbs decreased from 80.5% (1980) to 49.9% (2015). Green spaces, as indicated by RGS, have declined in Shanghai's suburbs from 3940.7 km^2 in 1980 to 3280.9 km^2 in 2005, and then to 2443.9 km^2 in 2015 (Fig. 4) as substantial areas were developed as construction and transportation land.

According to the land use and land cover data, the most striking changes occurred in the districts of Pudong, Jiading and Qingpu. RGS in Pudong decreased from 83.0% (1004.3 km^2) in 1980 to 51.9% (628.08 km^2) in 2015. The green spaces in Jiading and Qingpu districts also experienced a similar reduction trend. In these districts, RGS declined from 77.5% in 1980 to 39.0% in 2015 while the area of green spaces was reduced from 882.3 km^2 in 1980 to 444.0 km^2 in 2015.

3.1.4. Changes of urban green spaces in the islands of Shanghai

The area of green spaces on the islands increased from 1056.6 km^2 in 1980 to 1061.86 km^2 in 2015. The islands have maintained the largest RGS but, even so, experienced a decrease of 24.1% in the index over a period of 35 years (1980–2015) (Fig. 5). Although the data indicate that the area of green spaces has increased over time, RGS has in fact declined due to the rapid increase in the geographical area of Chongming Island. The island had an area of approximately 600 km^2 in 1949, but has more than doubled in size to 2016 due to a combination of large-scale land reclamation and the continued deposition of sediments from the Yangtze river (Wu, 2016). The reduced RGS over the time period means that much of the newly reclaimed area was developed for construction and transportation.

Nevertheless, Shanghai's islands have the highest RGS values of all the city zones, an observation that relates to the proposal by the Shanghai government that Chongming Island is to be developed as a global 'eco-island' and which includes wetland protection as a key element of natural ecosystem conservation (Huang et al., 2008). Notwithstanding this, the RGS decreased on the islands between 1980 and 2015. Chongming has been subject to large-scale land reclamation (Wu, 2016) and the area of wetlands/tidal flats on Chongming shrank from

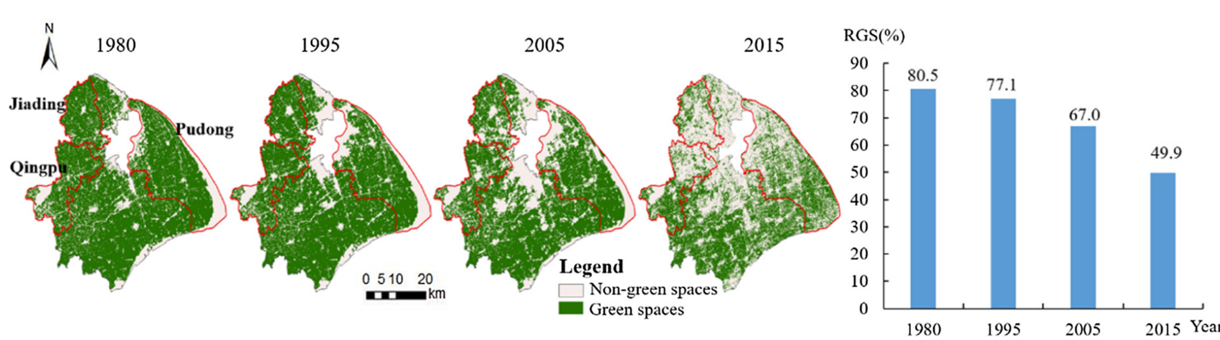

Fig. 4. Green spaces distribution and changes in RGS from 1980 to 2015 in Shanghai suburbs.

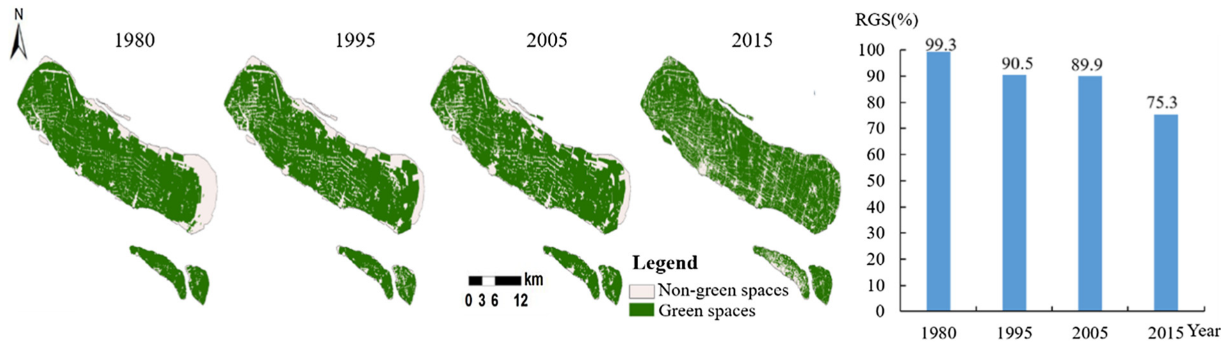

Fig. 5. The distribution of green spaces and changes in RGS from 1980 to 2015 in Chongming and associated islands.

13,432 ha in 1990 to 7915 ha in 1997, and 3856 ha in 2000; meanwhile the area of settlements increased from 4 to 107 ha (Zhao et al., 2003). These changes emphasize a decrease in the area of ecological wetlands and an increase in construction land uses (Zhao et al., 2004).

3.2. NDVI of Shanghai city and individual city zones from 1986–2015

3.2.1. NDVI in the city center

The NDVI from 1986 to 2015 was calculated to cast further light on the change of green spaces over time. In order to avoid the influence of excessive cloudiness, the images of summer (June, July, August) of 1986, 1991, 1996, 2000, 2005, 2010 and 2015 in all the sub-areas were selected. The NDVI changes in the city center document a decrease from 1986 to 1996 and an increase from 1996 to 2015, with the lowest vegetation cover in 1996 (Fig. 6).

3.2.2. NDVI in the suburbs of Shanghai

Vegetation coverage in the suburbs declined from 1986 to 2015, with the most striking changes in Pudong, Jiading and Qingpu. The decline was especially marked in the eastern coastal parts of Pudong (Fig. 7).

Due to land reclamation, the southeastern part of Pudong has shown the most dramatic changes. This area was water and wetland before 2000, but much has been reclaimed and subject to substantial urban development since.

3.2.3. NDVI in the islands of Shanghai

The NDVI of the islands has been decreasing from 1986 to 2015, and vegetation coverage was lowest in 2015 (Fig. 8), although vegetation cover in the southeastern part of Chongming Island has increased, which is related to the coastal land reclamation.

3.3. Changing landscape indices in Shanghai

Shanghai's various landscape indices illustrate the temporal and spatial evolution of green spaces in the city and indicate the nature of the relationship between landscape pattern and landscape change processes. The trends of PSI and MPAR for the city center, suburbs and the islands are similar, in all cases increasing from 1980 to 1995 and decreasing from 1995 to 2015, and both PSI and MPAR are the highest in city center from 1980 to 2005, but the islands exceeded the city center and the suburbs by 2015 (Table 1). Green spaces have become fragmented in all sub-areas of Shanghai and shifted from a trend of increase to decrease from 1980 to 2015.

The PSI and MPAR yield different values in the different zones. In the city center, PSI increased from 1.75 in 1980 to 2.68 in 1995 and then decreased to 1.19 in 2015, while MPAR values show the same trend, i.e. increasing from 1.97 in 1980 to 3.03 in 1995, and then decreasing to 1.34 in 2015. Both the suburbs and islands reveal similar trends (Table 1). Increasing PSI and MPAR values mean that patch shapes on average have become more irregular and fragmented in all the sub-areas from 1980 to 1995.

Lujiazui (121.50 °E, 31.24 °N), located in Pudong district, is the financial center of the city and is an especially informative example to reflect on the fragmentation of urban green space in Shanghai. In 2000, the district was characterized by large and continuous green spaces, but

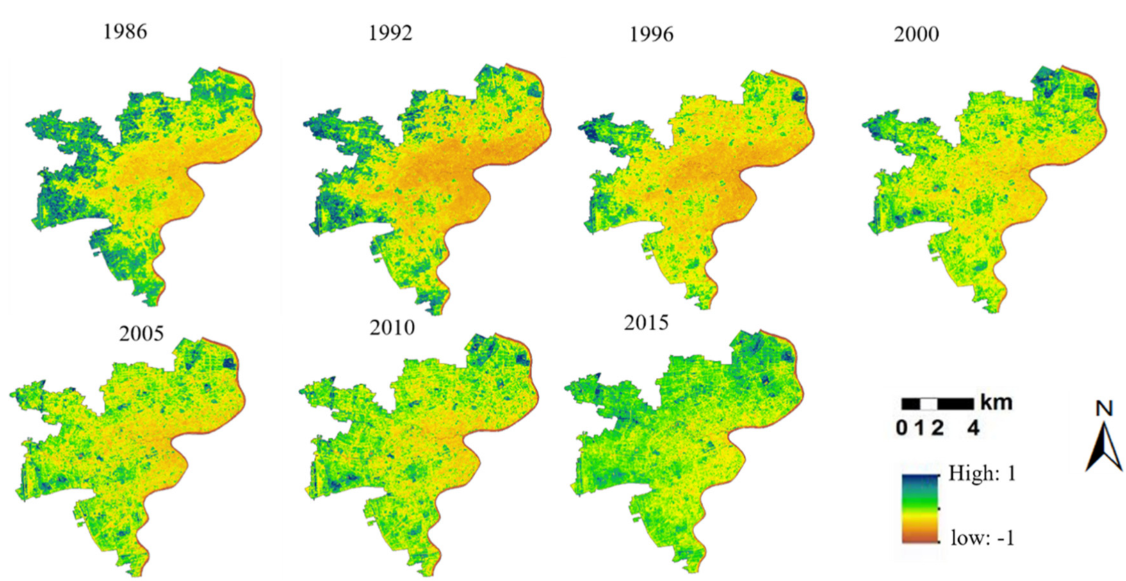

Fig. 6. NDVI in the city center from 1986 to 2015.

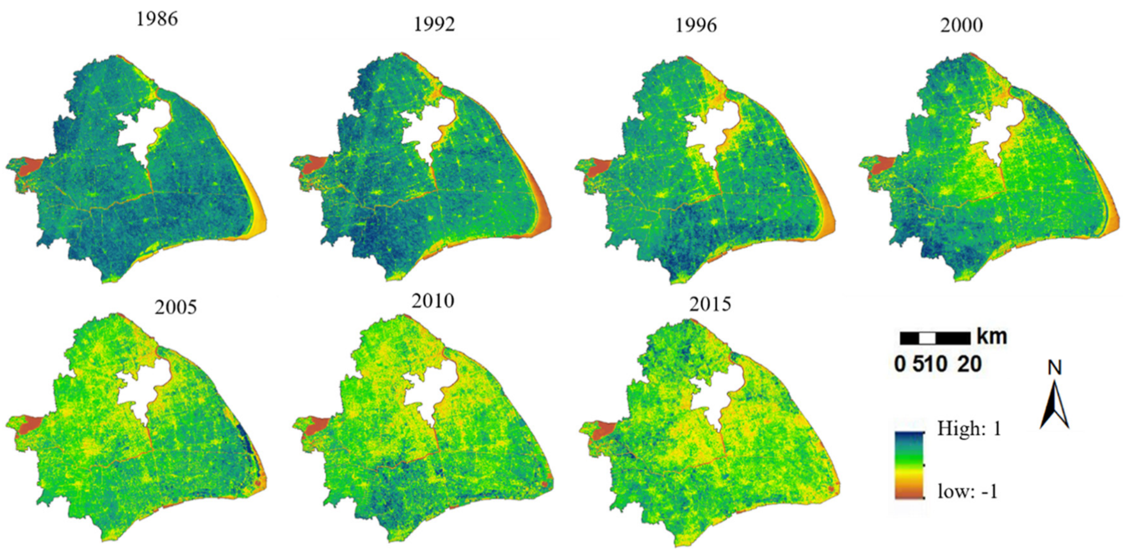

Fig. 7. NDVI in the suburbs from 1986 to 2015.

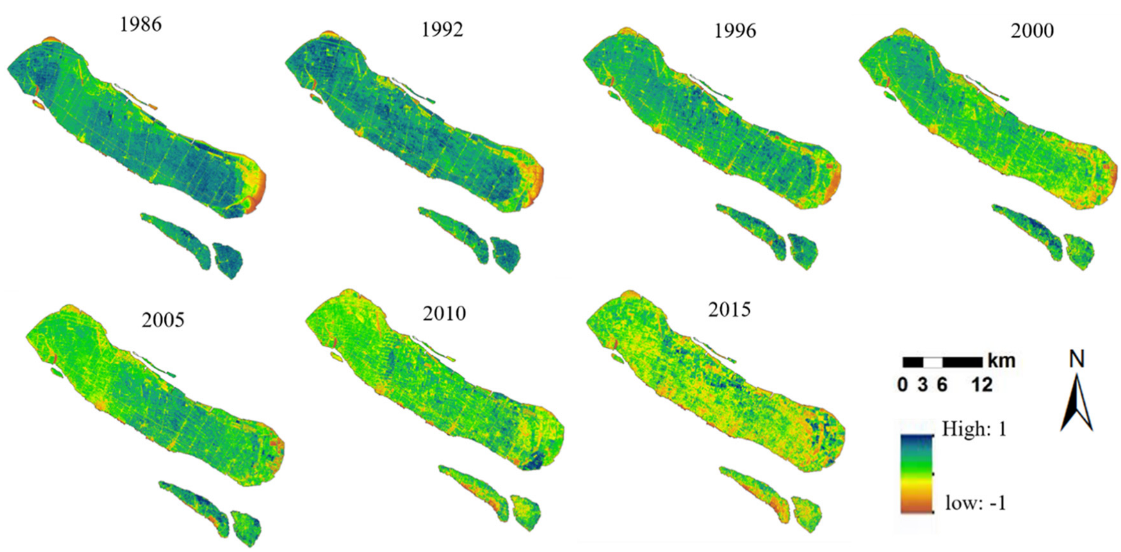

Fig. 8. NDVI in the islands from 1986 to 2015.

Table 1
Changes in landscape indices of urban green spaces in sub-areas.

Year	PSI				MPAR			
	1980	1995	2005	2015	1980	1995	2005	2015
City center	1.75	2.68	1.89	1.19	1.97	3.03	2.13	1.34
Suburbs	1.47	1.97	1.5	1.3	1.66	2.23	1.7	1.47
The islands	1.56	1.66	1.64	1.36	1.76	1.87	1.85	1.54

from this time onwards, the rapid development of Pudong new district was accompanied by a dramatic increase in the number of buildings and these green spaces became fragmented (Fig. 9).

3.4. Population and green area per capita

According to the population statistics of Shanghai, the population has increased from 11.52 million to 24.15 million between 1980 and 2015, and the population density has increased from 1862 in./km^2 (inhabitants per area) to 3809 in./km^2. The green area per capita decreased rapidly as the population increased (Fig. 10; data sourced from the Shanghai Statistical Yearbook).

Taking parks as an example of urban green space, it is notable that the number of parks in Shanghai have increased from 45 to 165 between 1980 and 2015, indicating that the government has strengthened the planning and management of this type of recreational area with the aim of improving the quality of life, especially in the city center. The 8 districts in the city center, which account for just 5.57% of the total city area, have 88 parks, representing more than half of the total number in Shanghai as a whole (Fig. 11).

Both the number and area of parks in Shanghai have been increasing since 1980, reflecting that the government has prioritized the development of green spaces, especially in the densely populated city center.

3.5. Evolution of urban green space policies in Shanghai

The Shanghai government has proposed many urban greening policies since the 1980s (Fig. 12). In 1983, the government issued the “Shanghai Landscape Greening System Plan” and the “Central City Greening System Plan” which focus on increasing green spaces along rivers, roads and parks in the city center (Shanghai Municipal Government (SMG, 1983). Between 1986 and 1998, Shanghai built a

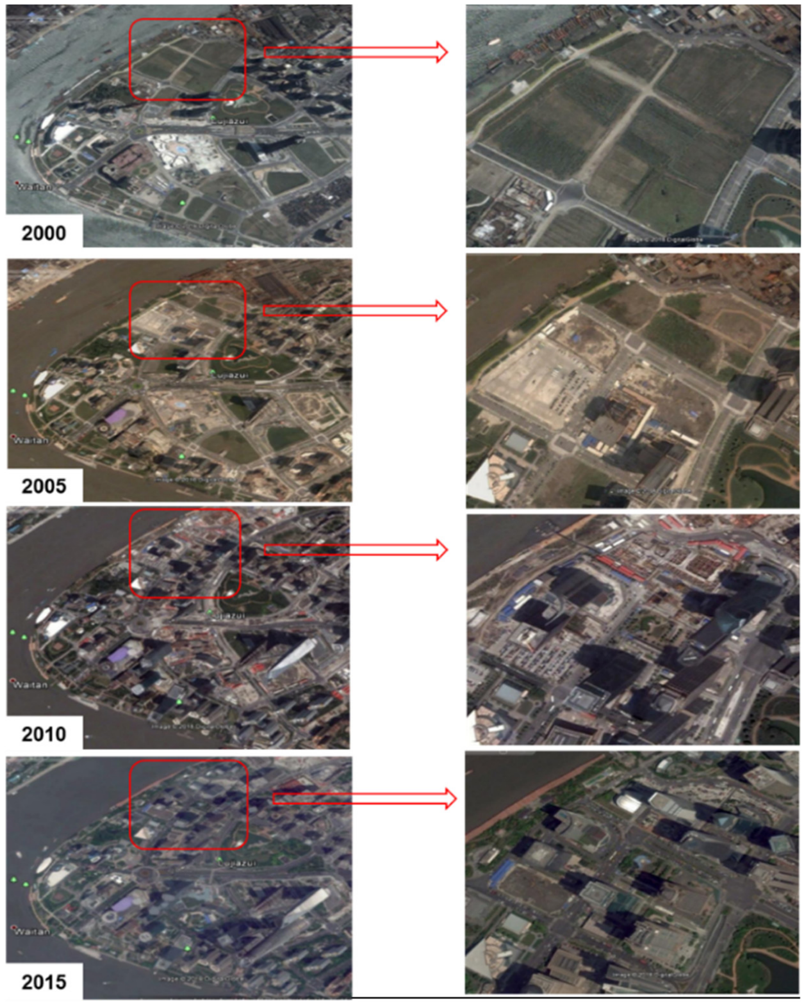

Fig. 9. The fragmentation of urban green spaces in Lujiazui (Shanghai).

green belt outside of the city center, the Lujiazui Center Green Space, Huangpu riverside promenade, and several recreational parks. In 1994, Shanghai issued the “Urban Green Spaces System Planning Program (1994–2010)” which has proposed a "Central City Public Green Spaces Plan" and formed a "Ring, Wedge, Gallery, Garden" spatial pattern (Shanghai Municipal Government (SMG, 1994), which not only aimed at improving the urban environment and enhancing urban health, but also meeting the requirement to reduce noise and air pollution on both

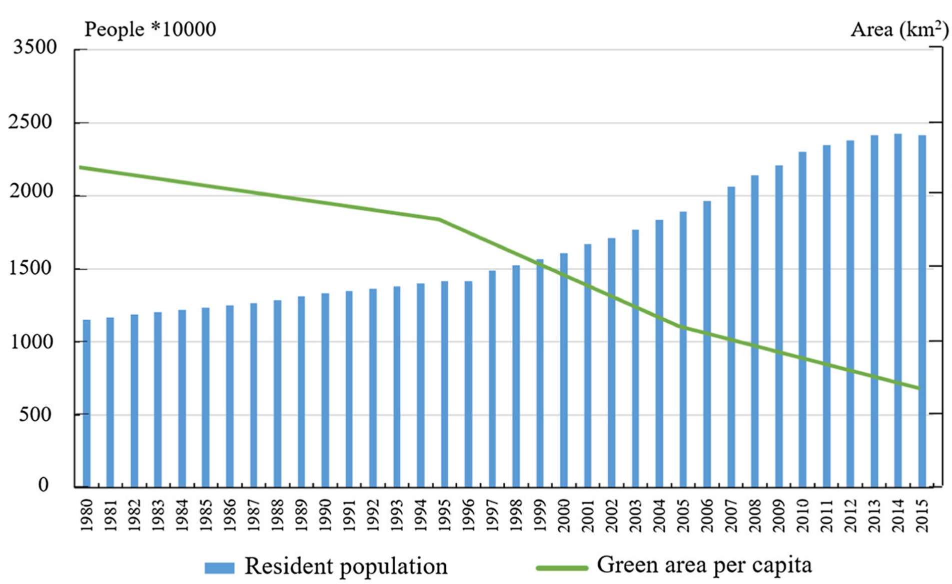

Fig. 10. The population and green area per capita in Shanghai (entire city).

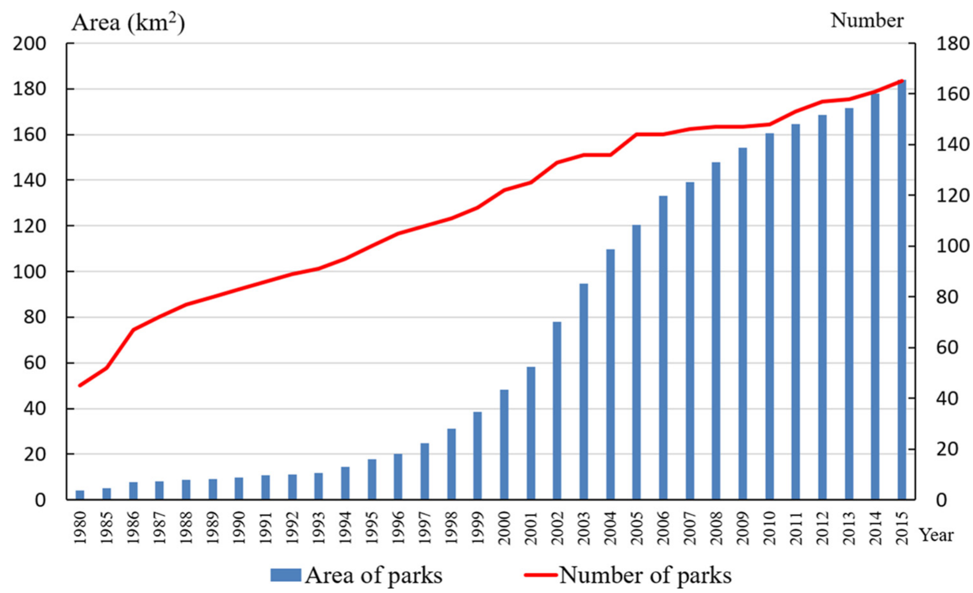

Fig. 11. The number and area of parks in Shanghai (entire city).

sides of major roads. Between 1983 and 1994, urban green space system planning was implemented, and more attention was paid to the connectivity of green spaces. Since 2002, the Shanghai government has aimed at creating an urban environment that promotes more harmonious interactions between people and nature (Shanghai Municipal Government (SMG, 2002a). The concept has also shifted from “green spaces in the city” to “the city within green spaces”. The former only recognized green spaces as a land use type, however, while the later conceptualized green space as an integrated system that supports the function of the city. The “Shanghai Land Use Master Plan (2006–2020)” designed a multi-level ecological land use structure in Shanghai (Shanghai Municipal Government (SMG, 2008). In 2010, the government proposed a “Basic Ecological Network Plan” which defined the area and spatial configuration of parks, forest and wetland, and delineated an eco-line to restrict the urban build-up development (Shanghai Municipal Government (SMG, 2010).

Along with the national policy and action on environmental protection, including the concepts of “Ecological Civilization”, “Green Development” and "Ecological Red Line" which are emphasized by China’s central government as an umbrella for future development, the green spaces received increasing attention. In the latest urban master plan (2017–2035), 23% forest coverage is planned throughout Shanghai by 2035, and per capita park space is expected to be increased to 13 m^2, while the city is envisioned to become a more sustainable eco-city (Shanghai Municipal Government (SMG, 2018). These policies have all contributed to the observed changes in Shanghai's green spaces. Governments at different administrative levels have recognized the importance of green space and include it specifically in land use and urban development plans. The implementation of the eco-island plan of Chongming island is a good example of this. The plan requires forest cover to reach 35%, an increase in natural wetland from 38% to 45%, and per capita park area to be raised from 6.8 m^2 to 20 m^2.

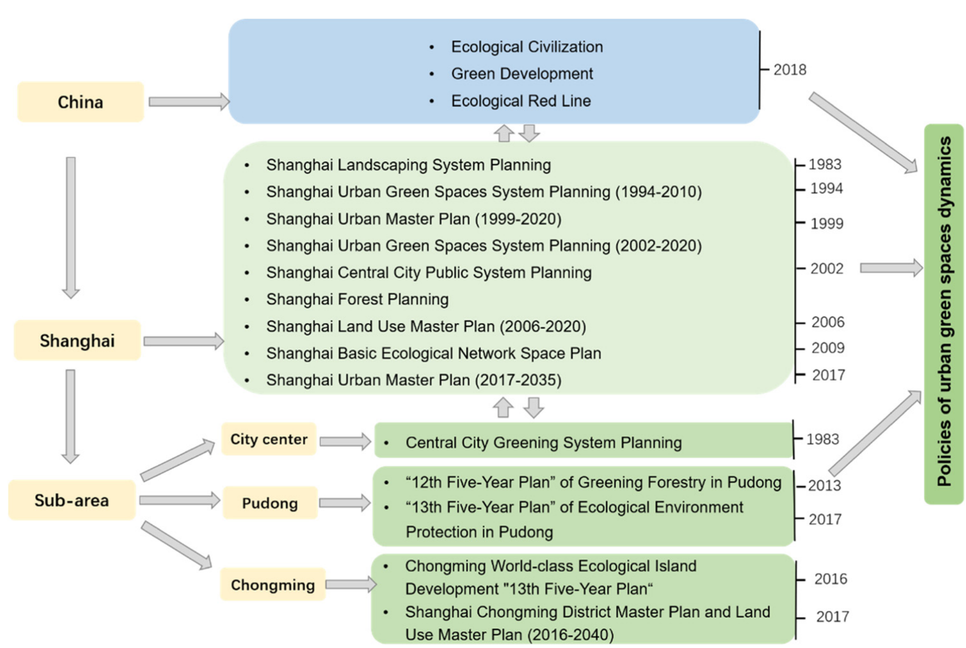

Fig. 12. Policies evolution on urban green spaces from 1983 to 2018.

4. Discussion

4.1. Spatio-temporal trends of urban green spaces

Urban green space plays important roles in urban areas, thus understanding its pattern and trajectory can help urban planning and human well-being. The land classification used in this paper illustrates the temporal and spatial evolution of Shanghai's green space. The RGS and NDVI changes in Shanghai shows that there has been a decline in green spaces from 1980 to 2015, which has been experienced in other cities as urbanization has increased. Such a pattern is common, and has been widely reported. For example, urban green spaces in Beijing (China), Macau, Hong Kong (China), Kuala Lumpur (Malaysia), Hanoi (Vietnam) and Karachi (Pakistan) have all decreased in recent decades (Xu et al., 2011; Ye et al., 2018; Jim, 2005; Akmar et al., 2011; Uy and Nakagoshi, 2007; Qureshi et al., 2010). Green space in central parts of some cities is the lowest and characteristically less than in the suburbs (You, 2016; Jiang et al., 2018). However, both the number and area of parks in Shanghai have been increasing from 1980 to 2015. This reflects the implementation of the greening policies, indicating that the government's management and planning of green space has increased. The spatial and temporal trends of green spaces differ between the city center, suburbs and islands of Shanghai. This variation has been measured through different parameters such as population density, development stage, time frame to construct residential zones, and the socioeconomic status of these residents (Xiao et al., 2017; Barrera et al., 2016; Haaland and van den Bosch, 2015).

Interpretation of remote sensing images can provide an understanding of the changing pattern and process of urban green spaces, although a detailed analysis needs to examine the dynamics of different green spaces types and integrate different sources of data, including government statistics, planning documents and historical maps. Comparing green space trends in different cities casts light on the degree to which there is a transition towards more sustainable cities and may assist planners to develop greener cities.

4.2. Fragmentation of green spaces in Shanghai

An increasing rate of urbanization is predicted in China (Chen et al., 2013; He et al., 2016; Song and Ding, 2007). Urban expansion and sprawl have led to a reduction in natural or semi-natural vegetation around the city center and the suburbs (Johnson, 2001). Between 1990 and 2010, urbanization in China was characterized by exponential growth as the urban built-up area increased by more than 2.3 times, most notably in the southeast coastal regions of the country (Wang et al., 2012). The area of green spaces has decreased and/or become fragmented due to the rapid pace of urbanization, which is associated with increased population pressure on resources and a concomitant increase in buildings and infrastructure. However, with improvement in living standards due to China's rapid economic growth, the environmental consciousness of urban inhabitants has gradually strengthened such that the focus of city governments has shifted from being solely GDP-oriented to one in which the quality of life plays a more prominent role in planning and the development of new green spaces (Kong and Nakagoshi, 2006). The demand for housing arising from the growing urban population, coupled with improved living standards, has resulted in conflicts between land use for urban construction and green spaces. Green spaces are consumed during urban development, or may only be incorporated into suitable gaps within the constructed land, resulting in their fragmentation (Fig. 13). However, when both government and the population of the city embrace the importance of urban green space, transformation to a 'city in the forest' may occur.

4.3. Understanding the driving policies on urban green spaces dynamics

Driving forces underlying the change in urban green spaces are diverse (Zhao et al., 2013) as their evolving distribution and structure are related to the combined effects of population growth and the implementation of urban greening policies (Yang et al., 2014). Population growth places pressure on urban infrastructure, and green spaces are sacrificed to make way for buildings and other infrastructure (Byomkesh et al., 2012). This has been confirmed in Hong Kong (Jim, 2005), Islamic Mahaud (Rafiee et al., 2009) and Dhaka (Byomkesh et al., 2012). However, population growth is not the only cause of the decline in green spaces (Xu et al., 2011), since institutional factors, such as the implementation of a development vision or spatial zoning master plan (for example the Shanghai Master Plan (1999–2020)(Shanghai Municipal Government (SMG, 2002b), can also contribute (Fan et al., 2017).

In general, greening policies are major drivers of green spaces recovery in cities (Yang et al., 2014).and strategic greening policies can lead to a substantial increase in green spaces in cities (Davies and Lafortezza, 2017; Harris et al., 2018; Tan et al., 2013; Zhou and Wang, 2011). Many cities around the world have proposed so-called green development as a means to maintaining the balance of environmental protection and socioeconomic development (Huo and Liu, 2011). Such government policies have also enabled urban residents to appreciate the benefits of green spaces. China has leveraged control over the supply of land to encourage urban greening (Wolch et al., 2014) and is prioritizing eco-city development. Under this framework, the Shanghai government has initiated policies and measures to maintain the balance between urbanization development and residents' demand for green spaces. These policies are intended to provide guidelines for Shanghai's green spaces development, and expanded the government's management and planning of green spaces from the city center to the entire city (Liu et al., 2007). However, the suburbs are often a focus of new development with subsequent negative impacts on green spaces (Xu et al., 2011). For example, the area of green spaces decreased in Pudong after 1980 mainly due to the construction of ports, the international airport and widespread real estate development. Given the potentially vulnerable coastal location of the city as a whole, it is important to have an appropriately green and ecological 'defense' to secure sustainable development (Ma et al., 2018). In 2016, the Shanghai government set a goal of building a world-class Chongming eco-island (Shanghai Municipal Government (SMG, 2016a, 2016b), and proposed to develop the island as a kind of global icon with the aim of developing an ecologically sustainable environment, balanced resource utilization and high human settlement quality (Shanghai Chongming District Government (SCDG, 2017). These policies are important driving forces for green space dynamics, and are aimed at avoiding further losses of green spaces in Shanghai.

5. Conclusion

Green space plays an important role on the quality of life and urban health, and there is growing interest in understanding its spatial pattern and temporal dynamics to plan for the urban future. The present study combines land use and land cover data and statistical yearbook data to illustrate temporal and spatial changes of such green spaces in Shanghai. Although the area of green spaces has decreased in the last three decades, there is a transition from a net loss to a net gain of green spaces in the city center of Shanghai, and the shape and distribution of green spaces has become more regular and less fragmented. Remote sensing, used in conjunction with data from other sources can be integrated as powerful tools to validate and understand the trend of green spaces change in cities. This study offers insights as to how the temporal and spatial evolution of green spaces can inform urban planning and, in so doing, offers a perspective for other cities that have experienced similarly rapid expansion. Urban governments should plan the development and preservation of an urban green spaces network at an early stage to avoid the substantial environmental and health costs associated with rapid urbanization and to circumvent the additional financial

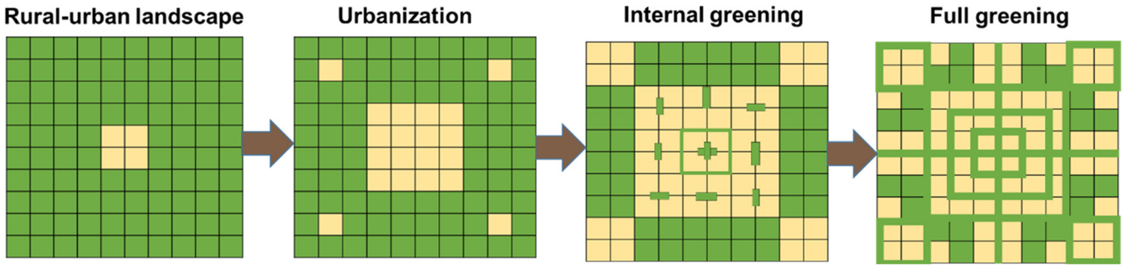

Fig. 13. The process of fragmentation of urban green spaces.

burdens of subsequent regeneration. The methods employed in the analysis of changing urban green spaces in Shanghai can be applied in other cities to promote more effective and equitable planning of urban green spaces. Our research highlights the immediate need for governments to develop careful planning and strategic interventions for green spaces to improve quality of life for urban residents.

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References

Akmar, A.N., Konijnendijk, C., Sreetheran, M., Nilsson, K., 2011. Greenspace planning and management in Klang valley, Peninsular Malaysia. Arboric. Urban For. 37 (3), 99–107.
Anguluri, R., Narayanan, P., 2017. Role of green space in urban planning: outlook towards smart cities. Urban For. Urban Greenn. 25, 58–65. https://doi.org/10.1016/j.ufug.2017.04.007.
Baur, J.W., Tynon, J.F., Gómez, E., 2013. Attitudes about urban nature parks: a case study of users and nonusers in Portland, Oregon. Landscape Urban Plann. 117, 100–111. https://doi.org/10.1016/j.landurbplan.2013.04.015.
Barrera, F.D.L., Reyes-Paecke, S., Banzhaf, E., 2016. Indicators for green spaces in contrasting urban settings. Ecol. Indic. 62, 212–219. https://doi.org/10.1016/j.ecolind.2015.10.027.
Byomkesh, T., Nakagoshi, N., Dewan, A.M., 2012. Urbanization and green space dynamics in Greater Dhaka, Bangladesh. Landscape Ecol. Eng. 8 (1), 45–58. https://doi.org/10.1007/s11355-010-0147-7.
Chen, M., Liu, W., Tao, X., 2013. Evolution and assessment on China's urbanization 1960–2010: under-urbanization or over-urbanization? Habitat Int. 38, 25–33. https://doi.org/10.1016/j.habitatint.2012.09.007.
Cheung, A.K.L., Brierley, G., O'sullivan, D., 2016. Landscape structure and dynamics on the Qinghai-Tibetan Plateau. Ecol. Modell. 339, 7–22. https://doi.org/10.1016/j.ecolmodel.2016.07.015.
Davies, C., Lafortezza, R., 2017. Urban green infrastructure in Europe: is greenspace planning and policy compliant? Land Use Policy 69, 93–101. https://doi.org/10.1016/j.landusepol.2017.08.018.
Fan, P., Xu, L., Yue, W., Chen, J., 2017. Accessibility of public urban green space in an urban periphery: the case of Shanghai. Landscape Urban Plann. 165, 177–192. https://doi.org/10.1016/j.landurbplan.2016.11.007.
Fang, J., Piao, S., Field, C.B., Pan, Y., Guo, Q., Zhou, L., Peng, C., Tao, S., 2003. Increasing net primary production in China from 1982 to 1999. Front. Ecol. Environ. 1, 293–297. https://doi.org/10.1890/1540-9295.
Gupta, A.K., Nair, S.S., 2011. Urban floods in Bangalore and Chennai: risk management challenges and lessons for sustainable urban ecology. Curr. Sci. (Bangalore) 100, 1638–1645. http://www.jstor.org/stable/24077767.
Haaland, C., van den Bosch, C.K., 2015. Challenges and strategies for urban green-space planning in cities undergoing densification: a review. Urban For. Urban Greening 14 (4), 760–771. https://doi.org/10.1016/j.ufug.2015.07.009.
Harris, V., Kendal, D., Hahs, A.K., Threlfall, C.G., 2018. Green space context and vegetation complexity shape people's preferences for urban public parks and residential gardens. Landscape Res. 43 (1), 150–162. https://doi.org/10.1080/01426397.2017.1302571.
He, C., Chen, T., Mao, X., Zhou, Y., 2016. Economic transition, urbanization and population redistribution in China. Habitat Int. 51, 39–47. https://doi.org/10.1016/j.habitatint.2015.10.006.
He, P., Zhang, H.R., 2009. Study on factor analysis and selection of common landscape metrics. For. Sci. Res. 22, 470–474 (In Chinese).
Hernández-Moreno, Ángela., Reyes-Paecke, Sonia., 2018. The effects of urban expansion on green infrastructure along an extended latitudinal gradient (23°S–45°S) in Chile over the last thirty years. Land Use Policy 79, 725–733. https://doi.org/10.1016/j.landusepol.2018.09.008.
Huang, B., Ouyang, Z., Zheng, H., Zhang, H., Wang, X., 2008. Construction of an eco-island: a case study of Chongming Island, China. Ocean Coastal Manage. 51 (8–9), 575–588. https://doi.org/10.1016/j.ocecoaman.2008.06.007.
Huang, L., Wu, J., Yan, L., 2015. Defining and measuring urban sustainability: a review of indicators. Landscape Ecol. 30 (7), 1175–1193. https://doi.org/10.1007/s10980-015-0208-2.
Huo, Y., Liu, T., 2011. Eco-economic Construction: the path choice for green development in China. Ecol. Economy 10, 63–64 (In Chinese).
James, P., Tzoulas, K., Adams, M.D., Barber, A., Box, J., Breuste, J., Elmqvist, T., Frith, M., Gordon, C., Greening, K.L., Handley, J., Haworth, S., Kazmierczak, A.E., Johnston, M., Korpela, K., Moretti, M., Niemelä, J., Pauleit, S., Roe, M.H., Sadler, J.P., Ward Thompson, C., 2009. Towards an integrated understanding of green space in the European built environment. Urban For. Urban Greening 8, 65–75. https://doi.org/10.1016/j.ufug.2009.02.001.
Jiang, Y., Hou, L., Shi, T., Ning, Y., 2018. Spatial zoning strategy of urbanization based on urban climate Co-movement: a case study in Shanghai Mainland Area. Sustainability 10, 2706.
Jim, C., 2005. Monitoring the performance and decline of heritage trees in urban Hong Kong. J. Environ. Manage. 74 (2), 161–172. https://doi.org/10.1016/j.jenvman.2004.08.014.
Johnson, M.P., 2001. Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environ. Plan. A 33 (4), 717–735. https://doi.org/10.1068/a3327.
Kong, F., Nakagoshi, N., 2006. Spatial-temporal gradient analysis of urban green spaces in Jinan, China. Landscape Urban Plann. 78 (3), 147–164. https://doi.org/10.1016/j.landurbplan.2005.07.006.
Liu, B., Wen, Q., Liu, S., 2007. Planning analysis and optimization strategies of shanghai green space system. Urban Plann. Forum 4, 108–112. https://doi.org/10.3969/j.issn.1000-3363.2007.04.016.
Liu, C., Chen, L., 2000. Analysis of the patch shape with shape indices for the vegetation landscape in Beijing. J. Ecol. 20 (4), 559–567. https://doi.org/10.3321/j.issn:1000-0933.2000.04.005. (In Chinese).
Liu, J., Zhan, J., Deng, X., 2005. Spatio-temporal patterns and driving forces of urban land expansion in China during the economic reform era. AMBIO: J. Hum. Environ. 34, 450–455. https://doi.org/10.1579/0044-7447-34.6.450.
Liu, X., 2000. Shape index and its ecological significance in salinized meadow landscape. Pratacultural Sci. 17 (1), 50–56 (In Chinese).
Liu, Y., Guo, J., 2009. The research of NDVI-based urban green space landscape pattern and thermal environment. Prog. Geogr. 28 (5), 798–804.
Ma, X., de Jong, M., den Hartog, H., 2018. Assessing the implementation of the Chongming Eco Island policy: what a broad planning evaluation framework tells more than technocratic indicator systems. J. Clean. Prod. 172, 872–886. https://doi.org/10.1016/j.jclepro.2017.10.133.
Nor, A.N.M., Corstanje, R., Harris, J.A., Brewer, T., 2017. Impact of rapid urban expansion on green space structure. Ecol. Indic. 81, 274–284. https://doi.org/10.1016/j.ecolind.2017.05.031.
Pauleit, S., Ennos, R., Golding, Y., 2005. Modeling the environmental impacts of urban land use and land cover change—a study in Merseyside, UK. Landscape urban plann. 71 (2-4), 295–310. https://doi.org/10.1016/j.landurbplan.2004.03.009.
Pettorelli, N., Vik, J.O., Mysterud, A., Gaillard, J.M., Tucker, C.J., Stenseth, N.C., 2005. Using the satellite-derived ndvi to assess ecological responses to environmental change. Trends Ecol. Evol. 20 (9), 503–510.
Qureshi, S., Kazmi, Hasan, Breuste, S.J., Jürgen, H., 2010. Ecological disturbances due to high cutback in the green infrastructure of karachi: analyses of public perception about associated health problems. Urban For. Urban Greening 9 (3), 187–198. https://doi.org/10.1016/j.ufug.2009.08.003.
Rafiee, R., Mahiny, A.S., Khorasani, N., 2009. Assessment of changes in urban green spaces of Mashad city using satellite data. Int. J. Appl. Earth Obs. Geoinf. 11 (6), 431–438. https://doi.org/10.1016/j.jag.2009.08.005.
Santamouris, M., 2014. Cooling the cities–a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Sol. Energy 103, 682–703. https://doi.org/10.1016/j.solener.2012.07.003.
Seto, K.C., Güneralp, B., Hutyra, L.R., 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proc. Natl. Acad. Sci. 109 (40), 16083–16088. https://doi.org/10.1073/pnas.1211658109.
Shanghai Chongming District Government (SCDG), 2017. Shanghai Chongming District Master Plan and Land Use Master Plan (2016–2040). https://www.supdri.com/2035/public/ebook05/.
Shanghai Municipal Government (SMG), 2016a. The 13th Five-Year Plan for

Environmental Protection and Ecological Construction in Shanghai. http://www.shanghai.gov.cn/nw2/nw2314/nw2319/nw12344/u26aw50076.html.
Shanghai Municipal Government (SMG), 1983. Shanghai Landscape Greening System Plan.
Shanghai Municipal Government (SMG), 1994. Shanghai Landscape Greening System Plan (1994–2010).
Shanghai Municipal Government (SMG), 2002a. Shanghai Urban Green Spaces System Plan (2002–2020). http://www.yuanlin.com/rules/Html/Detail/2006-4/462.html.
Shanghai Municipal Government (SMG), 2002b. Shanghai Master Plan 1999–2020. http://www.shanghai.gov.cn/nw2/nw2314/nw2319/nw10800/nw11407/nw12941/u26aw1100.html.
Shanghai Municipal Government (SMG), 2008. Shanghai Land Use Master Plan (2006–2020). http://www.pudong.gov.cn/shpd/InfoOpen/InfoDetail.aspx?Id=898779.
Shanghai Municipal Government (SMG), 2010. Shanghai Basic Ecological Network Plan (2006–2020). http://www.pudong.gov.cn/shpd/InfoOpen/InfoDetail.aspx?Id=898779.
Shanghai Municipal Government (SMG), 2016b. Chongming World-class Ecological Island Development “13th Five-Year Plan”. http://www.shanghai.gov.cn/nw2/nw2314/nw2319/nw12344/u26aw50776.html.
Shanghai Municipal Government (SMG), 2018. Shanghai Master Plan 2017–2035. http://www.shanghai.gov.cn/newshanghai/xxgkfj/2035004.pdf.
Shanghai Municipal Statistics Bureau (SMSB), 2018. Shanghai Statistical Yearbook 2018. China Statistics Press, Beijing.
Song, Y., Ding, C., 2007. Urbanization in China: critical issues in an era of rapid growth. Lincoln Institute of Land Policy 302.
Tan, P.Y., Wang, J., Sia, A., 2013. Perspectives on five decades of the urban greening of Singapore. Cities 32, 24–32. https://doi.org/10.1016/j.cities.2013.02.001.
Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., James, P., 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: a literature review. Landscape Urban Plann. 81 (3), 167–178. https://doi.org/10.1016/j.landurbplan.2007.02.001.
UN Habitat, 2016. Urbanization and development: Emerging futures. UN Habitat World Cities Report 2016. Retrieved from. . http://wcr.unhabitat.org/main-report/.
Uy, P.D., Nakagoshi, N., 2007. Analyzing urban green space pattern and eco-network in Hanoi, Vietnam. Landscape Ecol. Eng. 3 (2), 143–157. https://doi.org/10.1007/s11355-007-0030-3.
Wang, L., Li, C., Ying, Q., Cheng, X., Wang, X., Li, X., Hu, L., Liang, L., Yu, L., Huang, H., 2012. China’s 1990–2010 urban expansion satellite remote sensing mapping. Chinese Sci. Bull. 57 (16), 1388–1399. https://doi.org/10.1007/s11434-012-5235-7.
Wolch, J.R., Byrne, J., Newell, J.P., 2014. Urban green space, public health, and environmental justice: the challenge of making cities ‘just green enough’. Landscape. Urban Plann. 125, 234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017.
Wu, Y., 1990. "Ratio of green spaces" - Landscaping index worth promoting. Chinese garden 6 (2), 43 (In Chinese).
Wu, Y., 2016. Chongming reclamation chronicle. Spring and Autumn Files 4, 59–61 (In Chinese).
Xiao, Y., Wang, Z., Li, Z., Tang, Z., 2017. An assessment of urban park access in shanghai – implications for the social equity in urban china. Landscape. Urban Plann. 157, 383–393. https://doi.org/10.1016/j.landurbplan.2016.08.007.
Xiao, Y., Zhang, J., Ma, Y., Wang, J., 2015. Landscape pattern and scale effect of Yellow River Estuarine wetland based on ZY-3 Satellite. Mar. Sci. 39 (2), 35–42 (In Chinese).
Xu, X., Duan, X., Sun, H., Sun, Q., 2011. Green space changes and planning in the capital region of China. Environ. Manage. 47 (3), 456–467. https://doi.org/10.1007/s00267-011-9626-3.
Yan, L., 2003. Sustainable development and urban greening. Chinese garden 19 (5), 44–47 (In Chinese).
Yang, G., Wu, Z., Wu, W., 2010. Dynamic change of Hefei urban forest pattern. J. Anhui Agric. Univ. 37 (3), 529–534 (In Chinese).
Yang, J., Huang, C., Zhang, Z., Wang, L., 2014. The temporal trend of urban green coverage in major Chinese cities between 1990 and 2010. Urban For. Urban Greenn. 13 (1), 19–27. https://doi.org/10.1016/j.ufug.2013.10.002.
Ye, C., Hu, L., Li, M., 2018. Urban green space accessibility changes in a high-density city: a case study of Macau from 2010 to 2015. J. Transp. Geogr. 66, 106–115. https://doi.org/10.1016/j.jtrangeo.2017.11.009.
You, H., 2016. Characterizing the inequalities in urban public green space provision in Shenzhen, China. Habitat Int. 56, 176–180. https://doi.org/10.1016/j.habitatint.2016.05.006.
Zhao, B., Kreuter, U., Li, B., Ma, Z., Chen, J., Nakagoshi, N., 2004. An ecosystem service value assessment of land-use change on Chongming Island, China. Land Use Policy 21 (2), 139–148. https://doi.org/10.1016/j.landusepol.2003.10.003.
Zhao, B., Li, B., Ma, Zj., Chen, Jk., Nakagoshi, N., 2003. Wise exploitation of newly growing land resources. Chin. Geogr. Sci. 13 (2), 134–141. https://doi.org/10.1007/s11769-003-0007-6.
Zhao, J., Chen, S., Jiang, B., Ren, Y., Wang, H., Vause, J., Yu, H., 2013. Temporal trend of green space coverage in China and its relationship with urbanization over the last two decades. Sci. Total Environ. 442, 455–465. https://doi.org/10.1016/j.scitotenv.2012.10.014.
Zhou, H., Ding, J., Xu, Y., Huang, J., Yang, W., Fang, Y., 2002. The monitoring and evaluation of relation between heat island effect and greenbelt distribution Shanghai urban area. J. Shanghai Agric. Sci. 18 (2), 83–88. https://doi.org/10.3969/j.issn.1000-3924.2002.02.020. (In Chinese).
Zhou, X., Wang, Y.C., 2011. Spatial–temporal dynamics of urban green space in response to rapid urbanization and greening policies. Landscape Urban Plann. 100 (3), 268–277. https://doi.org/10.1016/j.landurbplan.2010.12.013.