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MASTER'S FINAL THESIS

MONITORING THE SPATIAL-TEMPORAL DYNAMICS OF URBAN GREEN SPACE IN SHANGHAI FROM 2000 TO 2020 WITH REMOTE SENSING DATA

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1. Abstract

Urbanization is an important process of human development and change, and is the result of economic, cultural and social development. Along with the rapid development of the global economy there has been a rapid deterioration of the ecological environment. The harmonious and sustainable development of population, resources and the environment is an important research topic in the world today, and the creation of eco-cities with resource conservation, green space and good environment is the main trend and the main goal of urban development in various countries at present.

Since the introduction of the policy of reform and opening up, Shanghai has entered a period of rapid urbanization, which has only slowed down in recent years. However, the building of an international metropolis in Shanghai has given rise to "urban diseases" such as high population density, limited land resources, deteriorating air quality, heat island effect. At the same time, the Shanghai government has adopted many policies and measures to improve environmental quality and build an eco-city. Based on this background, the aim of the article is to analyzing the temporal and spatial changes in Shanghai's urban green spaces and the differences between current situations and planning which can help to better build an ecological city.

The data for this study were obtained from major satellite data and open platforms for land cover data. An NDVI analysis was carried out based on the data obtained and compared with the official land cover data. Fragstats has also been used to analyze an overall landscape pattern index for Shanghai.

The results from the analysis show that:

1. The area of green space in Shanghai continued to decrease from 2000 to 2015 and increased from 2015 to 2020. The artificial surface area increased continuously from 2000 to 2010, especially between 2005 and 2010 when the city grew rapidly, and decreased from 2010 to 2020 when the urban growth rate tended to level off. Green space in the city centre decreases rapidly between 2000 and 2005, improves a little between 2005 and 2010, deteriorates again between 2010 and 2015, and improves considerably until 2020.

2. The comparison between the 2020 green space area calculated by GIS and the 2020 Shanghai land cover type map obtained by Copernicus Data Open Center shows that the overlap degree is 89.44%, which indicates that the protection and development of urban green space in Shanghai in the recent five years is good, and basically conforms to the planning goal.

3. Analysis of the landscape type transfer matrix reveals that a disproportionate amount of agricultural land has been transferred to built-up land, and the second largest area of water bodies transferred to built-up areas.

4. it is worth noting that the area of agricultural land, grassland and woodland used for construction has increased in recent years.

5. The analysis of the landscape pattern index reveals that there are many minor problems in Shanghai's urban development, with excessive density of urban buildings, excessive fragmentation of farmland and grassland, low landscape connectivity and irregular trends in patch shapes.

Keywords：Urbanization　Urban green space　Spatial-temporal dynamics　The shift matrix of land use　Landscape pattern

2. Introduction

2.1 Background

According to an article published by UN-Habitat, urban areas are today home to more than half of the population (UN Habitat, 2016). In addition, are responsible for more than 70% of the world's greenhouse gas emissions (Seto et al., 2014). By the middle of the century, however, the population living in cities is expected to reach around 70% (United Nations, Department of Economic and Social Affairs, 2019). The population and extent of cities will continue to grow.

The rapid growth of cities also brings with it many problems, including public safety, noise pollution, public health, traffic congestion and so on, but the most problematic of these is the urban climate. Greenhouse gases from the burning of the large amounts of fossil fuels required for industrial development and the large amounts of CO2 emitted during the construction of buildings, i.e. changes in land use, are the main causes of climate change, which is also due to rapid urbanization. In addition to global warming, inner-city areas of cities are experiencing the urban heat island effect, these phenomenas which, in addition to destroying the ecological balance, are also harmful to the psychological and physical health of people.

In addition to climate, resources are also an important challenge for humanity. A quantitative analysis of global urban resource requirements shows that the world's cities will increase their material consumption from 40 billion tones in 2010 to around 90 billion tones in 2050 if without a new approach to urbanization (Swilling, M. et al., 2014).

It is clear that protecting the environment, improving the climate and conserving resources is an urgent issue.

The development of some theoretical studies has also given us some inspiration. the World Outline for Nature Conservation, published in 1987 (Imperatives S., 1987), explicitly introduced the concept of sustainable development for the first time. Some scholars suggested that sustainable urban development is achieved through the coordinated development of material production, population production and environmental production, while environmental production is the basis of sustainable urban development, which provides environmental resources for other aspects (Ye Wenhu et al., 1997), and the relationship between the three is shown in the diagram, emphasising the importance of the link of environmental production in sustainable development.

And an important element in achieving sustainable development and building an eco-city is the construction of a complete green space system, for which the the United Nations Organization for Biosphere Ecology and Environmental Protection (OBEP) requires that urban green space coverage should reach 50%.

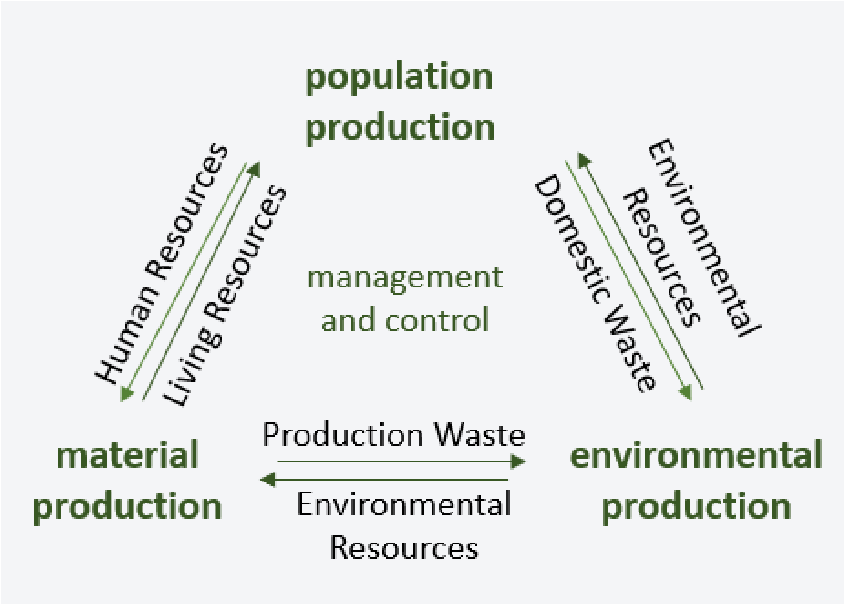


Figure 1. The relationship between material production, population production and environmental production.

Specifically in the case of Shanghai, figures 2 and 3 show the population, in-migration and GDP of Shanghai from 2000 to 2020 respectively. From 2000 to 2014, Shanghai continues to grow at a rapid rate, slowing down after 2014. And in 2020, the rate of urbanization of Shanghai is 89.3% (Shanghai Bureau of Statistics, 2001-2021).

It is evident that the rate of urban development and the level of urbanization in Shanghai is high.

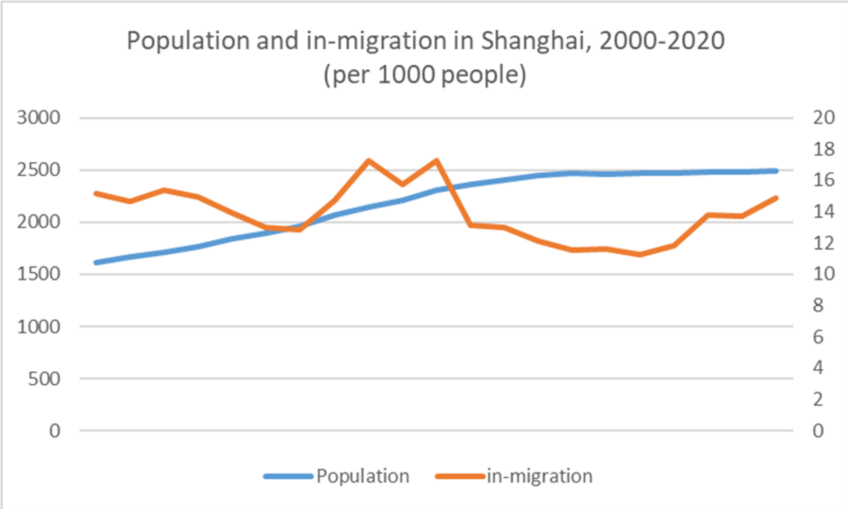


Figure 2. Population and in-migration in Shanghai from 2000 to 2020.

Source: Shanghai Statistics Bureau

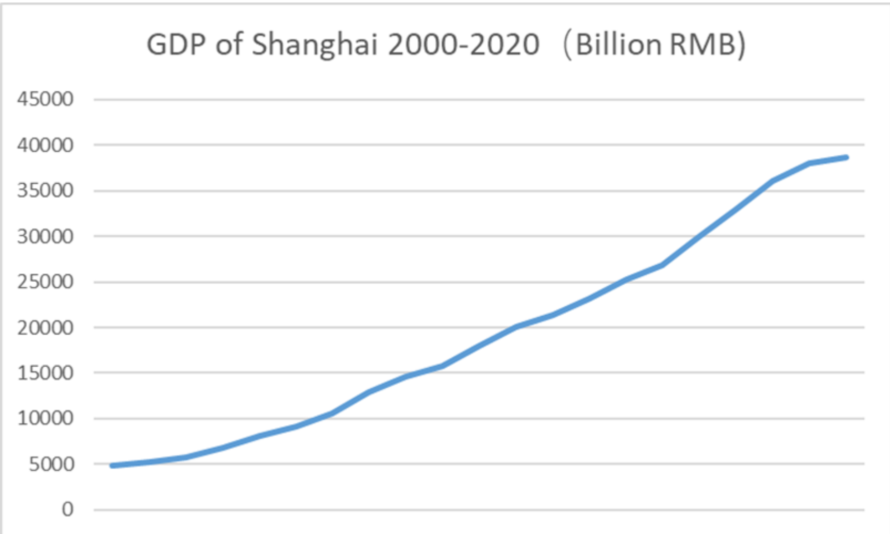


Figure 3. Gross Resident Product of Shanghai from 2000 to 2020.

Source: Shanghai Statistics Bureau

Shanghai is rapidly urbanizing and is facing many environmental and climatic problems. For this reason, the Shanghai government has been actively adjusting its urban development policy and is also paying more and more attention to the development and protection of urban green spaces.

Figure 4 summarizes the urban development policies formulated in Shanghai at different times and extracts the planning elements related to urban green spaces. Figure 5 shows the green space situation in Shanghai, including the area and coverage of green space (Shanghai Bureau of Statistics, 2001-2021).

Time	Policy name	Related contents
1994	Shanghai Urban Green Space System Planning (1994-2010)	The city center is the green core, and Pudong and Puxi develop together. Various green spaces are scattered everywhere.
2002	Shanghai Greening System Planning (2002-2020)	The centralized urbanization area takes public green space at all levels as the core, and the suburb takes large ecological forest land as the main body... to form a large urban greening cycle where "main body" interacts with "core" through "network".
2012	Shanghai's 12th Five Year Plan for Environmental Protection and Ecological Construction	Optimize the urban ecological space structure... Promote the construction of large public green spaces, wedge-shaped green spaces, and green spaces in new cities, small towns, and large residential areas, basically complete the outer ring green belt project, and start the construction of suburban green belts, central urban boulevards, and other construction projects.
2016	Shanghai's 13th Five Year Plan for Environmental Protection and Ecological Construction	Accelerate the implementation of basic ecological network planning, do everything possible to increase green rest space, and systematically promote the construction of green forest land.
2018	Shanghai Urban Master Plan (2017-2035)	Take the ecological environment requirements as the bottom line and red line of urban development, anchor the urban ecological base, and ensure that the ecological space will only increase.
2021	Shanghai Ecological Space Special Plan (2021-2035)	By 2035, ensure that the urban ecological land (including green square land) accounts for more than 60% of the

		urban land area, of which the forest coverage rate is about 23%, the per capita park green space area is expected to reach more than 13 square meters, and the per capita park green space area in the central city is expected to reach more than 7.6 square meters, and strive to achieve full coverage of the 500 meter service radius of park green space above 3000 square meters within the city's development boundary.

Figure 4. Evolution of Urban Planning Policy in Shanghai

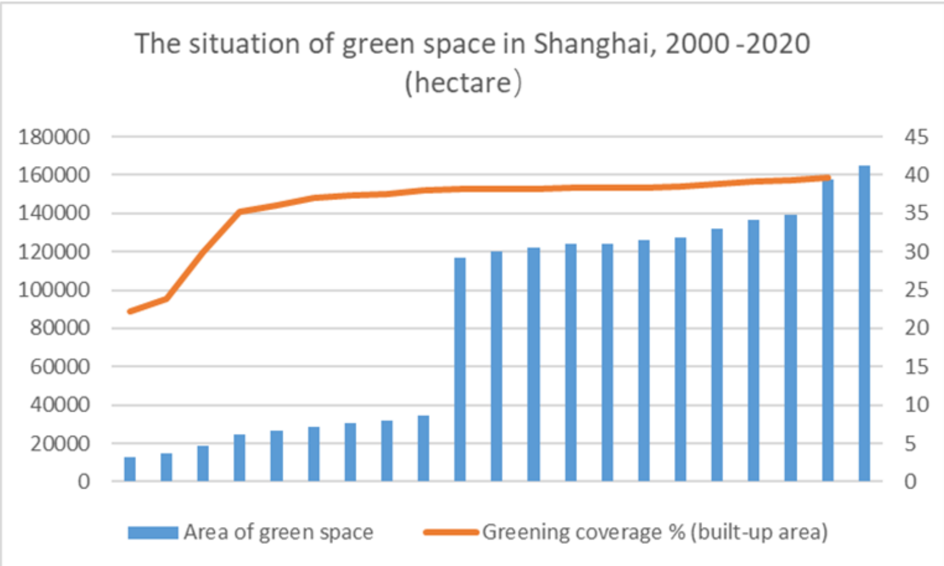


Figure 5. The situation of green space in Shanghai from 2000 to 2020

Source: Shanghai Statistics Bureau

A special note is required, Urban green space in the Statistical Yearbook from Shanghai Statistics Bureau refers to the area of all types of green space used for gardening and landscaping at the end of the reporting period. It includes the area of park green space, protective green space, subsidiary green space and other green space. Among them, park green space: green space open to the public, with recreation as the main function, with certain recreational facilities and service facilities, as well as a comprehensive function of ecological integrity, landscape beautification, disaster prevention and mitigation. It is an important part of urban construction land, urban green space system and urban municipal public facilities.

For the analysis in this paper, taking into account China's national conditions and Shanghai's climatic conditions, the definition of green space in this article is based on the concept of urban green space in the broad sense of China's Standard for Basic Garden Terminology, i.e. it refers to all kinds of green space within the urban planning area. This includes "park green space, production green space, protective green space, subsidiary green space and other green space. The green areas identified through NDVI calculations and compared with land cover are also mainly cultivated woodland and grassland.

2.2 Objective

a. General Objective

The spatial and temporal changes in urban green space in Shanghai over the past 20 years were analyzed through the acquired remote sensing image data. Compare with the green space in the current planning stage and analyze whether it fits in with the policies in the planning. An understanding of the dynamics of urban green space can help to promote a proper balance between urban development and environmental conservation.

b. Specific Objective

1. Read a large number of articles related to urban green spaces and green spaces in Shanghai to enrich the theoretical base.

2. Identify and analyse the different indicators that can be used to evaluate urban green spaces.

3. Calculate NDVI indicators and generate corresponding images by processing and analysing remote sensing images to produce corresponding results and analyse the spatial and temporal evolution of urban green spaces in Shanghai as well as the spatial and temporal evolution of man-made surfaces, with a separate analysis for the city centre area.

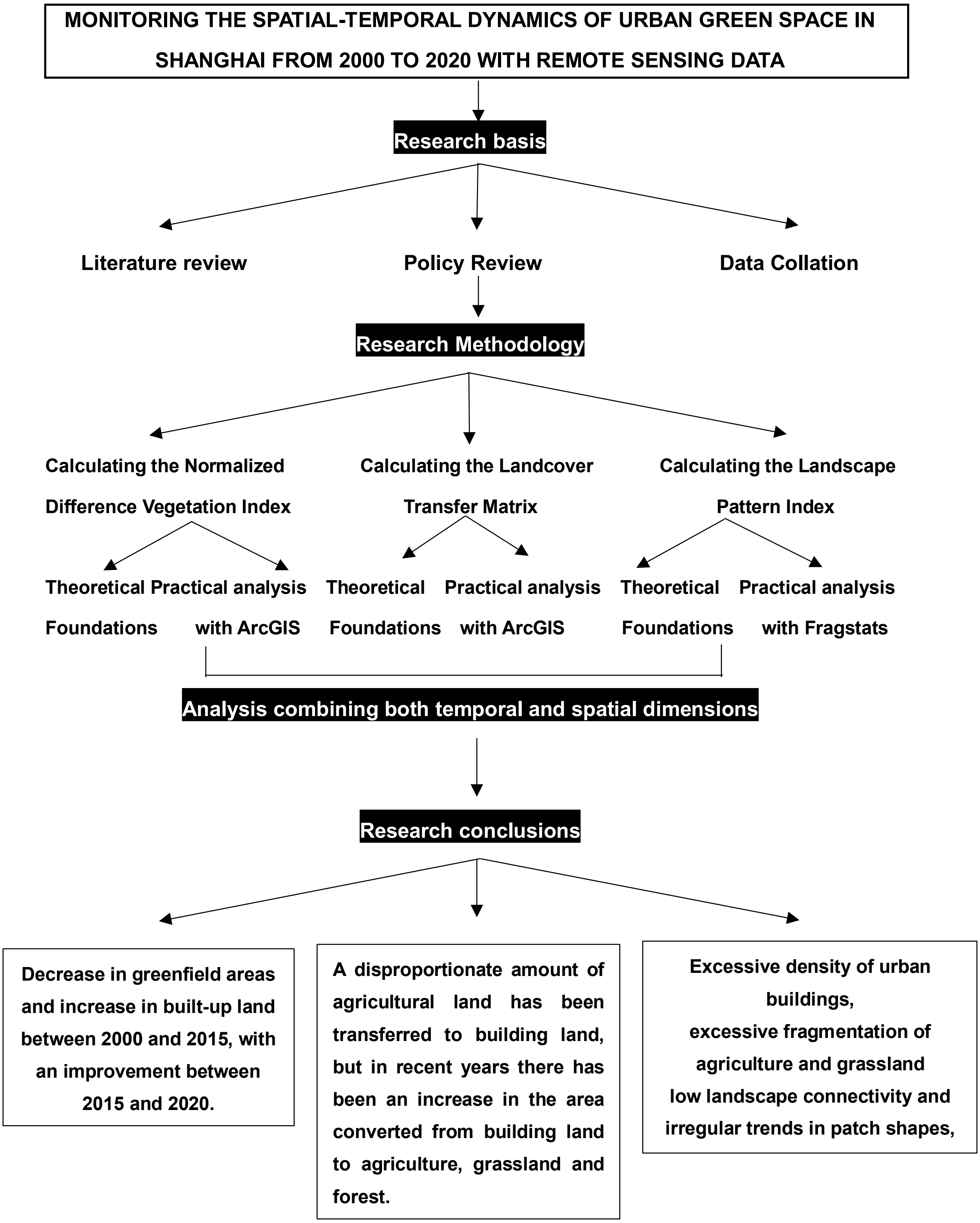
4. To analyse the differences between planned green spaces and actual green spaces, to determine whether the current stage of planning is in line with reality and to make scientific recommendations.

5. Analysis of the landscape landscape pattern index in the study area to give a general idea of the evolution of the ecological situation in the study area.

6. By calculating the land use matrix transfer, the direction and intensity of the transfer between different land use types is analysed.

7. Finally, the development of green space in Shanghai over the past 20 years is summarised and recommendations are made accordingly.

2.3 Thesis structure



3. Literature Review

The growth of urbanization has brought with it many problems, the climate being the first of these and urban climate is a growing concern. Urban ecology research has long studied. Within this broad area of inquiry, there have been several streams of research. One stream of research focuses on urban ecological issues, other stream have focused on how to deal with those climate issues for example, urban green space systems, and other stream about urban climate analysis techniques.

3.1 Urban ecological issues

Urban development increases the demand for water, energy, building materials and food, caused resource shortages and various urban ecological problems. Since urban ecological problems began to emerge, research on urban ecological problems has also emerged, consisting of two main aspects: analysis of the causes and hazards of the problems and, on the other hand, proposals for measures to deal with them. In terms of analyzing the hazards, Climate change is putting a lot of pressure on the urban environment, including the impact of the living environment on the psychological and physical health of urban dwellers, such as the increase in heat waves threatening the health of the elderly, the ill and the young (Rosenzweig C et al., 2011); The climate is also becoming more extreme, with more frequent and intense inland floods threatening the human condition. And for coastal cities, rising sea levels and storm surges due to a warming climate directly affect the survival of entire cities (IPCC, 2007). Cities are responsible for most of the greenhouse gas emissions that contribute to these hazards and should therefore take responsibility for global emissions reduction efforts.

On the causal aspects of urban climate problems. A research show that the urban heat island effect is caused by high densities of impermeable surfaces, altered air ventilation of building structures and waste heat emissions from the various processes of building construction (Oke, T.R. et al, 2017). In addition, air pollutants can alter the radiation and absorption of solar radiation and have an impact on radiation(Schneidemesser, E. et al, 2015); rising temperatures also affect volatile organic compounds, increasing their emissions and also leading to enhanced ground-level ozone; and the interaction between the urban heat island effect and urban air pollution can lead to changes in surface rainfall patterns, changes in regional microclimates, etc., and can extend from local to region-wide

(Liu, J. et al, 2019). while urban sprawl leads to greenhouse gas emissions and changes in surface albedo due to urban sprawl have global implications (Milesi C. et al, 2020).

There is also a lot of research into solving urban ecological problems. C Tang L, et al. assessed the impact of climate change on cities by means of establishing indicators. Wentz et al. review the mapping and modelling capabilities of remotely sensed Earth observations in global environmental change studies, with a particular focus on urbanization. Tang, Lina, Wang, Lin et al. designed a framework for urban ecological risk assessment to improve the capacity of urban ecosystems to provide material or physical services. Nancy B. Grimm, J. Grove Grove et al. present an integrated approach to the long-term study of urban ecosystems and the need to integrate social and ecological approaches, concepts and theories. While each of these research makes important and unique contributions to the literature on urban ecological.

3.2 Urban climate analysis techniques

It has not been long since the technology for studying urban climate was developed, but it has been developing at a faster pace in recent years. There have been several streams of research. One stream of research focuses on access to those data, other stream have focused on how to analysis those data.

Remote sensing technology has developed rapidly in recent years and Cristina Milesi et al. summarise the remote sensing tools currently available for observing urban climate problems and those that can be used to address them. Among the remote sensing technologies related to urban climate issues, those related to the extent and structure of cities and capable of monitoring urban areas and their expansion are Sentinel-1, Sentinel-2, Landsat 8, Gaofen 1 and 6, MODIS Vegetation Indices, MODIS land cover and VIIRS… These allow access to the land cover of cities and also the vegetation cover. In the case of urban climate issues related to energy consumption, multispectral nighttime light emissions data are available through EROS-B, Jilin-1 (JL1-3B) and Jilin-1 (JL1-07/08); Panchromatic nighttime light emissions data are available through VIIRS, LuoJia1-01 and DMSP/OLS; Thermal sensors data are available through Landsat 8, Sentinel-3, MODIS and VIIRS;
In the case of urban climate issues related to greenhouse gas emissions, concentrations of CO2 and CH4 in an air column data are available through OCO-3, Sentinel 5P, Tan SAT…
In the case of urban climate issues related to surface urban heat island and heat waves, air temperature, land surface temperature, water temperature data are available through Landsat 8, ASTER, MODIS, VIIRS and Sentinel-3.

The development of technology has given a huge boost to the solution of urban climate problems. And in this paper, data from OLS, EROS and Sentinel-2 will be applied.

On the other hand, there has been a relatively rapid development in the use of analysis of this data. In the application of data and urban sprawl, Arellano, Blanca; Roca, J. Identifying urban sprawl through nighttime light images of the Earth as an example from Barcelona. In the application of remote sensing to urban population, high-resolution settlement maps combined with micro-census surveys have been shown to be effective in estimating population independently of the census (Weber, E.M. et al., 2018). In the application of remote sensing data to the urban heat island effect, new satellite sensors and valuable methods have been developed to calculate surface temperature (LST) and UHI intensity(Hua Shi. Et al., 2021).

Although the use of remote sensing data to analyze urban problems has developed rapidly in recent years, there are still many problems that cannot be solved well, such as identifying populations in cities with high density of high-rise buildings, and the need to develop geospatial methods to delineate the boundaries between urban and rural land.

3.3 Urban green space

The concept of urban green space emerged in the 1970s. There have been several streams of research. One stream of research focuses on process and policy analysis of the development of urban green space, other stream has focused on the benefits and value of urban green space and other stream have focused on practical applications of urban green spaces: identification and planning.

In terms of analyzing the benefits and value of urban green space, by studying the causal relationship between urban green spaces and human health found that there is a negative correlation between lower urban green space coverage and higher mortality, heart rate and violent mood, while there is a positive correlation between higher urban green space coverage and higher mood, concentration and physical activity(Kondo M C.et al., 2018).

By combining spatially explicit survey data with GIS data on the spatial height decomposition of urban green spaces finally find an inverted U-shaped effect of urban green space on life satisfaction (Christine Bertram et al., 2015) And the positive effect of green space is largest for an area coverage of 11%.

There is also a lot of research into urban green spaces: identification and planning. Christine Haaland et al.(2015) review the challenges and strategies for urban green space planning in dense cities. At the same time some of the challenges in densely urbanised areas have been identified in the literature, such as focusing on protecting existing urban green spaces in high-density areas, resisting social inequalities, protecting green spaces in private areas, taking into account the views and wishes of residents, protecting biodiversity and developing laws and regulations related to the above. Martin Mwirigi et al.(2012) used landscape metrics to analyze the UGS and identify potential areas of expansion through suitability checklists and proximity buffers completed in a GIS environment. Jim C Y.(2004) proposes measures to achieve sustainable greening in compact cities and emphasises that the focus is not only on conservation but also on the distributional relationship between the different stakeholders.

3.4 Specifically to Shanghai

China's domestic systematic urban green space theory developed late, and China's urban green space development has gone through a development from greening embellishment to systematic planning to ecological green space. However, with the rapid advancement of urbanisation in China and the maturation of the theory, progress has been faster in recent years.

Based on ARCgis 10.0 software, Chinese scholar Wu Zhen et al. (2019) explored the evolutionary trends of urban green space dynamics in Shanghai from 1980 to 2015 by calculating the proportion of green space (RGS), NDVI, and patch shape index (PSI) indices, and found that from 1980 to 2015, the total area of urban green space in Shanghai decreased The results show that the total area of urban green space in Shanghai declined from 1980 to 2015, and that different regions show different trends.

A study by Chinese scholar Cui Linli et al.(2012) shows that urbanisation has brought serious environmental problems to Shanghai, with high temperatures, low wind speeds and low relative humidity in urban areas between 2001 and 2010, a decrease in the vegetation cover index NDVI, and a spatial pattern of LST that is broadly consistent with land use types, showing that urbanisation has placed a huge burden on the development of the ecological environment in Shanghai.

Liu Song et al. (2021) explored the pattern and intensity of green space change in Shanghai from 1990-2015 by calculating the green space ratio, landscape index, excess matrix and dynamic change degree, respectively. The study revealed that large areas of green space in Shanghai including farmland, forests, grasslands and waters were converted to built-up areas and that green space in Shanghai is becoming increasingly fragmented and independent.

Wang Xiangrong discusses the ways and measures of ecological city construction in terms of the structure, function and coordination of urban-rural ecological relations in Shanghai. He proposes to improve the ecological environment of Shanghai by adjusting the land use structure, population structure, energy structure and industrial structure. In addition, it also proposes to pay attention to the adjustment and improvement of the ecological relationship between urban and rural areas.

3.5 Conclusions

Early research on urban green space development focused on theoretical studies, and in recent years, with the development of remote sensing technology, more and more example studies have been conducted. These theoretical and empirical experiences of the summarized predecessors have laid a deep foundation for the following studies. The aim of this paper is to analyse the spatial and temporal evolution of urban green space in Shanghai, a theme that emphasises the combination of time and space, in addition to the fact that space is also 'multidimensional', it is important to analyse

4. Methodology

4.1. Selection of study area

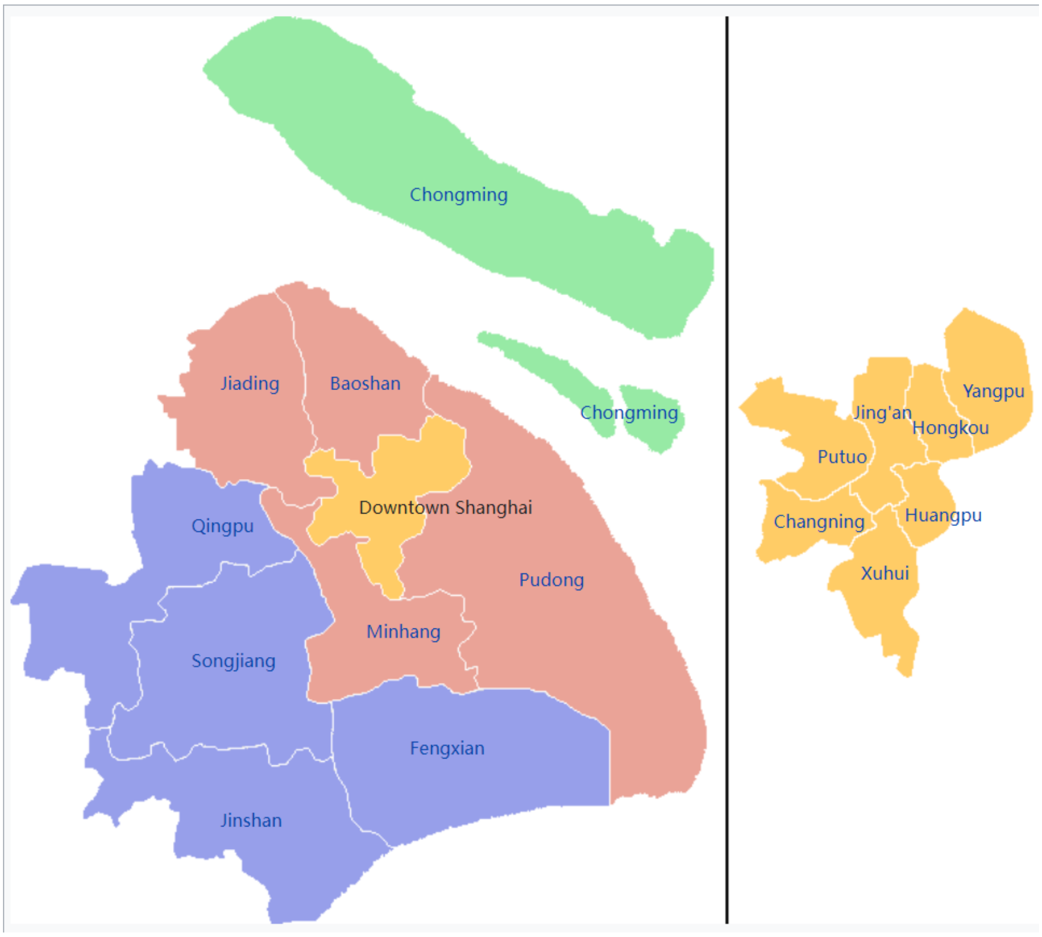


Figure 6. Shanghai Administrative Divisions

Source: Wikipedia

Shanghai is China's international economic, financial, trade, shipping and technology innovation center, the second most populous city in China, the most developed city in mainland China and a global city. It is located in East China, on the west coast of the Pacific Ocean and the eastern edge of the Asian continent. Shanghai has 16 districts under the jurisdiction of Pudong New Area, Xuhui, Changning, Putuo, Hongkou, Yangpu, Huangpu, Jing'an, Baoshan, Minhang, Jiading, Jinshan, Songjiang, Qingpu, Fengxian and Chongming (Wikipedia contributors, 2022).

The city centre is made up of seven districts of smaller size. By 2020, Shanghai have an area of 7,983km2, a GDP of 3,870.58 billion RMB, and a per capita GDP of 155,768 RMB (Wikipedia contributors, 2022).

Shanghai's developed economy is due to its advantageous geographical location at the mouth of the Yangtze River, with flat terrain, abundant resources and convenient transportation.

4.2. Research method

A. Calculating the RGS and NDVI

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 Y, et al.,1990).

$$RGS = \frac{S_{Greenarea}}{S_{Landarea}}$$

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 Y, et al., 2009; Pettorelli N., et al. 2005).

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

The Normalized Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between near infrared (strong vegetation reflection) and red light (vegetation absorption). The NDVI uses the NIR and red bands in its equation. The result of this formula produces a value between -1 and +1. If the red channel has a lower reflectance and the NIR channel has a higher reflectance, a higher NDVI value will be generated. The reverse is also true (Geographical information monitoring cloud platform).
Overall, NDVI is a standardized measure of healthy vegetation. When there is a high NDVI value, the vegetation is healthier. When the NDVI is low, there is less or no vegetation.

B. Calculating the landscape pattern index from the each patch types level and the overall level

In addition, the urban development changes in the study area during the study period were analysed from the perspective of landscape ecology, and the overall landscape pattern index for Shanghai in 2000 2010 and 2020 and the landscape pattern index for each landscape type at the patch level for five years in 2000, 2005, 2010, 2015 and 2020 were calculated using Fragstats software. Nine indicators were analysed in terms of total patch type area, number of patches, patch density, Shannon's Diversity Index, contagion Index, splitting Index, landscape shape index, aggregation index, interspersion and juxtaposition index, respectively. The meaning of each indicator is shown in the figure below, which is extracted from the indicator interpretation help within the Fragstats software.

Landscape pattern index	Abbre-viation	Unit	Interpretation of the meaning
Total area of patch type	CA/TA	Hm2	Indicates the total area of patches within a type of landscape or the total area within the whole area
Number of Patches	NP	None	NP equals the number of patches of the corresponding patch type (class). In general, landscape fragmentation is low for small NP values and high vice versa (Zhu Dongguo, et al.,2017).
Patch Density	PD	Number per 100 hectares	Indicates the number of patches per 100hm2 of land area.
Shannon's Diversity Index	SHDI	Information	SHDI ≥ 0, SHDI = 0 when the landscape contains only 1 patch (i.e., no diversity). SHDI increases as the number of different patch types (i.e., patch richness, PR) increases and/or the proportional distribution of area among patch types becomes more equifigure.
Contagion Index	CONTAG	%	0 < CONTAG ≦ 100 CONTAG approaches 0 when the patch types are maximally disaggregated (i.e., every cell is a different patch type) and interspersed (equal proportions

			of all pairwise adjacencies). CONTAG = 100 when all patch types are maximally aggregated. Describes the degree of agglomeration or trends in the extension of different patch types in the landscape.
Splitting Index	SPILT	None	1 ≦ SPLIT ≦ number of cells in the landscape area squared. SPLIT = 1 when the landscape consists of single patch. SPLIT increases as the focal patch type is increasingly reduced in area and subdivided into smaller patches. Reflects the degree of disturbance within a patch type or landscape area.
Landscape Shape Index	LSI	None	LSI ≥ 1, without limit. LSI = 1 when the landscape consists of a single square patch of the corresponding type; LSI increases without limit as landscape shape becomes more irregular and/or as the length of edge within the landscape of the corresponding patch type increases.
Aggregation Index	AI	%	0 ≦ AI ≦ 100, Given any Pi , AI equals 0 when the focal patch type is maximally disaggregated (i.e., when there are no like adjacencies); AI increases as the focal patch type is increasingly aggregated and equals 100 when the patch type is maximally

			aggregated into a single, compact patch.
Interspersion and Juxtaposition Index	IJI	%	0 <IJI≦100, IJI approaches 0 when the corresponding patch type is adjacent to only one other patch type and the number of patch types increases. IJI = 100 when the corresponding patch type is equally adjacent to all other patch types (i.e., maximally interspersed and juxtaposed to other patch types), It shows that the probability of being more than adjacent is equal between patches.

Figure 7. Landscape pattern evaluation indicators and their meaning

Source: Fragstats 4, Help - Indicator interpretation help

C. Calculating the land cover transfer matrix

The urban landscape type shift matrix provides a more comprehensive picture of the direction and number of transitions between land use types in the study area, reflecting the structure and state of land use type transitions within each time interval (Qigle Hen, et al., 2019).

The mathematical model is as follows.

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ \dots & \dots & \dots & \dots \\ S_{n1} & S_{n2} & \dots & S_{nn} \end{bmatrix}$$

where Sij represents the transition area from land use type i to j, where each element of the matrix is characterised by the assumption that Sij is non-negative and equal to 1 (Liu S, et al., 2021).

4.3. Data collection

This paper investigates the temporal and spatial dynamics of urban green space change in Shanghai using high resolution Landsat TM data for 2000 2005 2010 and Landsat OLI data for 2015 and Sentinel2 data for 2020. 2020 Sentinel2 images were obtained from the Copernicus Open Access Centre and the remaining years of Land use data for 2020 were obtained from Copernicus Open Access Centre for 10m resolution images of Shanghai. 2015 and 2005 land use data were obtained from China Resources and Environmental Science and Data Centre for 30m resolution images of Shanghai. 2010 and 2000 land The land cover data data for 2010 and 2000 were obtained from GlobeLand30 for 30m resolution data of Shanghai.

After atmospheric correction, image mosaic stitching and extraction based on masks were completed for the acquired remote sensing images, the summer NDVI images for each year were calculated based on the NDVI calculation method and thresholds were set to determine green space and non-green space. NDVI values range from -1 to 1, within which negative values indicate ground cover of water, snow, etc. with high reflection of visible light; 0 indicates rock or Positive values indicate vegetation cover, with smaller values being urban built-up areas and larger values being more vegetation cover. The map produced reflects the status of green spaces in Shanghai and their spatial distribution over the relevant time period. The distribution map was created using ArcGIS 10.2 software.
Using the same spatial overlay operation in ArcGIS 10.2, the urban land use type transfer matrix can be derived for each point in time.

Using the same spatial overlay operation in ArcGIS 10.2, the urban land use type transfer matrix can be derived for each point in time.

The image was also processed in ArcGIS 10.2 to convert the vector data to raster data, and the landscape pattern index was calculated using the landscape pattern analysis software Fragstats 4.2.

4.4. Data analysis

A. NDVI and RGS analysis

The first is an analysis of the overall green space in Shanghai from 2000 to 2020. The figure below reflects the spatial and temporal variation of green space as determined by NDVI.

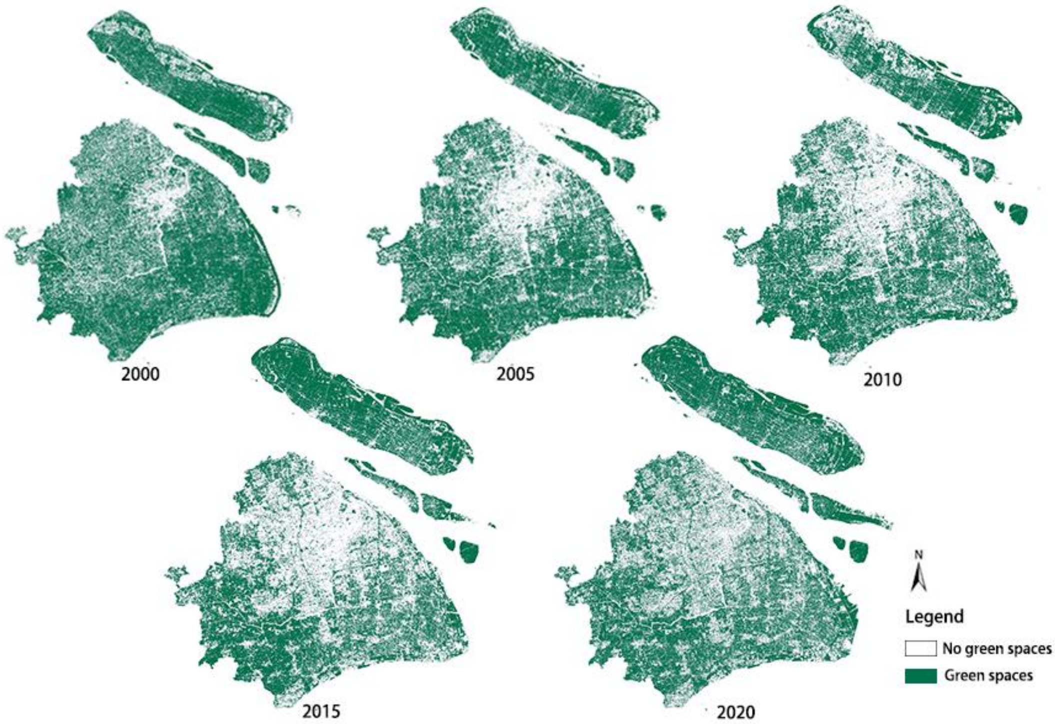


Figure 8. Changes in green space distribution in Shanghai, 2000-2020

The following is the relevant data obtained by calculation, the green spaces area in 2000 was about 4416.32 km2, the green spaces area in 2005 was about 4068.92 km2, the green spaces area in 2010 was about 3725.92 km2, and the green spaces area in 2015 was about 3643.26 km2, and the green spaces area in 2020 was about 4077.64 km2.

	2000	2005	2010	2015	2020
Area of GS(km^2)	4416.32	4068.92	3725.92	3643.26	4077.64
Proportion	55.32%	50.97%	46.67%	45.64%	51.05%

Figure 9. Changes in area and proportion of GS in Shanghai, 2000-2020

The area of green space in Shanghai has been decreasing between 2000 and 2015, especially during the period of the fastest economic development from 2000 to 2010 when the area of green space decreased the fastest, while from 2015 to 2020 the area of green space has gradually increased, and the calculated image also shows the trend of decreasing green space and expanding floor space.

This is followed by a comparison of the NDVI images calculated for 2020 with the official land cover data for the same year, firstly through the images and later by calculating the overlap rate.

Figure 10. Comparison chart of overlap in Shanghai, 2020

According to the land cover data of Shanghai in 2020 obtained by Copernicus Open Access Centre, the extracted area of woodland, shrubs, grassland, arable land and herbaceous wetland is 3828.85 km2 and the calculated NDVI area of green space of 4077.64 km2, with an overlap of 3424.55 km2 and an overlap of 89.44%.

This is followed by an analysis of the development of artificial surface change from 2000 to 2020 based on the land cover data obtained.

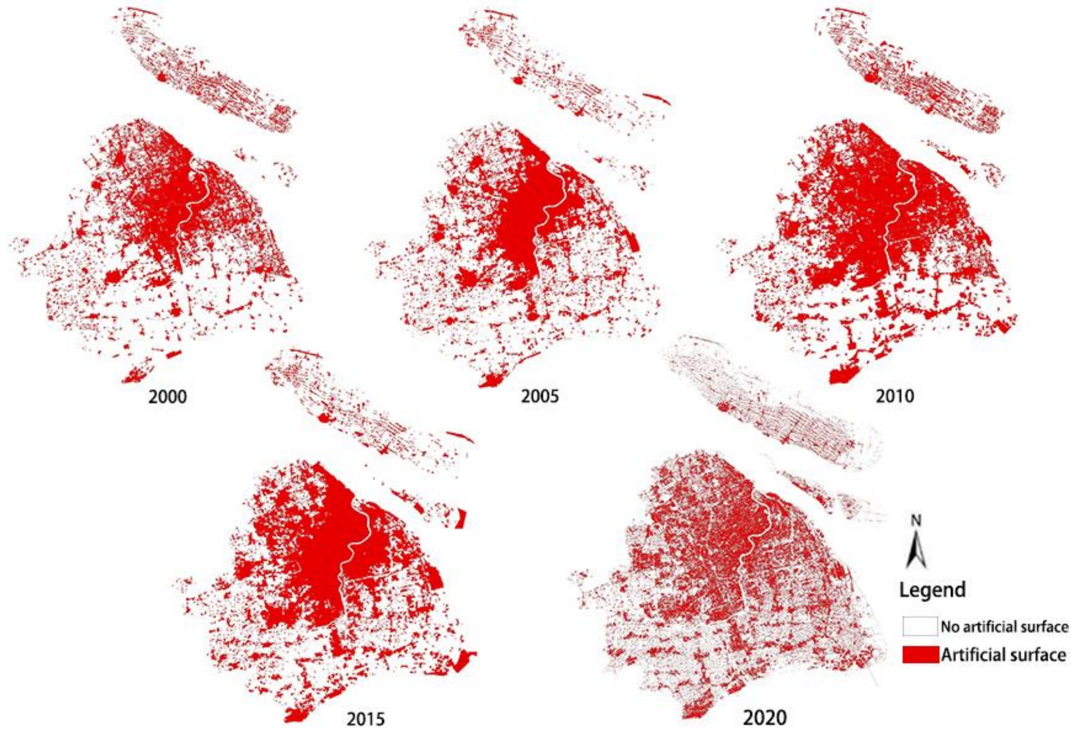


Figure 11. Changes in Artificial land distribution in Shanghai, 2000-2020

The following is the relevant data obtained by calculation, the artificial land area in 2000 was about 1800.1km2, the artificial land area in 2005 was about 1848.97 km2, the artificial land area in 2010 was about 2727.11 km2, and the artificial land area in 2015 was about 2562.06 km2, and the artificial land area in 2020 was about 2214.66 km2.

	2000	2005	2010	2015	2020
Area of AL(km^2)	1800.1	1848.97	2727.11	2562.06	2214.66
Proportion	22.55%	23.16%	34.16%	32.09%	27.73%

Figure 12. Changes in area and proportion of artificial land distribution in Shanghai, 2000-2020

The area of artificial land in Shanghai has been decreasing between 2000 and 2010, especially during the period of the fastest economic development from 2005 to 2010 when the area of artificial land decreased the fastest, while from 2010 to 2020 the area of artificial land has gradually increased, and the calculated image also shows the trend of decreasing artificial land and expanding floor space.

This section is detailed to the development of green space in the centre of Shanghai from 2000 to 2020 as determined by the NDVI.

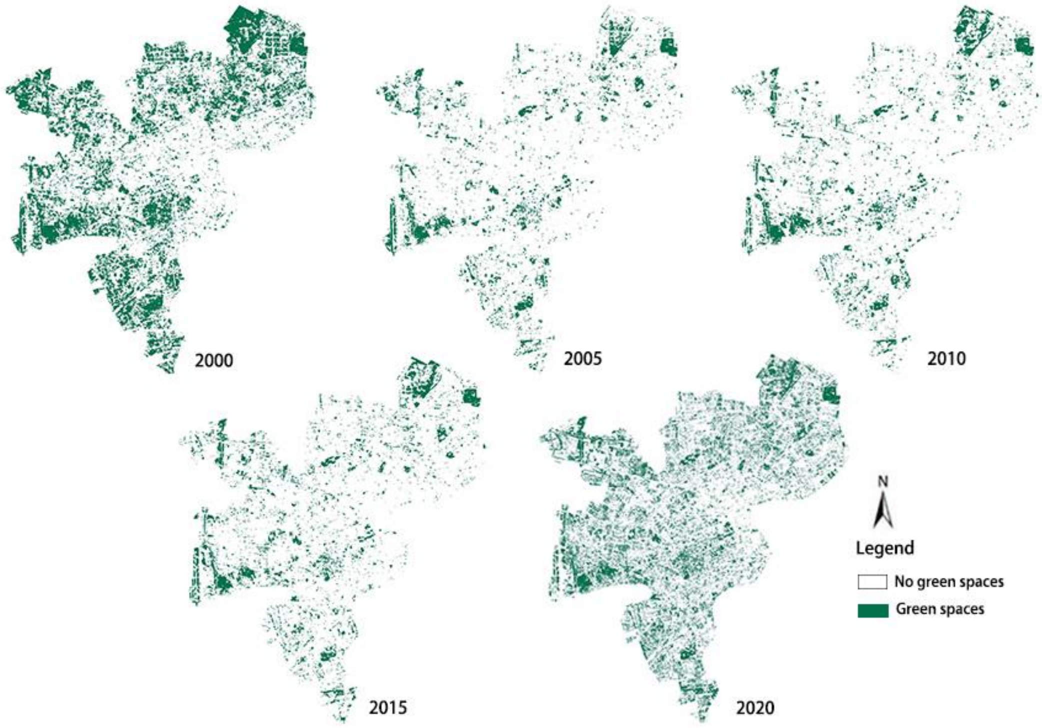


Figure 13. Changes in green space distribution in the center of Shanghai, 2000-2020

The following is the relevant data obtained by calculation, the green spaces area in 2000 was about 86.69 km2, the green spaces area in 2005 was about 28.93 km2, the green spaces area in 2010 was about 32.11 km2, and the green spaces area in 2015 was about 31.63 km2, and the green spaces area in 2020 was about 68.62 km2.

	2000	2005	2010	2015	2020
Area of GS(km2)	86.69	28.93	32.11	31.63	68.62
Proportion	29.98%	10.01%	11.11%	10.94%	23.73%

Figure 14. Changes in area and proportion of GS in the center of Shanghai, 2000-2020

The area of green space in the centre of Shanghai declined sharply between 2000 and 2005, increased slightly but not significantly between 2005 and 2010, varied little between 2010 and 2015, and increased significantly between 2015 and 2020. and the calculated image also shows the trend of decreasing green space and expanding floor space.

B. Landscape types transfer matrix analysis

Figure 15 shows a figure of the calculated land use conversion matrix. In the 2000 to 2020 interval, farmland is the most diverted greenfield type, with 130,623.2 hectares being converted to built-up areas and a total loss of 146,750.8 hectares of farmland, accounting for 89% of the total loss of farmland. The transition of water bodies to built-up areas is the second largest, at 10,584.15 hectares, with a total loss of water bodies of 28,202.59 hectares, or 38% of the total loss of water bodies. The transfer from forests into built-up areas was smaller at 2085.69 hectares, with a total forest loss of 4136.63 hectares, or 50% of the total forest loss. The least area transferred from grassland into built-up areas was 185.66 hectares, with a total grassland loss of 821.611 hectares, accounting for 22.6% of the total grassland loss.

It is worth mentioning that the transition of built-up areas to agricultural land was 15,431.05 hectares, the transition of built-up areas to forest was 814.11 hectares, the transition of built-up areas to grassland was 1,212 hectares and the transition of built-up areas to grassland was 3,498.65 hectares, a significant increase from previous years. This is also in line with the data derived from the NDVI analysis and Shanghai's urban planning policies.

Year range	Types	Agriculture (Hectares)	Forest (Hectares)	Grassland (Hectares)	Water (Hectares)	Build (Hectares)	Sum (Hectares)
00-05	**Agriculture**	412721.30	1176.11	9.45	2055.32	39392.83	455355.01
	Forest	175.67	9551.61	0.06	60.66	495.73	10283.72
	Grassland	66.72	195.65	993.43	18.82	7.27	1281.89
	Water	8127.15	100.53	994.58	161384.63	2903.42	173510.31
	Build	2755.57	76.32	1.25	58.56	141900.77	144792.47
	Sum	**423846.4127**	**11100.22042**	**1998.76324**	**163577.9925**	**184700.0191**	**785223.4079**
05-10	**Agriculture**	374558.44	201.96	10.45	598.96	48462.04	423831.86
	Forest	135.87	9822.86	0	19.35	1122.16	11100.24
	Grassland	12.44	0.05	1942.21	33.01	10.81	1998.52
	Water	445.28	46.62	12.27	160325.19	2736.29	163565.63
	Build	2061.22	53.17	1.46	96.80	182486.23	184698.88
	Sum	**377213.25**	**10124.66**	**1966.39**	**161073.31**	**234817.53**	**785195.13**
10-15	**Agriculture**	356509.33	89.53	7.29	317.19	20291.91	377215.25
	Forest	90.94	9658.73	0.03	22.77	352.18	10124.65
	Grassland	340.29	0.05	1467.16	33.31	126.29	1967.1
	Water	1089.59	16.20	7.02	159804.08	156.53	161073.42
	Build	1835.88	37.47	1.59	86.01	232832.44	234793.39
	Sum	**359866.03**	**9801.98**	**1483.09**	**160263.36**	**253759.35**	**785173.81**
15-20	**Agriculture**	303132.66	2343.21	1639.63	9040.04	43506.55	359662.09
	Forest	1407.57	6292.11	622.51	400.15	1079.45	9801.79
	Grassland	97.34	0	1026.89	189.64	168.46	1482.33
	Water	12996.37	1464.60	3045.67	133326.94	8918.41	159751.99
	Build	15431.05	814.11	1212.00	3498.65	233665.26	254621.07
	Sum	**333064.99**	**10914.03**	**7546.7**	**146455.42**	**287338.13**	**785319.27**
00-20	**Agriculture**	308498.24	2878.84	2139.08	11109.65	130623.20	455249.01
	Forest	1415.88	6146.79	214.87	420.18	2085.69	10283.41
	Grassland	479.28	19.85	452.93	136.82	185.66	1274.54
	Water	14734.05	215.84	2668.55	131758.15	10584.15	159960.74
	Build	4881.88	263.34	384.13	1307.85	137940.04	144777.24
	Sum	**330009.33**	**9524.66**	**5859.56**	**144732.65**	**281418.74**	**771544.94**

Figure 15. Land use conversion matrix for 2000 to 2020 of Shanghai

C. Landscape Pattern Index Analysis

Firstly, the analysis of the area of patches and the number of patches shows a decreasing trend for agricultural land, an increasing trend for building land, little change in the area of forests, an increasing trend for grassland between 2000 and 2005, a greater decrease between 2005 and 2015, and a major development between 15 and 20, and a decreasing trend for water patches between 2000 and 2010, a small increase and then a decrease between 2010 and 2015. There was a small increase and then a decrease between 2010 and 2015. Between 2000 and 2020, the largest change was in grassland, which increased by 6,298.65 hectares or 491% compared to 2000, and the next largest change was in building land, which increased by 142,615.3 hectares or 98% compared to 2000. The largest decrease was in agricultural land, which decreased by 122,127.3 hectares or 26.8% compared to 2000. It can be seen that the rapid urbanisation of Shanghai during the study period has placed more emphasis on the conservation of urban grassland, but less on the conservation of agricultural land.

The number of patches can reflect the degree of fragmentation of urban landscape types more intuitively. Between 2000 and 2020, the number of patches of agricultural land increased significantly, and grassland also basically showed an increasing trend, indicating that the fragmentation of agricultural land and grassland was serious during this period.
The landscape shape indices for agricultural land, grassland and watershed show an increasing trend over the study period, indicating an extremely pronounced irregularity in the patch shapes of these landscape types, with the largest increase being in watershed at 79%, followed by grassland at 75%. The only decline is in built-up land, which indicates that the magnitude of human activity interfering with urban ecosystems has increased, leading to irregularity in patch shape.

And then followed by the Landscape Aggregation Index, which has relatively high and uncorrected AI values above 90 for all landscapes between 2000 and 2020, indicating a high degree of aggregation and compactness of patches of the same type during the study period. One of the more noticeable trends is the increasing trend in AI values for built-up land, indicating that urban buildings are becoming more dense and compact.

Year	Types	CA/hm^2	NP	PD/100 hm^2	LSI	AI/%
2000	**Agriculture**	455075.28	136	0.02	47.53	97.93
	Forest	10307.88	357	0.05	26.64	92.40
	Grassland	1282.41	20	0.00	8.39	93.75
	Water	173563.92	745	0.09	21.06	98.55
	Build	145016.19	2876	0.37	65.14	94.94
2005	**Agriculture**	423615.24	227	0.03	49.39	97.77
	Forest	11123.28	359	0.05	25.29	93.06
	Grassland	2000.43	28	0.00	8.85	94.68
	Water	163620.81	740	0.09	21.17	98.50
	Build	184892.13	2603	0.33	59.47	95.92
2010	**Agriculture**	377022.24	300	0.04	53.65	97.43
	Forest	10148.04	343	0.04	26.15	92.48
	Grassland	1967.49	28	0.00	9.18	94.43
	Water	161136.09	720	0.09	21.90	98.44
	Build	234979.83	2176	0.27	56.69	96.55
2015	**Agriculture**	359689.50	340	0.04	52.69	97.41
	Forest	9825.93	330	0.04	25.50	92.56
	Grassland	1483.92	24	0.00	7.31	95.04
	Water	172934.01	718	0.09	21.73	98.50
	Build	256217.85	1979	0.25	52.63	96.94
2020	**Agriculture**	332947.98	464	0.06	53.80	97.25
	Forest	10934.19	273	0.03	24.51	93.23
	Grassland	7581.06	85	0.01	14.65	95.28
	Water	147243.69	570	0.07	37.75	97.12
	Build	287631.45	2037	0.25	48.62	97.33

Figure 16. Landscape pattern index of patch types in Shanghai from 2000 to 2020

Finally, the overall ecological level of the landscape in the study area is analysed from a global perspective. figure 17 shows that the LSI index increased from 62.37 to 64.63, indicating that the irregularity of patch shapes in the study area has increased, and the presence of too many irregularly shaped patches will disrupt the original ecological balance; the CONTAG value decreased from 64.38 to 62.7, with fewer patches of higher connectivity, and the spatial dominance of patches that were originally more connected breaking up; the IJI value decreased from SPILT values increased from 6.42 to 18.61, most directly reflecting the trend of spatial fragmentation in the landscape, and SHDI values increased from 1.2 to

1.35, indicating an increase in the diversity of patch types and an increase in spatial complexity within the area.

Year	NP	PD	LSI	CONTAG	IJI	SPLIT	SHDI
2000	8876	1.11	62.37	64.38	30.39	6.42	1.20
2010	7601	0.95	57.96	65.31	33.12	10.87	1.27
2020	6848	0.86	64.63	62.70	42.21	18.61	1.35

Figure 17. Overall Landscape Pattern Index for Shanghai in 2000, 2010 and 2020

5. Conclusions

5.1 Conclusions and recommendations

1.The data derived from the analysis of NDVI using gis found that the area of green space in Shanghai continued to decrease from 2000 to 2015 and increased from 2015 to 2020. The artificial surface area increased continuously from 2000 to 2010, especially between 2005 and 2010 when the city grew rapidly, and decreased from 2010 to 2020 when the urban growth rate tended to level off. Green space in the city centre decreases rapidly between 2000 and 2005, improves a little between 2005 and 2010, deteriorates again between 2010 and 2015, and improves considerably until 2020.

2.The comparison between the 2020 green space area calculated by GIS and the 2020 Shanghai land cover type map obtained by Copernicus Data Open Center shows that the overlap degree is 89.44%, which indicates that the protection and development of urban green space in Shanghai in the recent five years is good, and basically conforms to the planning goal.

3. Analysis of the landscape type transfer matrix reveals that a disproportionate amount of agricultural land has been transferred to built-up land, accounting for 89% of the total loss of agricultural land, with the second largest area of water bodies transferred to built-up areas. This indicates that too much emphasis was placed on urban construction in the previous period, and not on the protection of farmland and water bodies; it is worth noting that the area of agricultural land, grassland and woodland used for construction has increased in recent years, indicating that the government is paying more attention to the protection of the ecological environment.

4. The analysis of the landscape pattern index reveals that there are many minor problems in Shanghai's urban development, with excessive density of urban buildings, excessive fragmentation of farmland and grassland, low landscape connectivity and irregular trends in patch shapes, all of which are detrimental to the protection of the ecological environment and the survival of organisms. The NDVI map also shows visually that the fragmentation of Shanghai's urban landscape is a serious problem, and it is not

difficult to analyse previously summarised policy documents to see that the potential for landscape fragmentation has been present in the planning process.

After neglecting the protection of green spaces in the early stages of Shanghai's greening due to urban development, there has been more awareness of the importance of protecting green spaces in recent years, corresponding to the policies introduced in recent years, and there has been significant progress and development in the protection of green spaces in recent years.

Based on the findings of the analysis, the following recommendations are made for Shanghai.

1. balance the relationship between population, economic growth and the urban environment, and control urban sprawl

2. make more rational use of the existing land structure

3. Increase landscape connectivity and prevent further fragmentation of urban green spaces by building ecological networks and ecological bridges.

4. Pay particular attention to the protection of agricultural land.

5.2 Contributions

a. Due to the epidemic in recent years, which has had an impact on various aspects of Shanghai including economic and ecological aspects, there is little research on green space in Shanghai up to the year 2020, and this paper fills the gap in this regard.

b. My contribution is in terms of the spatial and temporal dynamics of the evolution of green space, not only focusing on the increase and decrease of green space as a whole, but also in terms of specific plot evolution trends, such as the apparent fragmentation of green space in Shanghai.

c. the evolutionary process is combined with urban policy to speculate on whether the development of green space in Shanghai is in line with the objectives of policy development.

d. In addition to the combination of the two dimensions of time and space, awareness of the 'multidimensional' nature of space. Not only from the overall changes, but also the specific shape changes and the relationship between the various land use types from the perspective of the plot, so as to better reflect the "spatial and temporal changes". This is where the innovation of this paper lies.

5.3 Future research

There are also the following points which the author believes are still in a research gap and will continue to be explored in the future.

a. During the epidemic, the area of green space in Shanghai increased significantly,
How has the epidemic affected the development of green space in Shanghai and what are the specific trends.

b. Although Shanghai has a high density of buildings and high heights, green space has been built up quite well in recent years. What are the differences between high density buildings and low buildings in terms of wind speed, wetlands, surface albedo, etc. and what are the reasons for the differences, given the same amount of green space.

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8. Figures

Figure 1. The relationship between material production, population production and environmental production.

Figure 2. Population and in-migration in Shanghai from 2000 to 2020. Source: Shanghai Statistics Bureau

Figure 3. Gross Resident Product of Shanghai from 2000 to 2020. Source: Shanghai Statistics Bureau

Figure 4. Evolution of Urban Planning Policy in Shanghai

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Figure 7. Landscape pattern evaluation indicators and their meaning

Figure 8. Changes in green space distribution in Shanghai, 2000-2020

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