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Correlations between Socioeconomic Drivers and Indicators of Urban Expansion: Evidence from the Heavily Urbanised Shanghai Metropolitan Area, China

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Abstract: Rapid urban expansion resulting in increased impervious surfaces causes a series of urban environmental problems, e.g., the urban heat island and urban forest fragmentation. Urban expansion is a serious threat to human quality of life and living environments. It has been studied from a variety of aspects, but its driving factors and time series expansion characteristics (i.e., expansion intensity, pattern and direction) need to be better explained in order to devise more effective management strategies. This study examined how social and economic factors are linked in driving urban expansion. Based on multi-temporal aerial images, a rapid urban expansion period, 2000–2010, in Shanghai was analysed. The urban area expanded from 1770.36 to 2855.44 km^2 in the period, with a mean annual expansion rate of 108.51 km^2. Urban expansion in 2000–2005 (40.42%) was much faster than in 2005–2010 (14.86%), and its direction was southeast, southwest and south. The main pattern was edge expansion in both sub-periods. Social factors, especially population density, significantly affected urban expansion. These findings can help understand the urban expansion process and its driving factors, which has important implications for urban planning and management in Shanghai and similar cities.

Keywords: urban expansion; spatial pattern; autocorrelation; Shanghai

1. Introduction

The urbanisation rate exceeded 50% for both the world as a whole and for China in 2010 [1,2]. Moreover, the rate is predicted to continue increasing in coming decades [3]. According to the World Urbanization Prospects, this increasing rate of urbanisation will probably lead to over 70% of the world's population living in cities by 2050 [4]. As an important social phenomenon, urban expansion has a clear influence on landscape pattern, processes and function at local and global scale [5,6]. Urban expansion refers to an increase, either disorderly or planned, in the area of impervious surfaces in an urban area. With increasing urban expansion, natural and semi-natural ecosystems are converted into impervious surfaces, causing habitat loss and urban forest fragmentation [7]. Furthermore, ecological processes such as biogeochemical cycles, the hydrological circle, energy flows and population dynamics are seriously affected [8,9].

Understanding the process of urban expansion and its driving factors is crucial for effective urban planning and for optimising urban forest pattern [10]. With the development of GIS science methods, a large number of studies have explored urban expansion and its consequences [10–12]. These studies have examined, for example, the size, intensity and spatial pattern of urban expansion [13,14]. In particular, much attention has been paid to understanding the effects of driving factors of urban expansion, as this is critical for effective design of urban planning and management strategies [15,16].

These quantitative studies have provided important research ideas and technologies for the analysis of the urban expansion process. However, various aspects still need to be described and improved. Some studies have analysed the relationship between urban expansion and socioeconomic drivers [17,18], but most of these have focused on single factors (e.g., population or gross domestic product (GDP)). Studies that simultaneously integrate multiple influencing factors into urban expansion are scarce [19]. On the other hand, some studies have demonstrated that urban expansion plays an important role in urban spatial patterns by revealing the qualitative relationships between urban expansion and spatial patterns [20,21]. However, most of these have failed to address the spatial heterogeneities in the effects of driving factors on spatial patterns in response to urbanisation [22]. Moreover, only analysing the changes in spatial patterns for one period would overlook the fact that the urbanisation process is not necessarily static in an intensely urbanised city. Urbanisation could shift its location within the urbanisation process, so the characteristics of the urbanisation process cannot be fully captured from analysis of a single period [22]. Multiple time series analyses and using high spatial resolution land use data would thus be very helpful.

Expansion intensity, pattern and direction are the most frequently used indicators to reveal the characteristics of urban expansion and can provide important information for urban policymaking [23]. In particular, expansion direction can provide more practical information for urban planning than expansion intensity and pattern [24]. This is because urban expansion direction, although affected by policy factors more than social and economic factors, provides useful information on spatial urban expansion trends [24]. Policymakers can link this information to the distribution of natural ecosystems and their rarity, allowing them to predict and take corresponding measures to prevent future urban expansion that can affect those ecosystems [25].

The study investigated the effects of socioeconomic factors on urban expansion and its characteristics in Shanghai in the period 2000–2010, in order to generate useful information for effective urban spatial planning. Social factors, for example population, play a dominant role in urban expansion [26]. Along with economic development, human beings' demand for better quality of life is increasing. Better food, housing and living environments lead to increased land supply or more intensive land use to satisfy people's requirements for higher quality of life. It brings new pressure on urban land and causes the acceleration of urbanisation [26,27]. Policies, through their hysteresis effects on urban expansion, play an important role in shaping urbanisation patterns [28]. The Opening and Reform of China policy in 1978 was a historical turning point for Shanghai's economy and trade [29]. Urban expansion was quickly accompanied by a boom in the economy. In 1990, China announced that it would speed up the development of Pudong district in Shanghai, resulting in rapid urbanisation of that area. When China entered the World Trade Organisation in 2001, Shanghai was further opened up to the world, with transportation and port construction dramatically increasing at that stage. Pudong district has had the best opportunities to develop since the establishment of the free trade zone in 2013 and its constructed area, comprising warehousing, industries and transportation, will undergo further rapid expansion in the near future.

In this study, we hypothesised that socioeconomic factors would be key for spatiotemporal expansion and jointly affect on urban expansion. Specific objectives of the study were to determine: (1) the characteristics of urban expansion in Shanghai in the study period, including its intensity, direction and spatial pattern; and (2) the relative importance and joint effect of different social and economic driving factors. GIS technology and spatial analysis were used to analyse the intensity, direction and patterns of urban expansion in Shanghai over the 10-year study period (Figure 1).

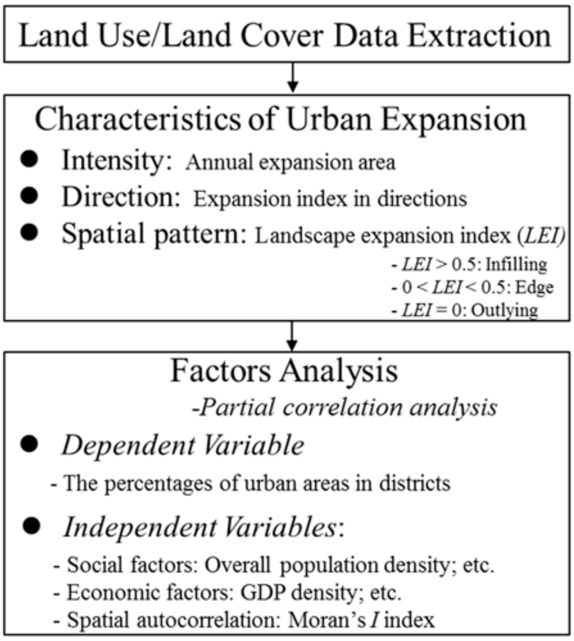


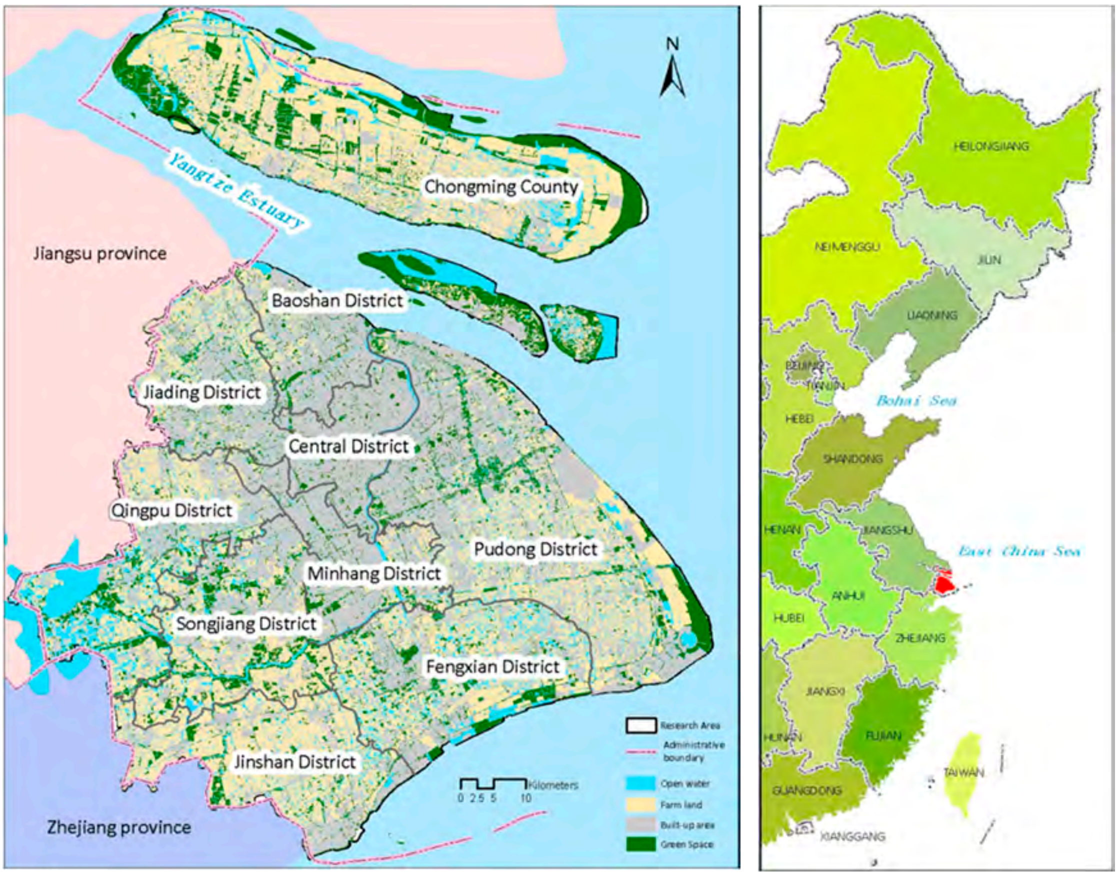
Figure 1. Workflow diagram of the research in this study.

2. Method

2.1. Study Area

Shanghai (lying between 30°40′–31°53′ N and 120°52′–122°12′ E) is located in the middle of China's coastline, on the eastern side of the Yangtze River delta, and occupies a total area of 6340 km^2 (Figure 2). As part of the Yangtze River delta alluvial plain the terrain is flat, with a mean elevation of 4 m and a highest point of 99.8 m. Shanghai has a subtropical monsoon climate, characterised by hot, humid summers but cold, wet winters. Mean annual temperature is 15.5 °C and mean annual precipitation is 1200 mm.

Shanghai is the economic, financial, commercial and shipping centre of China, which has experienced considerable socioeconomic transformation and urban expansion since 1978. The total population increased from 16.74 million in 2000 to 23.02 million in 2010. Gross domestic product (GDP) also increased rapidly in the same period, from 477.12 billion RMB in 2000 to 1716.60 billion RMB in 2010. The most well-known plans influencing Shanghai urban expansion during the study period were the general land use plan of Shanghai (1997–2010) and the Shanghai urban master plan (1999–2020). Both plans indicated that Shanghai would become a world-leading economic, financial and commercial centre, emphasising that Pudong district should play a leading role in development and opening up. Shanghai is composed of 16 districts (Baoshan, Jiading, Qingpu, Songjiang, Jinshan, Fengxian, Pudong, Minhang, Huangpu, Xuhui, Changning, Jingan, Putuo, Zhabei, Hongkou and Yangpu), the last eight of which are known as Central District, and one county (Chongming) (Figure 2). Farming is the major land use, occupying an area of 2321.13 km^2 (36.61% of total area) in 2010. However, urban development occupied 39.96% of total area by 2010.



(**A**) (**B**)

Figure 2. Maps showing (**A**) Shanghai and its different districts and (**B**) its geographical location on the coast of China.

2.2. Land Use/Land Cover (LULC) Data Extraction

Multi-temporal aerial images (spatial resolution 0.5 m) were used to extract land use/land cover (LULC) information on Shanghai in 2000, 2005, and 2010. The original aerial images were taken by helicopter in January in each study year. The duration of this data collection was nearly one month for the whole study area. The images were adjusted and assigned to a projection system (Universal Transverse Mercator, UTM) and then merged together in Erdas 9.3. The LULC information was extracted by visual interpretation in ArcGIS 10.0. The polygons of rivers and roads were first demarcated using onscreen digitisation. Other LULC polygons were then delineated by clipping existing polygons or adding new polygons. Accuracy assessment was conducted using data on 868 field GPS samples. We calculated the total accuracy, the user's accuracy, and the producer's accuracy. The total accuracy of the classification for 2010 with ground-based survey data was 95%. User's accuracy and producer's accuracy for residential land, for example, were 94% and 98%, respectively (Table S1). We did not conduct an accuracy assessment for 2000 and 2005, because the LULC maps for those two periods were derived from the 2010 LULC map. Urban area was defined in the analysis as developed land covered by impervious surface (e.g., residential land, commercial land, industrial land, roads) [10,30]. To facilitate the statistical analyses, information on urban areas was also extracted by subdividing the area into nine administrative districts and the percentages of urban area were then calculated. These nine districts were Baoshan, Jiading, Qingpu, Songjiang, Jinshan, Fengxian, Pudong, Minhang and Central District.

2.3. Quantifying the Intensity, Direction and Spatial Pattern of Urban Expansion

Annual expansion area was used to represent urban expansion intensity. It was calculated as:

$$I = \frac{\Delta U}{\Delta T} \tag{1}$$

where I is annual expansion intensity, ΔU is urban expansion area in the study period and ΔT is the time interval, usually years.

Information on urban expansion in eight directions (i.e., east, southeast, south, southwest, west, northwest, north and northeast) was extracted by taking People's Park as the central point, since it is in the city centre. Expansion index in each direction was used to detect the direction of urban expansion. It was calculated as:

$$SI = \frac{\Delta U_i}{S_i} \tag{2}$$

where SI is expansion index, ΔU_i is urban expansion area in the study period in direction i and S_i is total area in direction i.

Landscape expansion index (*LEI*) was used to represent the spatial pattern of urban expansion. Spatial expansion pattern can be categorised as falling into one of three types: infilling expansion, edge expansion and outlying expansion. As explained by Liu et al. [31], infilling refers to when a gap (or hole) between old patches or within an old patch is filled up with a newly grown patch. Edge expansion is defined as a newly grown patch spreading unidirectionally in more or less parallel strips from an edge. If the newly grown patch is isolated from the old, then it is defined as outlying expansion. In this study, the spatial expansion pattern was taken to be infilling expansion for $LEI > 0.5$; edge expansion for $0 < LEI < 0.5$; and outlying expansion for $LEI = 0$ (Liu et al., 2010). The value of *LEI* was determined based on buffer analysis in GIS. First, a 1-m buffer zone (as reported in Liu et al. [31] and supported by the image resolution in the present study) in each new urban patch was created; then, the original urban area and the empty area in each buffer zone were extracted. This allowed *LEI* to be calculated as:

$$LEI = \frac{U_o}{U_o + U_V} \tag{3}$$

where U_o is original urban area in the buffer zone and U_V is the blank area in the buffer zone.

2.4. Socioeconomic Indicator Selection

Socioeconomic development is one of the most important driving factors of urban expansion [10]. We assumed that socioeconomic factors would be key and jointly affect urban expansion. Specifically, two types of variables were selected to represent socioeconomic factors. These were social factors, which comprised overall population density (including rural population), and urban population density, and economic factors, which included GDP density, primary industry added value density, secondary industry added value density and tertiary industry added value density (Table 1).

The socioeconomic data available in the region were generally in the form of census data in administrative districts, so these data were collected by taking administrative districts as a unit from the Shanghai statistics yearbook in 2000, 2005, and 2010. For each year, nine groups of socioeconomic data (as independent variables) from 10 districts were extracted. Combined with the percentages of urban areas (as dependent variables) mentioned above, there were 27 samples of data for the following statistical analysis.

Table 1. Socioeconomic variables considered in this study.

Factors		Rep Reported/ Applied by	Definitions	Data Source
Social factors	Overall population density	[19,32]	Total population divided by the total area in a given research site, including urban population and rural population, person/km^2	Shanghai statistical yearbook 2000, 2005, and 2010
	Urban population density	[19]	Urban population divided by the total area in a given research site, person/km^2	
Economic factors	Gross domestic product (GDP) density	[19,32,33]	Gross domestic product divided by the total area in a given research site, million RMB/km^2	
	Primary industry added value density	[19]	Primary industry added value divided by the total area in a given research site, thousand RMB/km^2	
	Secondary industry added value density	[19,34]	Secondary industry added value divided by the total area in a given research site, thousand RMB/km^2	
	Tertiary industry added value density	[19,34]	Tertiary industry added value divided by the total area in a given research site, thousand RMB/km^2	

2.5. Spatial Autocorrelation

Spatial urban expansion is not a random process, but closely interlinked [35]. In this study, Moran's I index was used to test whether urban expansion in Shanghai is a random process. It was calculated as:

$$\text{Moran's } I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\overline{x})(x_j-\overline{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\overline{x})^2} \quad (4)$$

where x_i is the observed value in region i, w_{ij} is space weight, and n is the number of regions. Moran's I index was calculated using the Spatial statistics tools > Spatial autocorrelation (Moran's I) module in ArcGIS, taking the urban spatial distribution layer as input. Mean Moran's I index in each administrative district was then extracted as independent variables.

2.6. Factor Analysis

In order to eliminate the influences of the other variables, partial correlation analysis was used to explore the influence of the factors on urban expansion. Spatial autocorrelation was also taken into account. However, this study cannot remove the effect of temporal autocorrelation. The factor analysis was performed independently and is presented separately for each time period. The analysis was conducted using the Analyse > Correlate > Partial correlations in SPSS.

3. Results

3.1. Urban Expansion Characteristics

Constructed acreage within the study area ranged from 0 to 1892.66, 3428.83, and 2820.63 ha in 2000, 2005, and 2010, respectively, with a mean value of 1.86, 2.61, and 2.87 ha, and a standard deviation of 9.98, 18.42, and 15.33 ha, respectively. A significant positive spatial autocorrelation was observed for urban expansion (Moran's I = 0.013, 0.006, 0.009, $p < 0.01$) (Table 2).

Total constructed area was 1770.36, 2485.96, and 2855.44 km^2, in 2000, 2005, and 2010, respectively. Urban expansion was 715.60 km^2 in 2000–2005, and 369.48 km^2 in 2005–2010, with an annual expansion rate of 143.12 km^2 and 73.90 km^2 in these two sub-periods. The spatial distribution of urban expansion in Shanghai was determined for the whole area (Figure 3) and was also determined for 10 different census sub-areas in the city (Figure S1).

Table 2. Descriptive statistics on urban expansion (ha) and Moran's *I* index. S.D. = standard deviation.

	2000	2005	2010
Max	1892.66	3428.83	2820.63
Min	0	0	0
Mean	1.86	2.61	2.87
S.D.	9.98	18.42	15.33
Moran's *I*	0.013	0.006	0.009
Z score	33.38	20.81	29.18
p value	<0.01	<0.01	<0.01

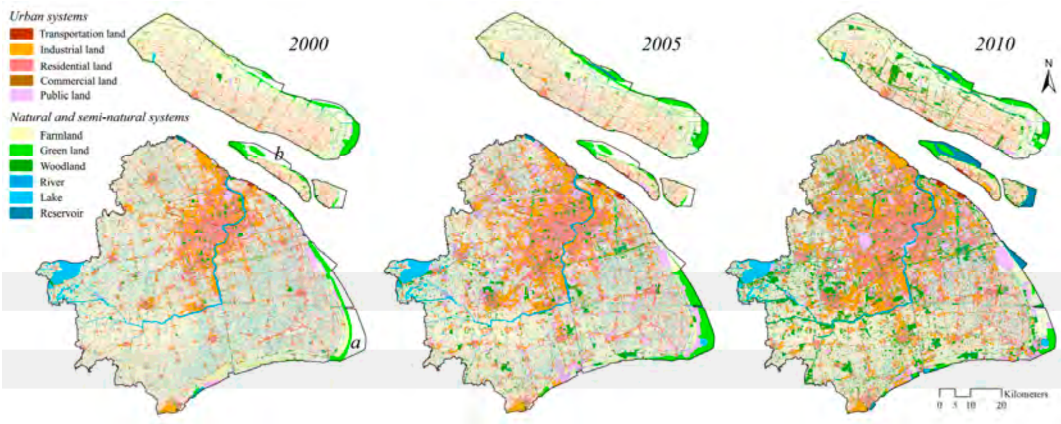


Figure 3. Map showing urban expansion in Shanghai in 2000, 2005, and 2010. (*a*, *b* were ocean in 2000. However, due to urbanisation, *a* was reclaimed from the sea in 2005; *b* was constructed as a reservoir, which is now the drinking water source for Shanghai residents).

Urban expansion in eight directions was extracted by taking People's Park as the central point. In general, urban expansion mainly took place towards the southwest (2000–2005), with an expansion of 160.61 km^2, and the southeast (2005–2010), with an expansion of 78.56 km^2 (Figure 4).

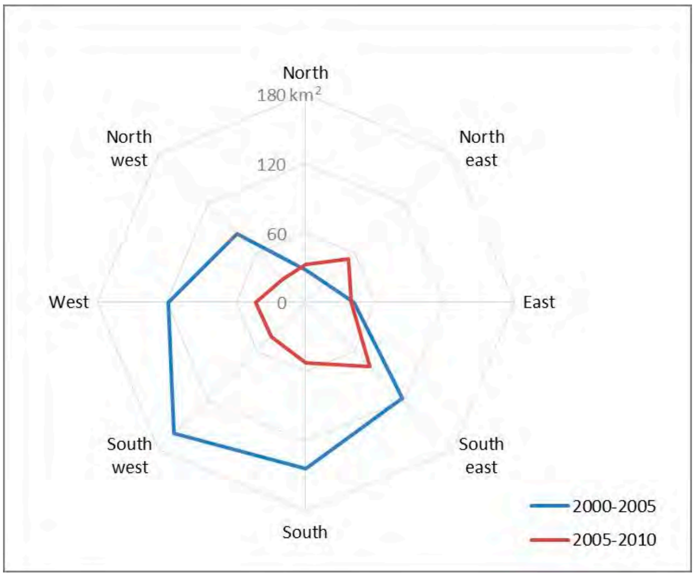


Figure 4. Urban expansion in eight different directions around Shanghai, 2000–2010.

Urban expansion in 2000–2005 was faster than in 2005–2010 in all directions except north and northeast.

Edge expansion was the main expansion pattern in both 2000–2005 (stage 1) and 2005–2010 (stage 2), accounting for 68.35% (48,912.80 ha) and 68.57% (25,333.48 ha) of the total expansion, with a mean value of 7.97 and 6.80 ha, and a standard deviation of 44.21 and 17.73 ha, respectively (Table 3 and Figure S2).

Infilling expansion decreased from stage 1 (22.06%; 15,784.16 ha) to stage 2 (18.86%; 6967.35 ha), while outlying expansion increased from stage 1 (9.59%; 6863.14 ha) to stage 2 (12.58%; 4647.17 ha) (Table 3). The spatial distribution of urban expansion pattern was also determined, as shown in Figure 5.

Table 3. Descriptive statistics on different expansion patterns. S.D. = standard deviation.

		Edge	Infilling	Outlying
2000–2005	Max	3187.18	236.20	92.48
	Min	0	0	0
	Mean	7.97	7.88	5.89
	S.D.	44.21	13.13	7.19
	Total Expansion	48,912.80	15,784.16	6863.14
2005–2010	Max	577.93	635.12	184.24
	Min	0	0	0
	Mean	6.80	6.96	6.53
	S.D.	17.73	21.43	12.54
	Total Expansion	25,333.48	6967.35	4647.17

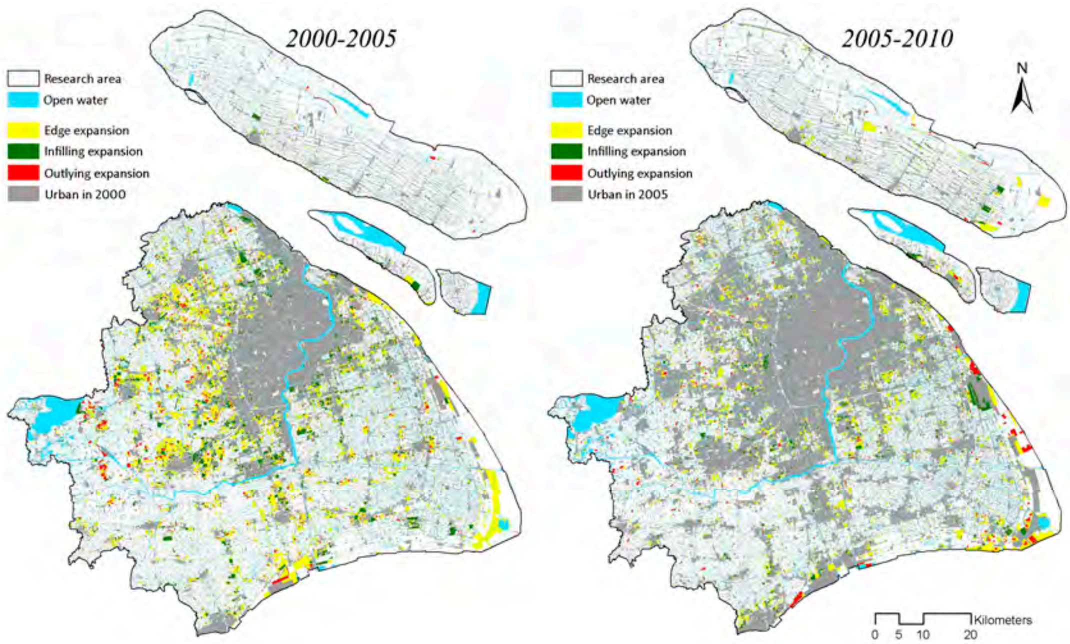


Figure 5. Spatial distribution and nature (outfilling, infilling, edge) of urban expansion pattern in Shanghai, 2000–2005 and 2005–2010.

3.2. Urban Expansion Factor Analysis

Various social and economic factors, as well as spatial autocorrelation factors, were selected to explore their influence on urban expansion (Table 4). According to partial correlation analysis, population density and urban population density had a significant positive correlation with percentage of urban area in 2000, with a partial correlation index of 0.941 and 0.867, respectively. In addition to population density and urban population density, GDP density and tertiary industry added value density were found to have a significant positive correlation with percentage of urban area in 2005. In 2010, population density and urban population density were also found to have a significant positive correlation with percentage of urban area. Generally, population density, urban population density and GDP density had significant positive influences on urban expansion during the three periods. Spatial autocorrelation had a positive impact on urban expansion. However, only 2005 and 2010 reached a significant level.

Table 4. Partial correlation analysis for each year.

	Population Density	Urban Population Density	GDP Density	Primary Industry Added Value Density	Secondary Industry Added Value Density	Tertiary Industry Added Value Density	Moran's *I* Index
2000	0.941 **	0.867 **	0.765 *	0.543	0.781 *	0.755 *	0.574
2005	0.982 **	0.979 **	0.944 **	−0.773 *	0.319	0.978 **	0.699 *
2010	0.976 **	0.926 **	0.761 *	−0.582	0.734 *	0.612	0.714 *

** $p < 0.01$; * $p < 0.05$.

4. Discussion

Shanghai experienced an obvious urban expansion process in 2000–2010. However, the intensity, direction and pattern of this urban expansion displayed significant differences across space and time. Not surprisingly, urban expansion intensity decreased between 2000–2005 and 2005–2010, in line with many other megacities in the process of urbanisation, for example, Beijing, London, and Tokyo [36–38]. However, urban expansion pattern is quite different among the megacities mentioned. Beijing and London, in the corresponding stage of urbanisation, were characterised as "expansion like a pie" [36], which means that urban area expanded gradually around the city centre. In contrast, the urban expansion pattern in Shanghai and Tokyo is known as the "satellite city" [38]. In this study, within the two stages of urban expansion there was mainly an edge expansion pattern, but the outlying expansion pattern increased and the filling expansion pattern decreased in 2005–2010 compared with 2000–2005. This meant that apart from edge expansion, urban expansion mainly filled in the gaps in existing constructed land in 2000–2005, while new land was exploited for construction in 2005–2010.

Analysis of urban expansion intensity and pattern thus clearly revealed the process of Shanghai's urbanisation and its phase, which will remind policymakers that Shanghai is still undergoing heavy urbanisation and that there is still time to set a limit. Urban planning has a great influence on urban expansion, especially in expansion direction. Shanghai's government has already stated in its 2040 urban master plan that constructed area will undergo zero growth or negative growth in coming decades [39]. Combined with information on urban expansion direction, the findings in this study on urban expansion intensity and pattern can have practical management implications. In the southwest of Shanghai's territory, the land cover is mainly farmland, indicating that urban expansion in the southwestern direction was mainly at the cost of farmland. In the southeast direction, urban expansion was mainly at the cost of both farmland and coastal natural habitat.

Based on this study, it can be concluded that urban expansion demand for land resources has continued to grow and the resulting urban expansion usually occupies farmland or natural habitat. Farmland and natural habitat can provide a number of vital ecosystem services that urban area cannot supply, including soil retention, carbon sequestration and biodiversity conservation [40]. In a coastal natural habitat area, these ecosystem services are scarce and valuable [41]. Therefore strong efforts should be devoted to controlling urban expansion into such areas around Shanghai.

Social systems, economic systems and natural systems are usually the main driving factors for LULC changes [5], and Shanghai proved to be no exception. By determining how those coupled systems drive LULC alteration in space and time, multi-scale land use dynamics and scenarios for decision making can be generated. The present analysis of social and economic factors affecting urban expansion in Shanghai city during the period of 2000–2010 revealed that socioeconomic drivers had a significant influence, as also shown in previous studies [11,42]. However, it was not possible to include all factors in this study due to the limited availability of data, which meant that some factors were not accessible and extractable. Moreover, some factors remain unknown at present, for example, policy, which is due to the nature of policy data. Physical factors, for example slope and elevation, introduced as the main driving factors of Beijing's urban expansion [10], were not considered in this study because Shanghai is a flood plain that has no obvious change in altitude and gradient. Natural factors in Shanghai, for example rainfall and temperature, have been studied by Liang et al. [43] and Cao et al. [44] and their results show that both rainfall and temperature had a close relationship with urban expansion rate in Shanghai in the period studied. However, natural processes are difficult to control and are integrated into landscape management [43]. Moreover, natural factors do not seem to influence Shanghai's urban expansion directly and are in fact likely to be influenced by urban expansion, for example, temperature is influenced by the urban heat island effect [45].

Policy usually has an overwhelming influence on urban expansion, especially in Shanghai. It is difficult to measure and integrate the policy effect into spatial analysis. With the Opening and Reform of China policy in 1978, Shanghai entered a stage of rapid urbanisation. Those planning policies, although having hysteresis effect on urban expansion, led Shanghai into rapid urbanisation since 2000. We found that urban area expanded by 715.60 km^2 in 2000–2005, mainly towards the southwest. Planning policies began to have an effect on Pudong district during 2005–2010. In this period, Pudong was working to become a world-class economic centre and shipping centre, causing the urban expansion direction of this period to be towards the southeast. In this study, social factors, for example population density, were found to be the main factors driving Shanghai's urban expansion, as they explained 72.3% of the total variation. This indicates that controlling urban population density would be an effective way to slow down the urbanisation rate. Reducing population density would benefit from optimising population spatial distribution. Convenient urban infrastructure, like transportation and medical treatment, as well as industrial structure, has a great impact on population distribution in cities [46]. Improving the population density of the central urban area and core industrial areas could result in reducing the population density elsewhere. This supports the idea of compact city construction and optimisation of industrial structure. Secondary industry added value density was also found in this study to be the main driving factor for urban expansion. Optimisation of industrial structure will optimise the industrial land distribution in space, which will have positive effects on urban expansion control.

With the help of GIS, RS and GPS technology and fine-resolution aerial images, this study selected urban expansion intensity, pattern and direction as indicators, and addressed an important international issue of how to comprehensively and quantitatively measure urban expansion. Fine-resolution aerial images allowed more precise and more sophisticated LULC data extraction and urban expansion characteristics analysis than sparse data sources, especially for urban spatial pattern analysis. By integrating the data with social and economic datasets, this study also analysed the mechanisms driving urban expansion, which has rarely been done in previous studies [5,47]. Moreover, by taking spatial-autocorrelation into account, the analysis more accurately revealed how joint social and economic factors influence urban expansion, which is an important complement to existing methodology [10]. When the results obtained here were compared with findings on other megacities worldwide [36,37], it was found that the urban expansion indicators tested can provide comprehensive information to reflect the process of urban expansion and the potential influence on ecosystems, which has clear practical applications for future urban decision making. The Shanghai government already limits its population density and the expansion of industry area in its 2040 master plan [39].

5. Conclusions

Using fine-resolution aerial images and GIS technology, Shanghai's urban expansion intensity, pattern and direction were analysed and the individual and combined effects of social, economic and spatial-autocorrelation influences on urban expansion were examined. It was found that social factors, especially population density, significantly affected urban expansion. Only seven variables were included in this study, however, and more potential variables (policies, slope, elevation and rainfall, etc.) need to be considered in the future. Moreover, since this study revealed that combined social and economic systems have a joint impact on urban expansion, future research should focus more on how urban expansion affects ecosystems and possibly ecosystem services. This will provide important information for optimising the landscape pattern and urban landscape management.

Supplementary Materials: The following are available online at www.mdpi.com/2071-1050/9/7/1199/s1.

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