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# Trends and Features of China's Urban Expansion from 1992 to 2012 Based on DMSP/OLS Data

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**Abstract.** Based on DMSP/OLS data, this study discusses the trends and features of China's urban land expansion in eight regions during 1992-2012. The results show that China's urban land area extracted using threshold values 8, 20, and 41 was inversely related to the threshold values and had a high reliability when DN≥20. There was the highest urban land proportion in the coastal region and the lowest in the western region. The intensity index of annual average expansion showed the similar change trend. For the speed of land urbanization was faster than that of population urbanization, the population density in urban areas tended to be sparse. The elasticity coefficient of urban land expansion had different characteristic in different region. Thus it is necessary to deal with the relationship between improving people's living condition and land conservation, and develop moderate compact cities in the process of urbanization.

**Keywords:** DMSP/OLS data, threshold classification, urban land area, urbanization, urban population density.

## 1. Introduction

The nighttime light data have been used widely in the study of urban geography and regional geography as the index of reflecting population density and socioeconomic activity development indirectly for the widespread use of electricity. DMSP/OLS data can effectively show the nighttime light situation in the earth surface, and has accuracy, economic and simple characteristics [1], so it has been used extensively in urban expansion [2], population simulation and prediction [3], economy development [4] and human healthy [5].

Delineating urban boundary is the key point in the study of urban issues applying DMSP/OLS data. Liu *et al.* got the optimal thresholds of eight regions in China in different periods based on Land-use/cover data [6]. Imhoff *et al.* extracted urban areas of 48 states in USA using mutation detection and the error of this result was less than 5 percent comparing with the census data [7]. Zhang *et al.* revealed the temporal and spatial changes in urbanization dynamics for China, India, Japan and the United States by applying an iterative unsupervised classification method [2]. Whereas other studies proved the same threshold used in different periods and regions was also feasible. Small *et al.* got the results that a 14% threshold (DN≥8) was the optimal value in 2000 and 1992/1993, and a 10% threshold for the 1994/1995 dataset set by comparing detection frequency threshold with cities' areas [8].

The rapid urbanization process in China has produced a broad and profound impact on resources and environment. Urban land areas extracted using different DN values in different regions [6] led to regions with a same DN value to generate differentiation in attribution. Using natural breaks classification method, the changes of urban land areas of eight regions in three periods were analyzed when thresholds were 8, 20, and 41 in this paper. This would reflect the spatial and temporal dynamics of urban land areas under different DN values and provide suggestions for the construction of new urbanization in China.

## 2. Data and Method

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China was divided into eight economic regions in the Coordinated Regional Development Strategy and Policy Reports [6]. They are Eastern Coast (EC), Northern Coast (NC), Southern Coast (SC), Middle Reaches of the Yangtze River (MRYTR), Northeast (NE), Middle Reaches of the Yellow River (MRYLR), Southwest (SW) and Northwest (NW), respectively (Fig. 1). This paper conducts to study according to eight regions.

## 3. Data

The nighttime stable light (NSL) data (version 4) were downloaded from NGDC website, including 3-years data (F101992, F152 002, F182012). The vector map was from 1:4,000,000 dataset published by the national fundamental geographic information system. Urban population data were obtained from the Sixth National Population Census Data in 2010 and built-up areas data were from China's Statistical Yearbook.

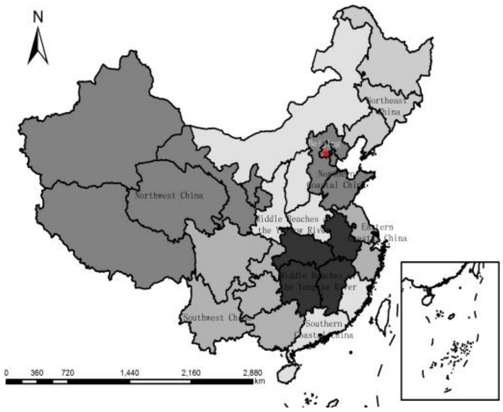


Fig. 1. Division of research region

## 4. Method

Firstly, NSL data were projected using Albers equal area projection and resampled to a pixel size of 1 km$^2$. Then, they are extracted according to eight regions' administrative boundaries for three periods. This paper assumed the pixel with the same DN value represented the same meaning in China. According to Small [8], Wang [9], Yang [10] and others' researches, this paper set the minimum DN threshold value as 8 and got three thresholds 8, 20, and 41, respectively, using natural breaks classification method. Took the threshold as the base and made a binarization processing: the value greater than and equal to the threshold was 1, on behalf of urban land, while less than the threshold was 0, representatives of non-urban land. The urban land areas were counted at three thresholds in three periods. The relevant measure indicators are as follows:

（1）The proportion of urban land area (%)：

$$p_{ij} = A_{ij} / A_j \times 100 \tag{1}$$

（2）The urban population density(per/km$^2$)：

$$d_{ij} = P_{ij} / A_{ij} \tag{2}$$

（3）The annual growth rate of urban land area (%)：

$$r_j = 100 \times \left( \sqrt[t]{\frac{A_{ij}}{A_{0j}}} - 1 \right) \tag{3}$$

（4）The annual average expansion intensity index of urban land area：

$$e_j = \frac{A_{ij} - A_{0j}}{tA_j} \times 100\% \tag{4}$$

（5）The elasticity coefficient of urban land expansion：

$$k_j = r_j / r_{pj} \tag{5}$$

Where $A_{0j}$ and $A_{ij}$ are the urban land areas in region $j$ in base year and $i$ year. $A_j$, $P_{ij}$ and $r_{pj}$ represent the total land area, the total urban population and the annual growth rate of urban population in region $j$. $t$ stands for the time interval.

## 5. Results

## 5.1. The urban land area change under three thresholds

Light threshold is inversely related to the urban land area. The features of eight regions show the same trend in three periods (Fig. 2). While great difference exists among different DN values in the same year.

In 1992, the total urban land area extracted was 222776 $km^2$ at DN≥8, which was 3.8 times of DN≥20 and 12.5 times of DN≥41. It is relatively close to statistical data of 211889.62 $km^2$ from the Ministry of Land and the result of 207742 $km^2$ from He *et al.* who extracted using DMSP/OLS nighttime light based on statistical data [11]. The urban land area accounted above 2% of total land area. The urban population density was about 1500 per/$km^2$ which was lower than the actual population density, implying the urban land area extracted at DN≥8 was too large. The urban land area was 58932 $km^2$ and urban population density was nearly 5459 per/$km^2$ at DN≥20. The urban land area was 17893 $km^2$ which was close to built-up area 17415 $km^2$ from the China Statistical Yearbook and the urban population density was nearly 17979 per/$km^2$ at DN≥41. Although some cities were densely populated in 1992, the average urban population density in China was not so dense. Therefore, using DN≥20 to extract urban land area is relatively reasonable.

After 1992, China's urbanization process has accelerated and the urban landscape enters a rapid expansion period. Lots of cities were epitaxial growth and the original suburban urbanized. The amount of cities increased from 570 to 660 and towns increased from 14539 to 20601 after new establishment of a group of cities and towns. The urbanization rate increased from 27.45% to 39.1% and the new added urban population reached to 180 million during 1992 to 2002. So both the original urban size expansion and the new towns establishment made urban land rise in this period. The total urban land areas were 424488, 144716, and 55640 $km^2$ at DN≥8, DN≥20, and DN≥41 in 2002, respectively, which were much larger than the statistic data of 25972.46 $km^2$. The urban population densities were 1183, 3470, and 9024 per/ $km^2$ in decade at three DN values, respectively. The faster land urbanization promoted the urban population to mitigate. In comparison, the urban land area extracted at DN≥20 is more convincing.

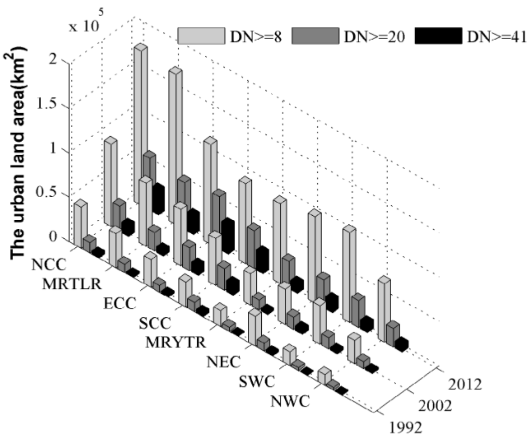


Fig. 2. The urban land areas under different DN values in three periods（$km^2$）

The urbanization process accelerates further as the rapid economic development when China enters into WTO in 2002. Although the amount of newly established cities and towns were limited, the original towns spread rapidly. Lots of cities set some industrial parks, technology economic development zones, new urban areas, residential areas, logistics parks and tourist attractions in suburbs and urban landscape entities expanded. In 2012, the total urban land area extracted increased a lot. They were 899567, 325588, and 145321 $km^2$ at DN≥8, DN≥20, and DN≥41, respectively, which exceeded much larger than the statistic data of 45566 $km^2$. The great difference is due to most of new construction land was not included in the urban districts of the statistical data. The urbanization rate reached 52.57% and newly increased urban population was 210 million during 2002-2012. The speed of population urbanization was slower than that of land urbanization. The urban population densities were 791, 2186, and 4899 per/ $km^2$ at DN≥8, DN≥20, and DN≥41, which were lower than that of in 2002. Research data from the World Bank shows that China's urban land area takes 4.4% of the total area in 2008, about 420000 $km^2$ [12], which is close to 325588 $km^2$ in this study (excluding Hongkong, Macao and Taiwan regions) at DN≥20 in 2012. This indicates that the urban land area at DN≥20 is more reliability.

It is difficult to give accurate urban land areas due to the following reasons: (1) Lack of clear definition of urban construction land; (2) different statistics caliber data include different spatial scales; (3) some differences exist in regions and periods; (4) we do not find more circumstantial evidence and effective inspection methods. However, what sure is: (1) the growth of urban land is stronger; (2) the urban land area extracted at DN≥20 has stronger explanatory power; (3) land urbanization is faster than population urbanization and urban population density tends to be sparse; (4) the urban land area extracted using DMSP/OLS data has some reference value.

## 5.2. Comparison of land use changes in urban areas among eight regions

The proportion of urban land area can reflect land urbanization level and is inversely related to light threshold (Table 1). China's land urbanization level could be divided into three categories from the results. Three coastal regions were the high-value category, of which the EC was the highest and the NC and SC were lower in 2012 at DN≥20. The MRYTR, MRYLR and NE were the middle-value category and the proportions were around 4% in 2012 at DN≥20. Among them, the MRYTR had larger increase at DN≥8 and DN≥20, while the NE had the largest increase at DN≥41. The SW and NW were the low-value category in 2012 at DN≥20. The sparsely populated NW had the lowest proportion. The overall land urbanization pattern was high in eastern, low in western and middle in center regions.

Table 1: The proportions of urban land areas under different thresholds (%)

| Region | DN≥8 | | | DN≥20 | | | DN≥41 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1992 | 2002 | 2012 | 1992 | 2002 | 2012 | 1992 | 2002 | 2012 |
| EC | 14.95 | 30.35 | 53.75 | 3.57 | 12.31 | 28.22 | 1.13 | 5.24 | 15.45 |
| NC | 12.54 | 25.17 | 47.07 | 3.19 | 7.72 | 15.74 | 0.96 | 3.18 | 7.33 |
| SC | 8.46 | 15.90 | 27.08 | 3.18 | 7.36 | 12.87 | 1.26 | 3.66 | 6.79 |
| MRYTR | 2.53 | 4.98 | 12.73 | 0.65 | 1.55 | 4.28 | 0.18 | 0.47 | 1.47 |
| NE | 4.25 | 5.04 | 12.30 | 1.11 | 1.76 | 4.00 | 0.33 | 0.71 | 1.81 |
| MRYLR | 2.29 | 4.23 | 10.11 | 0.56 | 1.24 | 3.15 | 0.13 | 0.37 | 1.22 |
| SW | 1.13 | 3.18 | 7.45 | 0.25 | 0.93 | 2.22 | 0.06 | 0.24 | 0.74 |
| NW | 0.30 | 0.66 | 1.64 | 0.08 | 0.19 | 0.53 | 0.02 | 0.06 | 0.20 |

The urban population density is positively related to the threshold (Table 2). The urban population densities in the SW and the MRYTR were largest at DN≥41 in 1992 and far more than the resident population density 23896 per/km$^2$ in Tianjin in 2010[13]. The value is obviously unreasonable, indicating that the urban land areas extracted of the two regions were too small and reflecting DN≥41 was not applicable. The urban population densities of eight regions were between 406-1223 per/km$^2$ at DN≥8 in 2012, which were obviously too low. The urban land area at DN≥20 had a good explanation effect. The urban population density decreased over time under the same threshold reflecting that the speed of urban population growth was slower than that of urban land expansion. The urban population density of the SW was the highest, the MRYTR was the second highest and the SC was the lowest at DN≥20 in 1992. In 2002 and 2012, the urban population density of the MRYTR was the highest, the SW was the second highest and the NW was the lowest. The density change of urban population was lack of spatial tendency.

Table 2: The urban population densities under different thresholds (per/km$^2$)

| Region | DN≥8 | | | DN≥20 | | | DN≥41 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1992 | 2002 | 2012 | 1992 | 2002 | 2012 | 1992 | 2002 | 2012 |
| EC | 1326 | 1165 | 976 | 5565 | 2874 | 1860 | 17485 | 6757 | 3397 |
| NC | 1130 | 819 | 666 | 4450 | 2670 | 1994 | 14753 | 6475 | 4283 |
| SC | 1283 | 1327 | 1130 | 3415 | 2868 | 2378 | 8582 | 5767 | 4506 |
| MRYTR | 2740 | 2180 | 1223 | 10658 | 7026 | 3642 | 38606 | 23148 | 10614 |
| NE | 1453 | 1432 | 666 | 5559 | 4102 | 2052 | 18807 | 10173 | 4543 |
| MRYLR | 1028 | 842 | 542 | 4242 | 2861 | 1739 | 17718 | 9620 | 4477 |
| SW | 2813 | 1586 | 998 | 12593 | 5420 | 3353 | 51599 | 20816 | 10031 |
| NW | 1101 | 688 | 406 | 4297 | 2342 | 1273 | 15553 | 7638 | 3267 |

## 5.3. The expansion intensity index and elasticity coefficient of urban land

The cardinal numbers of indicators are quite different owing to dense population in east China and sparse population in the west. The expansion intensity index and elasticity coefficient of urban land can further compare the regional variation range under different thresholds in 1992-2002( i ) and 2002-2012( ii ).

Fig. 3 shows the annual growth rate of urban land area in two phases ( i and ii ). The annual growth rates of urban land areas in three coastal regions and the SW were larger in 1992-2002 than that in 2002-2012 for the rapid socioeconomic development in early stage. While the results in other regions were opposite due to the lagging socioeconomic development.

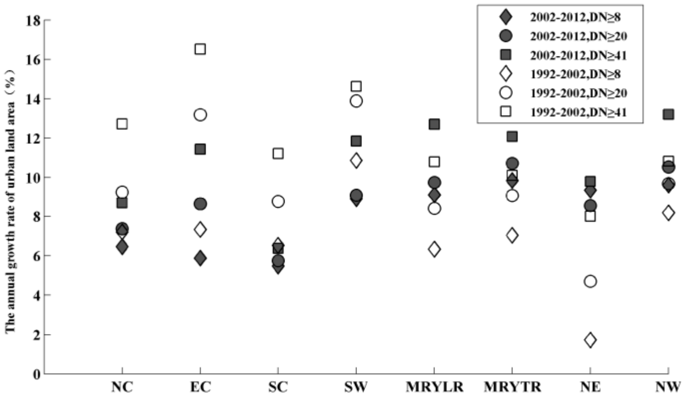

Fig. 3. The annual growth rate of urban land area (%)

The annual average expansion intensity index of urban land area is more comparable (Table 3). The results showed that the annual average expansion intensity index was larger in 2002-2012 than that in 1992-2002 of each region under the same DN value. The intensity index decreased with the increase threshold in the same phase. The intensity indexes in three coastal regions were large and the highest was the EC at DN≥20. The following was the MRYTR, MRYLR, NE and SW, respectively. The lowest was the NW at DN≥20. The equally newly increased urban land area in the densely populated coastal region accounted for a larger proportion of the total land area, while in the sparsely populated western region accounted for a smaller proportion.

Table 3: The annual average expansion intensity indexes and elasticity coefficient of urban land expansion and the annual growth rate of urban population

| Region | Annual average expansion intensity indexes | | | | | | Elasticity coefficient of urban land expansion | | | | | | Urban population annual growth rate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DN≥8 | | DN≥20 | | DN≥41 | | DN≥8 | | DN≥20 | | DN≥41 | | | |
| | i | ii | i | ii | i | ii | i | ii | i | ii | i | ii | i | ii |
| EC | 1.539 | 2.340 | 0.874 | 1.591 | 0.410 | 1.022 | 1.23 | 1.46 | 2.21 | 2.15 | 2.27 | 2.84 | 5.96 | 4.02 |
| NC | 1.262 | 2.191 | 0.453 | 0.802 | 0.222 | 0.414 | 1.89 | 1.51 | 2.43 | 1.72 | 3.34 | 2.02 | 3.81 | 4.29 |
| SC | 0.744 | 1.118 | 0.418 | 0.551 | 0.240 | 0.313 | 0.95 | 1.45 | 1.27 | 1.52 | 1.63 | 1.69 | 6.88 | 3.78 |
| MRYTR | 0.246 | 0.775 | 0.090 | 0.273 | 0.029 | 0.100 | 1.52 | 2.68 | 1.96 | 2.92 | 2.19 | 3.29 | 4.61 | 3.67 |
| NE | 0.079 | 0.726 | 0.065 | 0.224 | 0.038 | 0.110 | 1.09 | 7.26 | 2.99 | 6.65 | 5.09 | 7.62 | 1.57 | 1.29 |
| MRYLR | 0.194 | 0.588 | 0.069 | 0.191 | 0.024 | 0.085 | 1.50 | 2.07 | 1.99 | 2.21 | 2.55 | 2.88 | 4.23 | 4.41 |
| SW | 0.204 | 0.427 | 0.068 | 0.129 | 0.018 | 0.050 | 2.32 | 2.24 | 2.97 | 2.29 | 3.12 | 2.98 | 4.68 | 3.97 |
| NW | 0.036 | 0.099 | 0.012 | 0.033 | 0.004 | 0.015 | 2.55 | 2.41 | 3.01 | 2.64 | 3.37 | 3.31 | 3.21 | 3.99 |

The elasticity coefficient is an indicator to test the rationality of urban land use. Previous studies has pointed out that the elasticity coefficient of 1.12 was the reasonable state of urban land use [14].

The annual growth rates of urban population in 1992-2002 and 2002-2012 for eight regions were also calculated according to China Statistical Yearbook and the Sixth National Population Census Data 2010. The results show that the NE had the lowest population growth rates. While the rates of other seven regions were above 3%, of which the SC and EC had the highest growth rate with the quantity of 6.88 % and 5.96% in 1992-2002 and the MRYLR, EC and NC increased most rapidly with the rate more than 4% in 2002-2012.

In addition to the SC and NE in the prior period, the rest elasticity coefficients of urban land expansion were greater than 1.12. The result meant that the growth of China's urban land area was too fast and its land use was unreasonable. With the increase of DN value, the elasticity coefficient increased in the same stage and was consistent with the annual growth rate of urban land. Different regions showed different change trend under the same DN value. It should be noted that the elasticity coefficient in the NE was high in prior period at DN≥41 due to its slower growth of urban population and became the highest in later period, which meant there is a serious waste of land resources. This conclusion is consist with Yin’s study [15].

### 5.4. The space distribution of urban land expansion under three thresholds

The town’s density changes from dense to sparse with the increase of DN value with 1 $km^2$ pixel (Fig. 4). The findings at DN≥20 are similar to Li’s results [5]. The coastal region showed flaky or ribbon development style relying on favorable terrain and urban clusters. The most highly dense regions appeared in the Pearl River Delta, Yangtze River Delta and Bohai Bay. The brightness of light in some small coastal towns was even higher than that of some small cities in western. The second highest density regions were mainly distributed in Harbin - Changchun - Shenyang line in Northeast, the Luoyang - Zhengzhou - Kaifeng line in Central Plain, Chengdu - Chongqing region, Jianghan plain, Fen River Basin, Guanzhong Basin, Chang - Zhu - Tan regions. Then were some capital cities in Midwest.

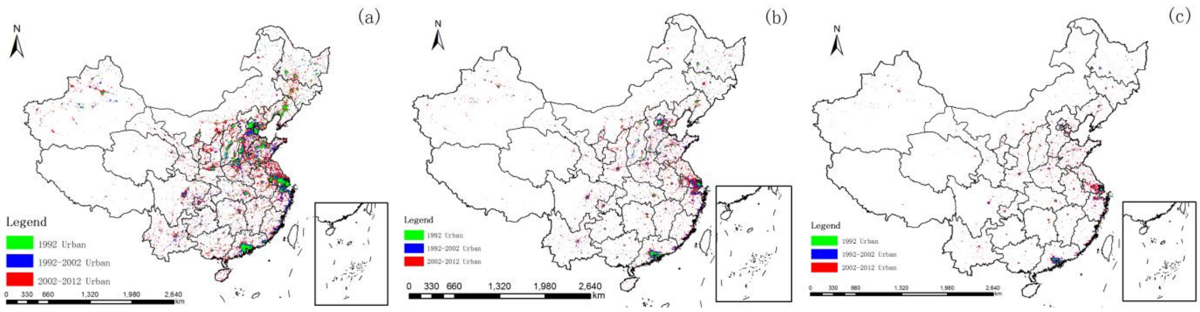


Fig. 4. The urban space expansion at DN≥8 (a), DN≥20 (b) and DN≥41 (c)

## 6. Conclusion

By extracting urban land area under three thresholds 8, 20, and 41, the study revealed that light threshold is inversely related to the urban land area. Combined with five indicator analyses, this study found that the urban land area extracted at DN≥20 has high reliability in China. The urban land areas in China were respectively 58932, 144716, and 325588 $km^2$ in 1992, 2002, and 2012 at DN≥20. Accordingly, the urban population densities were respectively 5459, 3470, and 2186 per/$km^2$. The speed of land urbanization was faster than that of population urbanization and the urban population density tended to be sparse and decreased by 1.5 times nearly 20 years.

The proportions of urban land area in eight regions can be divided into three categories: three coastal regions are in high-value group, the western regions are in low-value group and the middle regions are in central-value group. The trend of annual average expansion intensity index of urban land area is similar to the trend of urban land proportion. Urban population density changes of eight regions lack spatial tendency. The change of urban land expansion elasticity coefficient shows different characteristics in different regions, and the remarkably feature is the high elasticity coefficient value in Northeast for its slowly urban population increase.

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