

Analyzing Cities with the Global Human Settlement Layer: A Methodology to Compare Urban Growth Using Remote Sensing Data



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Abstract Data is a key resource to analyze and compare cities and to track urbanization processes and changes in cities. Nowadays, innovative procedures for acquiring and processing remote imagery provide analysts and policy makers with globally consistent multitemporal data on human settlements, which promise unprecedented advances in urban analysis. The Global Human Settlement Layer (GHSL) has been developed by the European Commission Joint Research Centre. It contains fine-scale global and multitemporal geospatial data on populations and built-up areas. The GHSL opens the possibility to study all cities in a globally consistent and comparative way. This study proposes a new methodology to work on the GHSL at city level and to monitor the process of urban expansion, both in terms of spatial footprint and population dynamics. The methodology introduces seven indicators: area [in km²], population [inhabitants], built-up [square kilometers], built-up to area ratio, population density [inhabitants per square kilometer], and built-up and area per capita [in square meters]. The changes across reference points in the years 1975–1990 to 2000–2015 are used to monitor and benchmark urban growth and expansion. This research paper illustrates the methodological procedure for data preparation, and it explains the GHSL-derived indicators for monitoring urban analysis. The second part of the research applies the methodology to the Chinese cities of Beijing and Guangzhou to analyze, by a comparative perspective, the two cases. The paper contains data analysis capturing the dynamics of growth of urban areas, population, and built-up surfaces between 1975 and 2015. Guangzhou and Beijing are representative examples of rapid urbanization: Beijing grew faster than Guangzhou in the period 1990–2015 in terms of population, while built-up growth over the same years has been faster in Guangzhou. The comparison of the two cities elicits interesting phenomena such as the different speeds of population and built-up growth in the period 1990–2015.

Keywords Urbanization · Remote sensing data · Megacities · GHSL

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1 Introduction

Data for policy making and analysis are among the key priorities for the future of sustainable urban development as it emerges from the data revolution being promoted at the level of the United Nations. Territorial analysis is among the sectors in which technological innovations has enabled remarkable advances in the way in which analyses are carried out (Geertman et al. 2013). The more systematic use of evidences and data is needed by institutions to improve policy making and by scientists to open new scenarios for modelling and to understand the processes that significantly shape the territory. Contemporary technology enables the production of fine-scale data on human settlements that is useful within several thematic domains, including emergency response, transport, ICT-related information, and energy, among others.

The European Commission Joint Research Centre has developed, between 2010 and 2016, the Global Human Settlements Layer (GHSL), which contains fine-scale data on populations and built-up areas for the entire globe for the epochs 1975–1990 to 2000–2015 (Pesaresi et al. 2016).

The GHSL is part of the key dataset of the Group on Earth Observation (GEO) Human Planet Initiative, and it is also supported by the Directorate-General for Regional and Urban Policy of the European Commission.

The JRC GHSL project team released in October 2016 the Atlas of the Human Planet 2016 (Pesaresi et al. 2016), which contains novel analytics of the GHSL data and showcases the trends in global urbanization since 1975. The atlas analyses the patterns of growth of human settlements around the globe in terms of population dynamics and increases of built-up areas, maintaining the analysis at the continental or national level. The GHSL also offers the possibility to analyze individual human settlements in a globally consistent and comparative way, disaggregating the statistics. Preliminary feasibility tests on the use of GHSL for city analysis were applied to rank cities by total population, built/up area and built/up per capita (Melchiorri and Siragusa 2016). On the basis of that research stream, this paper further explores the potential use the GHSL to implement multi-temporal analysis of urban growth. The scope of the paper is twofold: on the one hand, to elaborate a set of indicators to be used together with GHSL baseline data for urban analysis; on the other hand, to test these indicators in two case-study cities, Guangzhou and Beijing (China). Guangzhou is the biggest urban center¹ in the world per population and area, and fourth per built-up (Melchiorri and Siragusa 2016), while Beijing is the world greatest urban cluster with a population exceeding 100 million (Pesaresi et al. 2016).

¹A *city center* is an agglomeration with a density greater than 1500 people per km² and more than 50,000 total inhabitants, while an *urban cluster* is a cluster of cells with more than 300 people per km² and at least 5000 inhabitants and (Dijkstra and Poelman, “A harmonised definition of cities and rural areas: the new degree of urbanisation”).

This research proposes statistical data in tables and maps to describe the process of expansion in these two cities during the period 1975–2015.

The study feeds the stream of research in urban analysis with big-data and remote sensing. In 2011, Taubenböck et al. (2012) provided a comparative analysis of megacities growth between 1975 and 2010 on the basis of Landsat images.

The relevance of this new effort stands on two guiding research questions that attain methodological and content-related matters. On the one hand, it is relevant to elaborate on the potential of the GHSL and therefore to identify which are the suitable indicators that can be monitored with its baseline data; on the other, having provided a portfolio of seven indicators, it is consequential to apply them to test case studies.

In the paper, we provide evidence to show that, in the 40 years between 1975 and 2015, the cities of Beijing and Guangzhou have undergone a swift and stark expansion, both in terms of population and built-up areas. According to the GHSL datasets, the two cities, while both witnessing expansion, have shown different growth paths in terms of built-up to area ratio and built-up per capita.

The paper is framed as a contribution to stimulate the debate providing scientific input to the world policy debate about indicators sustainable urbanization monitoring.

2 Methodology

The paper addresses the opportunity provided by the GHSL to bring the analysis of population and built-up areas (and related indexes) from a national-continental level to a city one, addressing urban analysis. Through the set of tested indicators and the use of the GHSL data, it is potentially possible to analyze, in a comparative and consistent way, over 13,000 urban centers around the world, namely, the settlements that exceed a population of 50,000. The GHSL contains three thematic sets of information: the first layer accounts built-up areas of human settlements, the second contains the population information based on population grids and the third the settlement model that classifies urban and rural settlements. The set of definitions and methodological concepts used in the GHSL production are contained in the technical report “Operating procedure for the production of the Global Human Settlement Layer from Landsat data of the epochs 1975, 1990, 2000, and 2014” (Pesaresi et al. 2016). The GHSL-baseline data is obtained from the processing of large masses of data collected from three main sources: Earth Observation satellite sensors (Landsat satellite imagery), national statistical surveys collected in the CIESIN’s Population grids and crowd sources such as voluntary geographic information (VGI). The main GHSL product is the built-up layer with reports the values of built-up areas of each pixel (approximately 38×38 m). A built-up area is typically expressed with continuous values representing the proportion of building-footprint area within the total size of the cell. This paper takes the baseline data of the GHSL built-up and population layers to extract the statistics of the two

selected Chinese cities: Beijing and Guangzhou. These two cities were selected as representative samples of the urbanization process that has been taking place in China.

This paper analyses the two cities on the basis of three plain data estimating the population in the human settlements, the area of built-up areas (in hectares), the area of the settlements (in hectares), and four additional indicators derived as ratios from the three plain data above: population density (inhabitants per km²), built-up per capita (m² per inhabitant), area per capita and built-up to area ratio (as a percentage).

- (a) Population—estimates the total number of inhabitants modelled by the GHSL in the urban center. The population is assigned to each pixel downscaling the CIESIN population grids at 10 km of resolution (CIESIN 2016) according to the built-up presence detected from the GHSL;
- (b) Built-up areas—estimates the total surface covered by built-up structures as classified by the definition in Pesaresi et al. (2013);
- (c) Area of the human settlement—estimates the physical extension of the urban center;
- (d) Population density—estimates the number of modelled inhabitants over the total built-up surfaces; it is calculated as a ratio of population over the area of the settlement;
- (e) Built-up per capita—estimates the amount of built-up of constructions theoretically available per person modelled in the settlement; it is obtained as the ratio between the total built-up and the population of the settlement;
- (f) Area per capita—estimates the surface of city area available per each inhabitant; it is calculated as the ratio of urban area over population;
- (g) Built-up to area ratio—is a percentage and describes the degree of the settlements' area that is covered by buildings.

These seven indicators can describe both the physical structure of human settlements (area, built-up and built-up to area ratio), as well as provide information about principles of sustainable urban planning such as population density that are considered key indicators by UN-Habitat and OECD (UN-Habitat 2015; OECD 2012).

The comparative analysis has been carried out with GIS technology and through spreadsheet computation and analytics.

The choice of the two case-study cities is due to the swift process of expansion that human settlements in China are experiencing. In China, between 1975 and 2015, 65 cities doubled their populations and around 100 had populations that increased 1.5 times. In 2015, the urban population in China exceeds 1.22 billion, with a 20% increase since 1990: overall, 88% of the Chinese population lives in urban areas (Pesaresi et al. 2016). With about 17% of the global population living in Chinese cities, it is of great interest to develop a methodology and a case analysis to understand how this tremendous growth has taken place and which physical characteristics it has assumed.

3 Results

This section presents tables, charts and maps to portray the process of urban growth that occurred in Beijing and Guangzhou between 1975 and 2015. It is important to recall that the Chinese context has significantly evolved within this timeframe. The GHSL gathers data about the status of human settlements in China since 1975, an epoch in which significantly different planning policies had been applied in China. Between the 1980s and early 1990s, China had undergone a process of economic opening. Indeed, these 40 years coincide with the period of unprecedented growth of the Chinese economy—including an average GDP growth of some 10% a year, construction of modern infrastructures and development and modernization of its society.

Since Beijing and Guangzhou are two considerably different cities, they are separately analyzed in dedicated sections, and then a comparison of the contrasting trends for the seven indicators is provided.

3.1 *Beijing*

Beijing, the capital city of the People's Republic of China, is located in the north-eastern part of the country. In 1975, the area of Beijing was slightly less than 1000 ha and its population above 2.8 million. Over the past 40 years, its area has tripled from 1000 to 3000 ha, and its population has increased by seven-fold, up to nearly 20 million. Figure 1 and following show the process of expansion of Beijing. Two distinct urban centers in 1975 fill the area enclosed by the blue line (the perimeter of Beijing in 2015). In the period 1975–1990 the city developed broadly towards south-west (i.e. Liangxiang), and around poles in the northern part (i.e. Channping and Shunyi). Between 2000 and 2015, the population tripled—equivalent to more than 9 million people. In spatial terms, the city has saturated the south and north edges (Figs. 2, 3 and 4). The built-up area also tripled, while the total area increased at a faster rate than the built-up, by an average of 6% per year between 1975 and 1990. The growth of population in Beijing has been faster than the built-up expansion. It follows that built-up per capita has declined: between 2000 and 2015, it shrunk by one-third, and in 2015 (at 111 m² per capita), it is half that of 1990 (229 m²). The built-up to area ratio, after increasing from 76 to 83% between 1975 and 1990, declined to 81% in 2000, returning to around the 1975 level in 2015 (see Chart 1). Area per capita has constantly decreased since 1975; today's area per capita of 151 m² per inhabitant is less than one-third that of 1975 (Table 1).

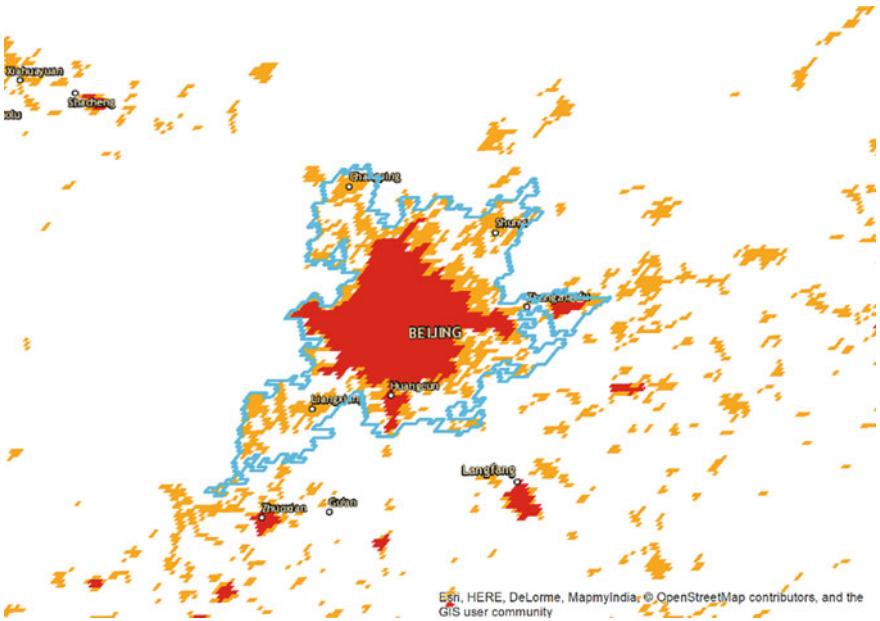


Fig. 1 Beijing 1975: 96 ha area, 2.8 million population (2015 perimeter of the urban center in blue)

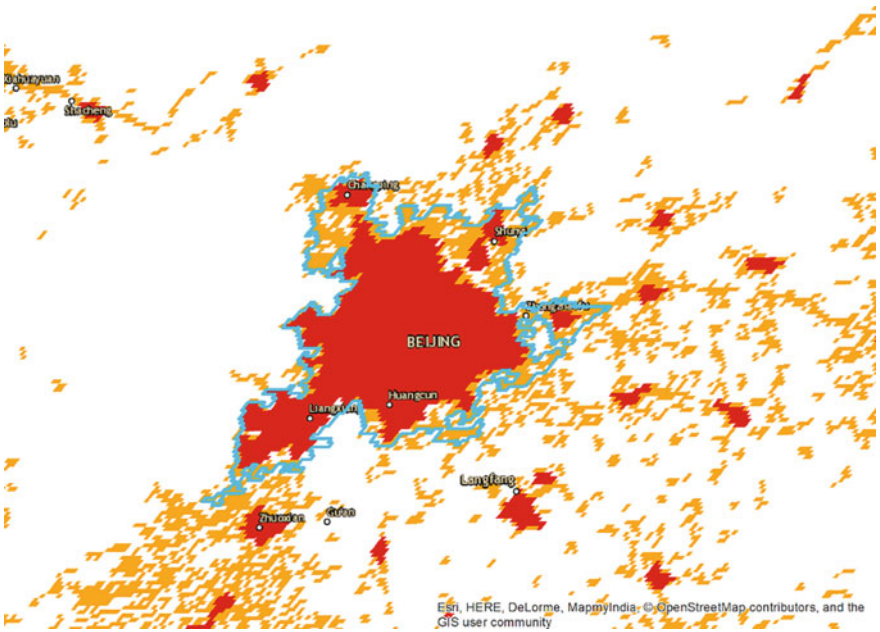


Fig. 2 Beijing 1990: 1900 ha (+918 ha area doubled); 6.9 million people (+ 4.07, 2.4 times 1975 one)

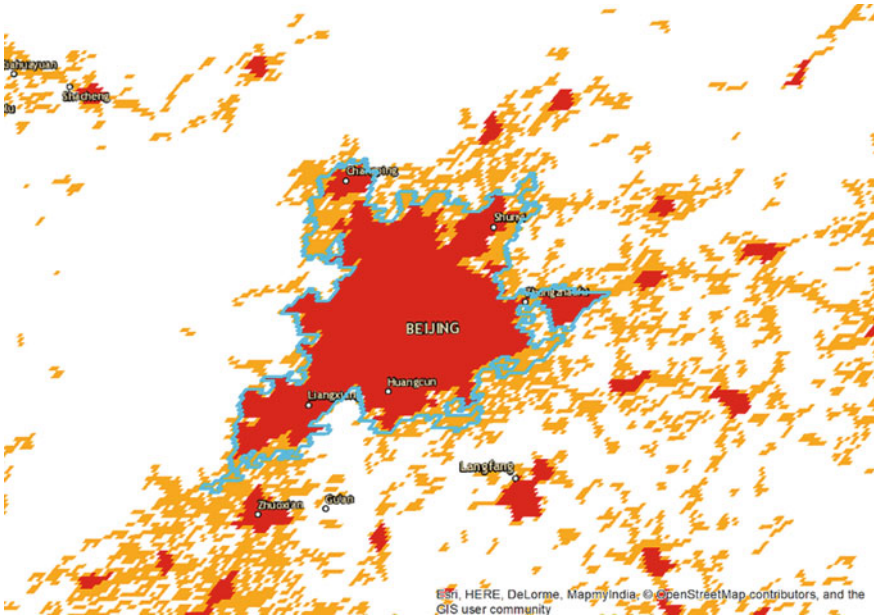


Fig. 3 Beijing 2000: 2100 ha (+268 ha, +14%); 10.8 million people (+56%)

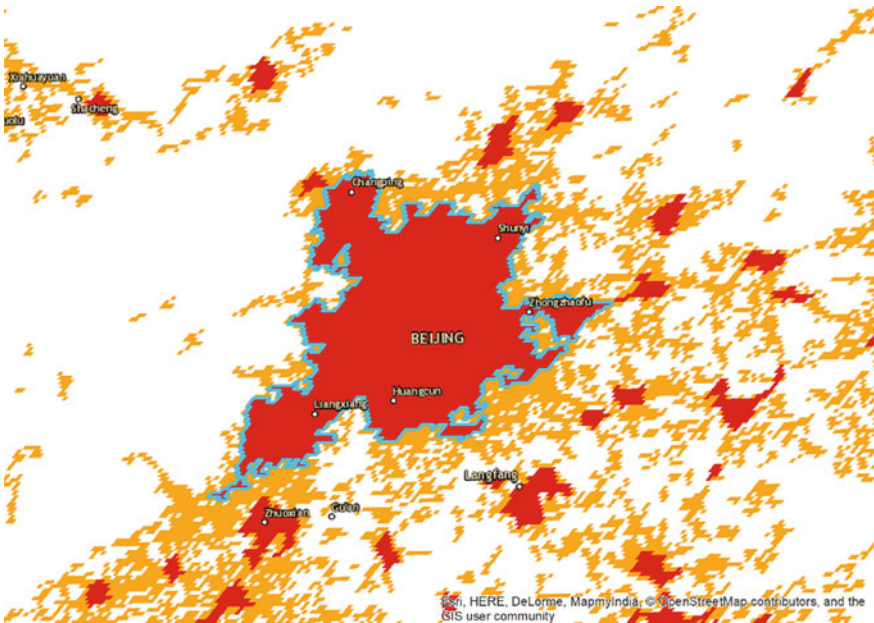


Fig. 4 3000 ha area (+815 ha, +37.4%); 19.9 million people (+9.1, 1.8 times increase)

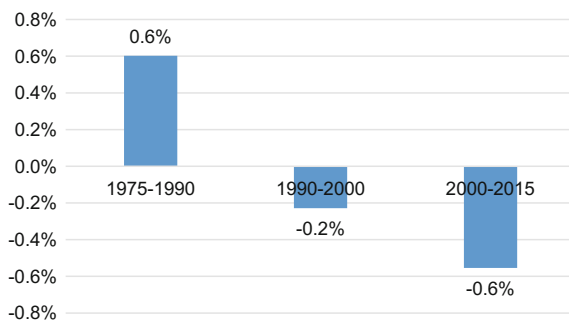


Chart 1 Changes in built-up to area period

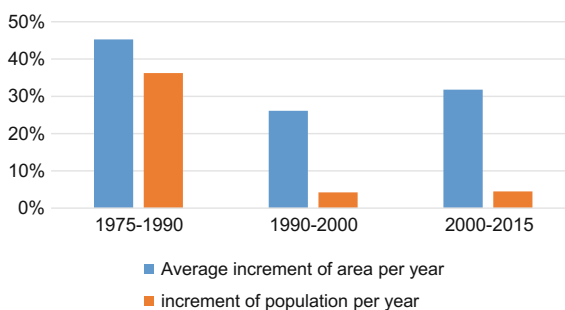
Table 1 Beijing Indicators 1975–1990 to 2000–2015

Beijing				
	1975	1990	2000	2015
Area (ha)	995	1915	2180	2995
Population	2,834,000	6,904,000	10,804,000	19,902,000
Built-up (ha)	755	1580	17,600	2200
BU/Area ratio (%)	75.7	82.6	80.7	74.0
Population density (inhab/ha)	2845.5	3607.4	4951.7	6640.6
Built-up per capita (m ²)	266.2	228.9	163.0	111.4
Area per capita (m ²)	351.4	277.2	202.0	150.6

3.2 Guangzhou

Located in south China on the estuary of the Pearl River, Guangzhou's urban expansion has been remarkable. According to the GHSL database, the area increased by 15 times in 40 years, from 540 to more than 8200 ha: Guangzhou is currently the largest city in the world, followed by Jakarta. The increase occurred

Chart 2 Comparison of yearly growth rate of area and population



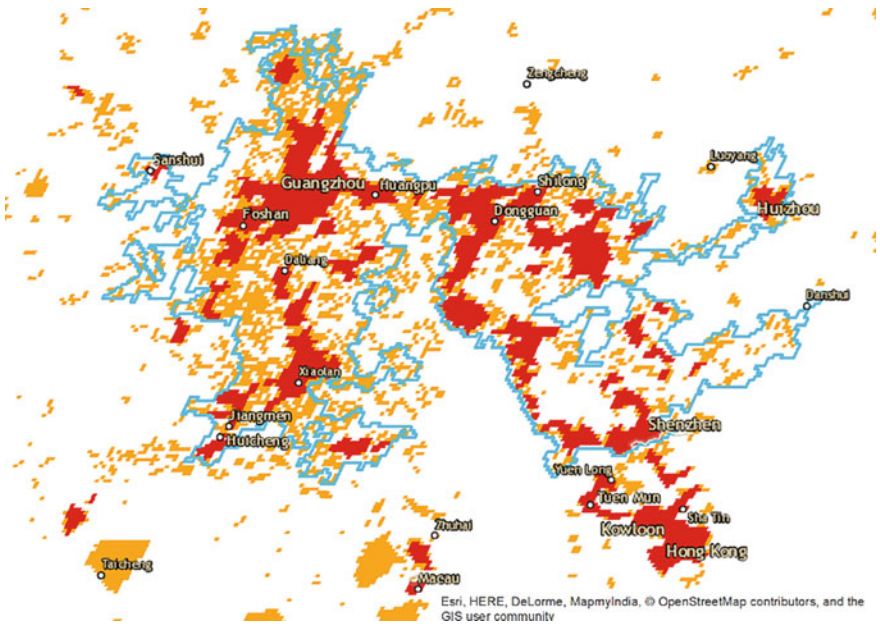


Fig. 5 Guangzhou 1975: 540 ha area, 3 million people

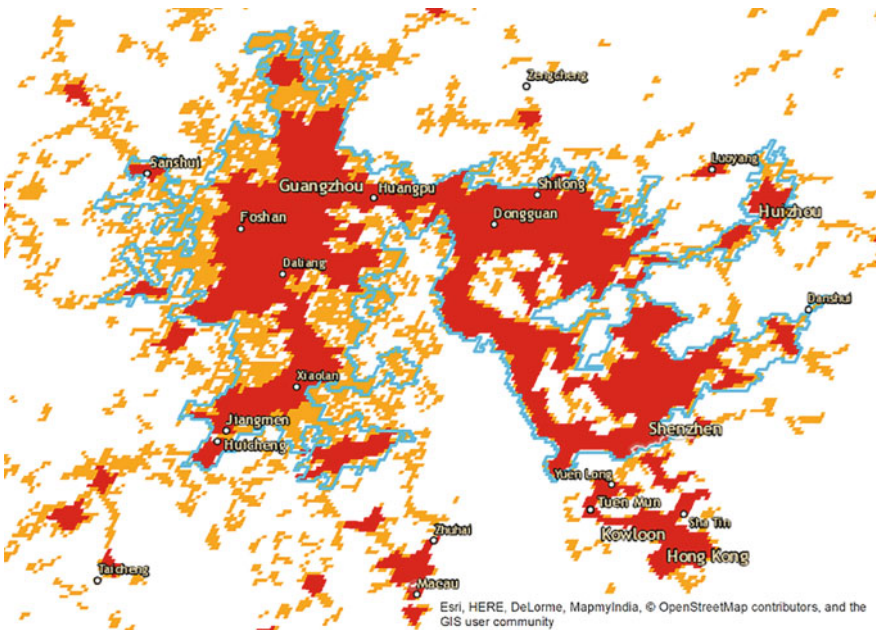


Fig. 6 Guangzhou 1990: 4.200 ha area (+3667 ha), 19 million people (+16 million)

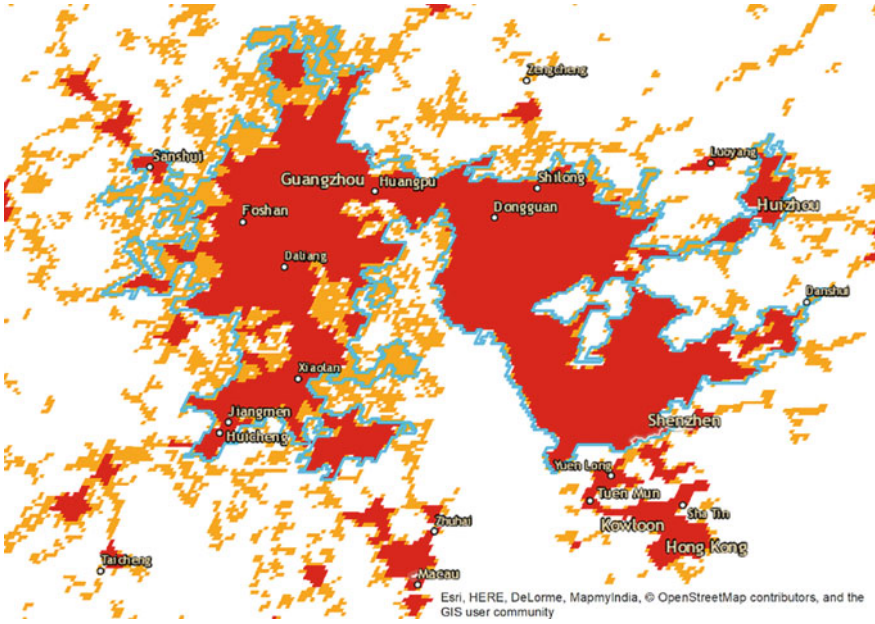


Fig. 7 Guangzhou 2000: 5.600 ha area (+1.410 ha, +33.5%), 27 million people (+8.1 million, +42%)

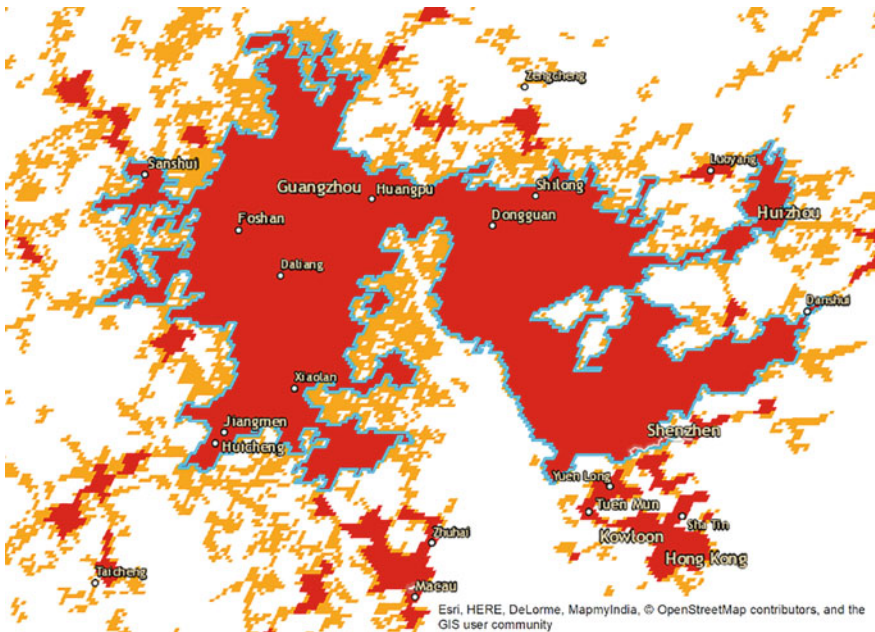


Fig. 8 Guangzhou 2015: 8.100 ha area (+2575 ha, +45.8%), 46 million people (+18.5 million, +42%)

on average by 45% a year between 1975 and 1990; it slowed to 3.4% a year between 1990 and 2000; and it increased again rapidly between 2000 and 2015 (by more than 3.1% a year). In only 15 years, between 1990 and 2015, the area almost doubled. Built-up area in Guangzhou covers today nearly 45% of the total city area. The growth of built-up area has been very fast: in the last 25 years, the surface has doubled, to 3666 ha. Today, Guangzhou's population exceeds 46 million. Figures 5, 6, 7 and 8 show how the surface of Guangzhou urban center in 2015 is the result of the junction of more than 30 urban centers. Two main pattern of growth are observed. In the first period (1975–1990) centers like Guangzhou, Foshan, Huangpu, Dongguan and Shenzhen expands and connect. After 1990 these settlement expand to saturate the shape of the center. First in the eastern part (around Shenzhen, between 1990 and 2015), and then in the north and western part (2000 to 2015). Average population growth per year has been faster in the last 15 years (4.5% a year) than between 1990 and 2000 (4.2%) (Chart 2 depicts and compares population to growth of average built-up). The size of the population increment is enormous: between 2000 and 2015, Guangzhou population increased by more than 18.5 million over an expanded settlement area of more than 8100 ha (compared to the area in the year 2000). This impressive growth, also generated by the melding of ten urban centers (Guangzhou, Dongguan, Sanshui, Foshan, Jiangmen, Huichung, Huangpu, Shilong, Shanzen, and Huizou), had impacted the population density of Guangzhou, which exceeds 5600 inhabitants per hectare in 2015. However, the increment of built-up area in Guangzhou has been greater than the increase of population both between 1975 and 1990 and between 1990 and 2000, resulting in a growth of built-up per capita between 1975 and 2000 and, only in the last 15 years, a decrease. Built-up per capita increased from 41 m² per capita in 1975, to 74 in 1990 and 86 in 2000; it decreased to less than 80 in 2015. It is also important to point out that Guangzhou expanded its area at a faster rate than its population growth (Table 2).

Table 2 Guangzhou Indicators epochs 1975–1990 to 2000–2015

Guangzhou				
	1975	1990	2000	2015
Area (ha)	540	4200	5600	8200
Population	3,011,000	19,373,000	27,515,000	46,038,000
Built-up	120	1435	2390	3660
BU/Area ratio (%)	22.8	34.1	42.6	44.8
Population density (inhab/ha)	5576.4	4605.1	4898.6	5619.9
Built-up per capita (m ²)	40.9	74.1	87.0	79.6
Area per capita (m ²)	179.3	217.2	204.1	177.9

4 Discussion

This last section of the analysis focuses on the comparison between the plain data and the indicator trend in the two cities.

Between 1975 and 2015 the seven chosen indicators follow three different dynamics in the case study cities:

- Area, population, built-up and population density increase both in Beijing and Guangzhou;
- Built-up to area ratio increases in Guangzhou and decreases in Beijing;
- Area per capita and built-up per capita decrease both in Beijing and in Guangzhou.

Within the dynamic of growth (Case a), the rates of growth of built-up and areas are faster in Guangzhou than in Beijing. Population density (Chart 3) instead grows faster in Beijing up to an average of 3.7% a year between 1990 and 2000 and by 34% between 2000 and 2015—equivalent to over 1600 additional inhabitants per hectare in 15 years.

The divergence of built-up to area ratio (b) (Chart 4): in Beijing, it has decreased since 1990; in Guangzhou, it increases; it doubled in 40 years, moving from 22% in 1975 to 45% in 2015.

Chart 3 Changes in population density 1975–2015

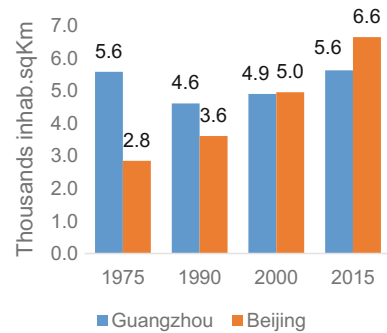
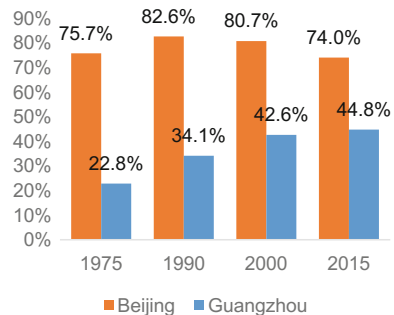


Chart 4 Changes in built-up to area ratio 1975–2015



The common dynamic of decline in built-up per capita (Chart 5) is limited to the period 2000–2015. While the trend of decrease in built-up per capita in Beijing is consolidated, as it occurs since 1975, in Guangzhou there has been a continuous increase up to 2000 (by around 50%); then it starts to decline. However, the absolute value is rather different: in Beijing, built-up per capita in 1990 was more than triple that of Guangzhou. Disparities in built-up per capita in the two cities have reconciled over time.

The process of growth that the two cities encountered is extensive but has taken different forms. Beijing has mainly developed from a single center (that of Beijing) and has expanded around a the core (the original one detected since 1975—Fig. 9).

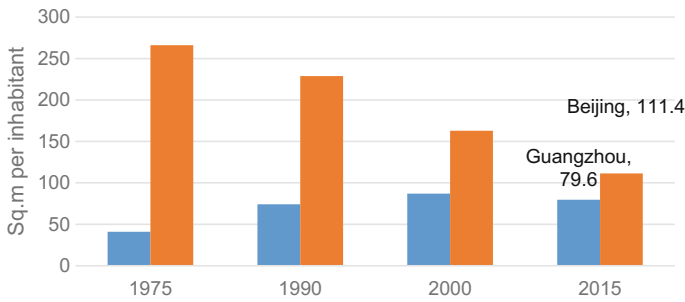


Chart 5 Changes in built-up per capita 1975–2015

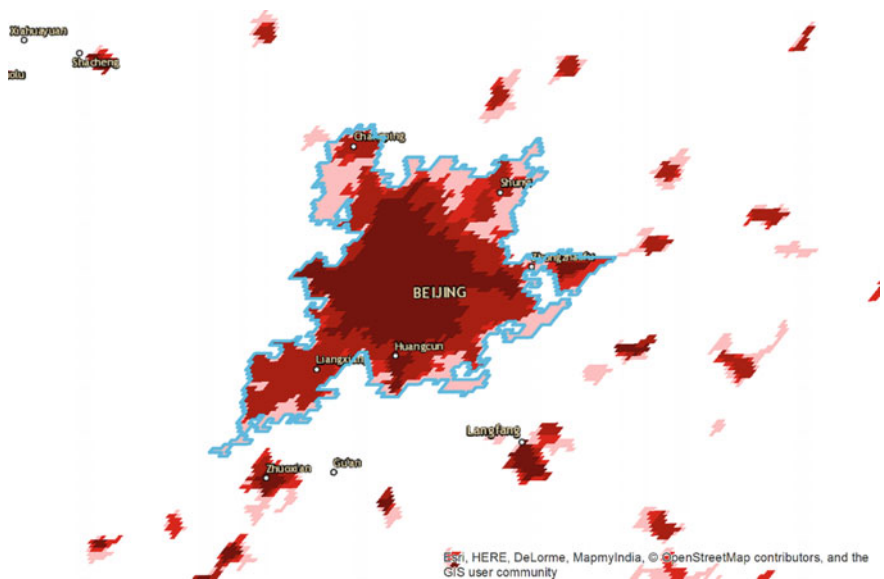


Fig. 9 Multitemporal expansion of Beijing

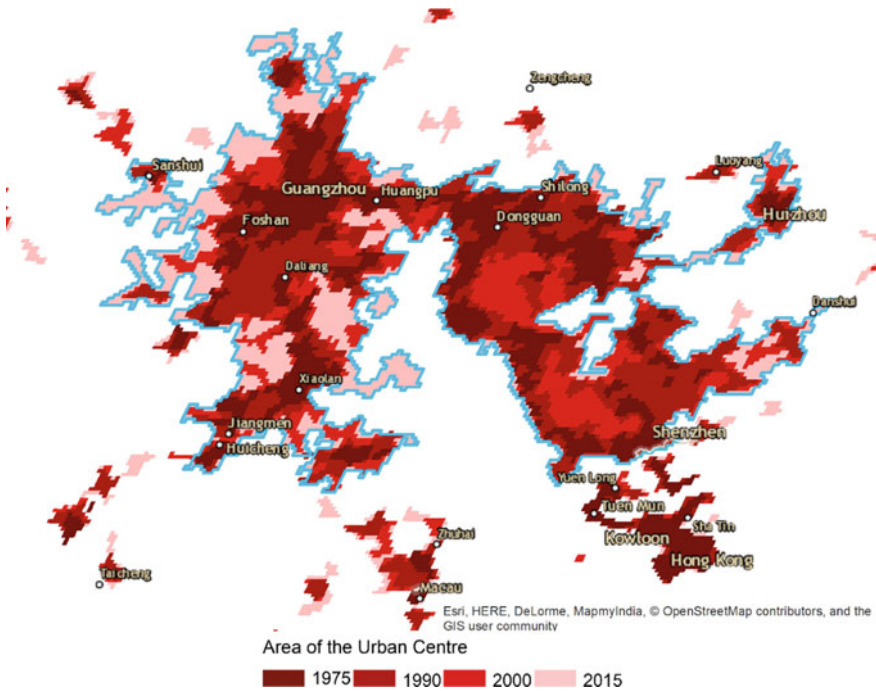


Fig. 10 Multitemporal expansion of Guangzhou

The development of Guangzhou has the trait of extensive conurbation (Schneider and Woodcock 2008). The 30 centers progressively expand and connect one another. A process of extension and gap filling has occurred only in most recent epochs (Fig. 10).

5 Conclusion

This paper proposed a methodology to analyze in a comparative way cities around the globe thanks to the opportunity provided by the Global Human Settlements Layer datasets. The GHSL is one of the most complete and up-to-date big-data layers for territorial analysis and has global coverage. Therefore, the effort to showcase its potential and the research to identify suitable indicators for urban analysis—including some of the Sustainable Development Goals targets—is relevant for launching a global evidence-based and consistent comparative study of the process of growth of cities around the world.

This paper also showcased the rapid and paramount process of urban expansion that the cities of Guangzhou and Beijing experienced between 1975 and 2015.

It is impressive to track that, just in the last 15 years, Guangzhou added more than 18.5 million inhabitants (less than 10 million in Beijing) which exceeded the total population of Chile in 2015.

References

- Center for International Earth Science Information Network—CIESIN—Columbia University. (2016). *Gridded population of the world, version 4 (GPWv4): Population density*. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). <http://dx.doi.org/10.7927/H4NP22DQ>.
- Geertman, S., Toppen, F., & Stillwell, J. (2013). *Planning support systems for sustainable urban development*. Heidelberg: Springer.
- Habitat, U. N. (2015). *International Guidelines on Urban and Territorial Planning: Towards a Compendium of Inspiring Practices*. Nairobi: UN HABITAT.
- Matsumoto, T., Sanchez-Serra, D., & Ostry, A. (2012). *Compact City Policies: A Comparative Assessment*. OECD.
- Melchiorri, M., & Siragusa, A. (2016). City analysis using the GHSL, an example of city ranking. In M. Pesaresi, M. Melchiorri, A. Siragusa, T. Kemper (Eds.), *Atlas of the Human Planet 2016. Mapping Human Presence on Earth with the Global Human Settlement Layer*. EUR 28116 EN. <https://doi.org/10.2788/889483>.
- Pesaresi, M., Ehrlich, D., Ferri, S., Florczyk, A., Freire, S., Halkia, M., et al. (2016). *Operating procedure for the production of the Global Human Settlement Layer from Landsat data of the epochs 1975, 1990, 2000, and 2014*. JRC Technical Report.
- Pesaresi M., Melchiorri M., Siragusa A., & Kemper T. (2016). *Atlas of the Human Planet 2016. Mapping Human Presence on Earth with the Global Human Settlement Layer*. EUR 28116 EN. <https://doi.org/10.2788/889483>.
- Schneider, A., & Woodcock, C. E. (2008). Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. *Urban Studies*, 45(3), 659–692.
- Taubenböck, H., Esch, T., Felber, A., Wiesner, M., Roth, A., & Dech, S. (2012). Monitoring urbanization in mega cities from space. *Remote Sensing of Environment*, 117, 162–176.

Datasets

- Pesaresi, M., & Freire, S. (2016). *GHS settlement grid following the REGIO model 2014 in application to GHSL Landsat and CIESIN GPW v4-multitemporal (1975-1990-2000-2015)*. European Commission, Joint Research Centre (JRC) [Dataset] PID. http://data.europa.eu/89h/jrc-ghsl-ghs_smod_pop_globe_r2016a.