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Research note

Evaluating cities' vitality and identifying ghost cities in China with emerging geographical data

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ABSTRACT

With the rapid urbanization of China, plenty of new urban lands have been developed with the great expectation to deal with all kinds of issues in old urban areas such as high population density, great demand on limited land resources, and decaying environment. However, a great proportion of vacancy in these newly developed units leads to the undesired observation of ghost cities. Lacking of clear and effectively evaluation criterion, the understanding of ghost cities in China is then rather limited. Considering the fact of ghost cities, we borrow the theory of urban vitality to identify and evaluate ghost cities in this paper. We argue that ghost cities are associated with very low urban vitality. In the light of big/open data, we are able to profile ghost cities of China based on 535,523 recent project-level residential developments from 2002 to 2013. We use the national-wide and million magnitude road junctions, points of interest and location based service records of 2014/2015 for measuring the morphological, functional and social vitality of each residential project. We then aggregate the project level evaluation results into the city level and thirty ghost cities are then identified by comparing the residential projects' vitality in the old (developed before or in 2000) and new (developed after 2000) urban areas in each city. Our profiling results illustrate the big picture of China's past residential developments, and then of ghost cities. We find the average vitality of residential projects in new urban areas is only 8.8% of that in old urban areas, denoting the potential existence of ghost cities in newly developed areas in Chinese cities. We have also benchmarked our identified ghost cities with existing rankings, the Baidu searching engine and night-time light images. Although we admit that ghost cities may exist in the particular urbanizing phase of China and that some ghost cities now may be well developed in the future, this study provides a thorough evaluation on the ghost city condition in China. This may shed light on policy implications for Chinese urban development.

1. Introduction

Urbanization in China has attracted much attention from around the world and is regarded as one of the most important events in human civilization (Liu, He, Zhang, Huang, & Yang, 2012; Montgomery, 2008). With the rapid urbanization of China, plenty of new urban lands have been developed with the great expectation to deal with all kinds of issues in old urban areas such as high population density, great demand on limited land resources, decaying environment, and etc. In China, urban areas increased from 12,253 km^2 in 1990 to 40,534 km^2 in 2010 (Wang et al., 2012). In recent years, real estate developments are the main form of urban spatial development in China and they generally cover over 20% of total urban development in terms of area (see Section 2.2 for more details). With the massive migrants from rural to urban areas, residential land developments have been one of the main forms of urban development in China. However, some of these developments do not match with the local residential demand and economic developments, thus leading to the increasing housing vacancies in some Chinese cities (so called "ghost cities"). The occurrence of these ghost cities has been widely criticized for debilitating the suitability of urban land as habitats, lowering the functioning effectiveness of urban system, hurdling the immigration trend of urban land, leading to disordered increase of urban land, messing up the whole plan of urbanization, and etc. (Chi, Liu, & Wu, 2015). Although there is unneglectable media coverage on ghost cites, which are supposed to be associated with wasting land resources and deteriorating healthy city development (Batty, 2016), the understanding on ghost cities in China is rather limited by lacking of clear and effectively evaluation criterion. This has been emphasized during the Central Urban Work Conference of China which is held at the end of 2015.[1]

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[1] http://www.citymetric.com/politics/so-what-happened-habitat-iii-2555.

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Up to now, there has still been no widely recognized definition of ghost cities. The term 'ghost estate' was first proposed for describing empty or unfinished housing developments in Ireland by economist David McWilliams in 2006. O'Callaghan, Boyle, and Kitchin (2014) focused their analysis on Ireland's ghost estates: residential developments left abandoned or unfinished after a property crash and their treatment within mainstream media. In Shepard's book "Ghost Cities of China", he defines "ghost city" as "a new development that is running at significantly under capacity, a place with drastically fewer people and businesses than there is an available space for" (Shepard, 2015). Nie and Liu (2013) summarize the reasons for ghost cities: wars, natural disasters, as well as urban planning driven high housing vacancies and even abandonment. They have classified ghost cities into various types, ranging from disaster ghost cities and decaying ghost cities to planned ghost cities.

There are no common accepted standards of ghost cities either. The vacant housing rate is one of the most important indicators to evaluate the health of real estate in a city. This indicator can also be used to identify the "ghost cities". Besides using the vacant housing rate, there are two other definitions for defining a ghost city. The Ministry of Housing and Urban-Rural Development of China establishes a standard of 10,000 residents per 1 km^2 of urban area. Based on this standard, Su (2014) ranks and identifies ghost cities as those with less than half of this standard. Chen (2014) proposes an alternative equation to calculate an indicator of "ghost cities": $(S\text{-}D)/n$, where S is the supply of new houses in the following five years, D is the demand of new houses in the following five years, and N is the number of houses at present. This equation reflects the proportion of current houses that should be removed to satisfy the balance between the supply and demand. Xiao, Wang, Feng, Zhang, and Yang (2014) detect and analyze China's urban expansion during the past 30 years using the Defence Meteorological Satellite Program/Operational Linescan System (DMSP-OLS) nighttime light images. They develop a method for extracting China's urban expansion pattern and analyze the dynamics of urban areas in China to explain the phenomenon of 'ghost cities'. These aforementioned standards are at the city level and do not take the inner city spatial structure and developments into account. An exception is that Chi et al. (2015) use the location based service (LBS) data from Baidu, for deriving home locations of users and calculating population density for each 100 by 100-m grid. They identify more than 50 ghost cities in China and distinguish between ghost cities and towns that are seasonally empty in China.

Considering the fact of ghost cities, we borrow the theory of urban vitality to identify and evaluate ghost cities in this paper. We argue that ghost cities are associated with very low urban vitality. Kevin Lynch believes that the primary criterion in the quality assessment of urban space form is the vitality, which is defined as a settlement (the dimension urban morphology) that supports the vital functions (the dimension urban function) and the biological requirements and capabilities of human beings (the dimension urban society), and how to protect the continuation of the species (Lynch, 1984). It is usual to say that, under these circumstances, people have 'quality of life'. Urban vitality is then an essential element to achieve urban quality of life, originating from a good urban form, well developed urban functions as well as sufficient urban activities. Jane Jacobs argued that human activity and life place intertwined constitute the diversity of city life, the vitality is the performance of the diversity in the city life (Jacobs, 1961). This is also consistent with Lynch's theory. The both theories inform us decomposing urban vitality into three components, urban morphology, urban function and urban society, which is also in a sequential order for the life course of a city. The components are then employed in our paper for calculating urban vitality using fine-scale data.

In this paper, we have opportunities to access all the residential developments of China from recent years, enabling us to detect ghost cities from a bottom-up approach considering residential lands as the main form of urban developments and the main contribution to ghost cities. Moreover, the new data environment formed by the emerging big data and open data make it possible to evaluate the vitality of these residential projects from various dimensions, for example, the morphological, functional and social dimensions. We focus on a comparison between the so-called old developments and new developments to profile the ghost level of each city. The research questions of this paper are, how is the vitality of recent residential projects? What are ghost cities in China and the driving forces for them? This study is timely in that about 1/3 Chinese cities are experiencing population shrinkage but with rapid urban expansion (Long & Wu, 2016). This makes it different with their counter parts in western countries, thus extending our knowledge on ghost cities in the literature.

This paper is structured as follows. Section 2 discusses the necessary dataset used in the study. The next section describes the adopted methodology. The analysis results are described in Section 4. Sections 5 and 6 give discussion and concluding remarks on this study, respectively.

2. Data

2.1. The Chinese city system

The Chinese city system has long been defined from the administrative view, and most statistical data corresponds to Chinese cities' administrative areas. There are 653 Chinese cities in 2014[2] (Fig. 1). On the basis of the Chinese administrative system, there are mainly five levels of cities classified in this way, including: municipalities (MD) directly led by the nation (with 4 cities, tier 1), sub-provincial cities (SPC) (with 15 cities, tier 2), other provincial cities (OPCC) (with 17 cities, tier 3), prefecture-level cities (PLC) (with 250 cities, tier 4), and county-level cities (CLC) (with 367 cities, tier 5). We focus on all cities in this paper and aim to identify ghost cities from these. The administrative boundaries shown in Fig. 1 are used for extracting our data for each historical urban development.

We assume that the formation of ghost cities is generally due to the newly developed areas, thus making it necessary to define the relevant boundaries. Considering the study period and data availability, the interpreted urban areas from remote sensing images in the year 2000 are used to differentiate the so-called old developments (from within the year 2000's urban areas) and new developments. The data are from the Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences (Kuang, Liu, Dong, Chi, & Zhang, 2016; Tian et al., 2005). The urban areas are interpreted from remote sensing images, and the overall accuracy is 94.3%. There are 9128 patches within 33,148 km^2 in total, and the mean patch size is 3.6 km^2.

2.2. Land transactions during 2002–2013

We collect all land transactions during 2002 to 2013 from the online system: Land Market Monitoring System, developed by the Ministry of Land and Resources of China (http://jcjg.mlr.gov.cn/). Residential land transactions are used for the basic data of this study since they are the direct proxy for Chinese residential land development in the last years. They are also the direct contribution to the potential "ghost cities" in China. In total, there are 535,523 residential projects within a total area of 7770.2 km^2 from 2002 to 2013 (Table 1). We see an increasing trend of residential transactions in terms of both count and area. The specific location, transaction date, land supply type,[3] land use type, as well as land supply area in ha attributes are available in each transaction record. We geocode all records using the Baidu online geocoding service using the detailed address of each record and derive the GIS ShapeFiles layer for further analysis in the study. It should be mentioned that almost all land transactions, especially residential type, mean complete

[2] Due to changes in the urban system, several inconsistent cities have been excluded.

[3] In China, land supply types mainly include agreements, bidding and auctions.

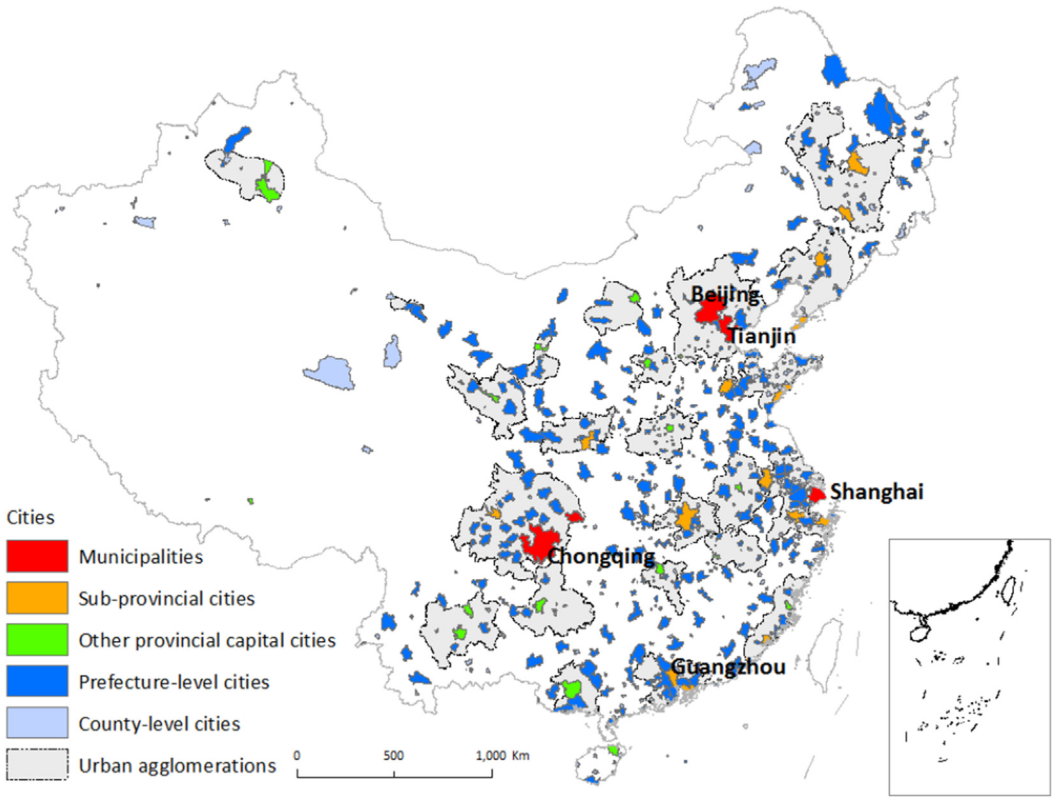


Fig. 1. Administrative areas of Chinese cities (the polygon in color stands for the administrative area of each city) (Liu & Long, 2016). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

construction and existence of new residential areas for residential transactions in China. About two years are required from a residential land transaction to complete the construction. In this sense, the land transactions during 2002–2013 may well present the developments during 2004–2015.

2.3. Road junctions in 2014

For evaluating residential developments from the morphological dimension using road junctions, we obtain road networks from 2014 of the whole of China from a Chinese navigation company NAVINFO. Urban streets, regional roads and many other detailed streets are encompassed within these road networks, and the quality is guaranteed by our previous study (Liu & Long, 2016) which used the 2011 version of the same dataset. We conduct the necessary data pre-processing of road networks to derive more practical road junctions using ESRI ArcGIS. Detailed procedures are available in Long (2016). We then derived 8.24 million road junctions for 2014 (Fig. 2a for the whole China and Fig. 2b, c for a small area in Beijing).

Table 1
A profile of residential transactions from 2002 to 2013.

Year	Count sum	Type		Area sum in ha	Type	
		Market #	Social #		Market in ha	Social in ha
2002	2576	2182	394	4042.1	3726.4	315.7
2003	3194	2887	307	6149.2	5715.5	433.7
2004	10,840	3965	6875	13,839.8	11,641.6	2198.2
2005	7321	2933	4388	10,435.4	8755.3	1680.1
2006	7880	3897	3983	10,270.5	9232.9	1037.7
2007	48,910	32,924	15,986	65,496.5	54,676.9	10,819.6
2008	43,545	29,682	13,863	60,112.3	48,901.4	11,210.9
2009	73,678	54,849	18,829	85,472.7	71,338.1	14,134.6
2010	87,017	78,234	8783	127,848.2	109,779.3	18,068.9
2011	86,999	77,888	9111	133,875.5	108,372.4	25,503.1
2012	72,618	62,861	9757	116,444.5	87,714.5	28,730.0
2013	90,945	87,141	3804	143,030.6	136,326.1	6704.5
Sum	535,523	439,443	96,080	777,017.2	656,180.2	120,837.0

2.4. Points of interest (POIs) in 2014

To evaluate residential developments from the functional dimension, POIs in 2014 are gathered and geo-coded by business cataloguing websites using web scraping techniques. The POI data quality is secured through manual by checking of randomly selected POIs (see Liu and Long (2016) for the 2011 version of POIs). There are 10.6 million POIs in 2014 (Fig. 2e, with Fig. 2d for the 2009 version for comparison) and their relationship with streets/roads is illustrated in Fig. 2c for a small area in Beijing.

2.5. LBS data in 2015

For evaluating residential developments from the social dimension, we have gathered human activity density revealed by the location based service data from one of the largest internet companies in China. The human activity records cover a whole week in July of 2015. Considering the data cover of about 800 million users in China, the data can well reflect human activities in China. We show the LBS density in a small area as shown in Fig. 3 for demonstrating the data.

2.6. Night-time light images

For benchmarking our ghost city evaluation results, we use night-time images for comparing our results. Night-time light imagery which excludes glare and sunlit effects is extracted from the DMSP-OLS images and provides spatially explicit observations of artificial lighting sources across human settlements at night without moonlight

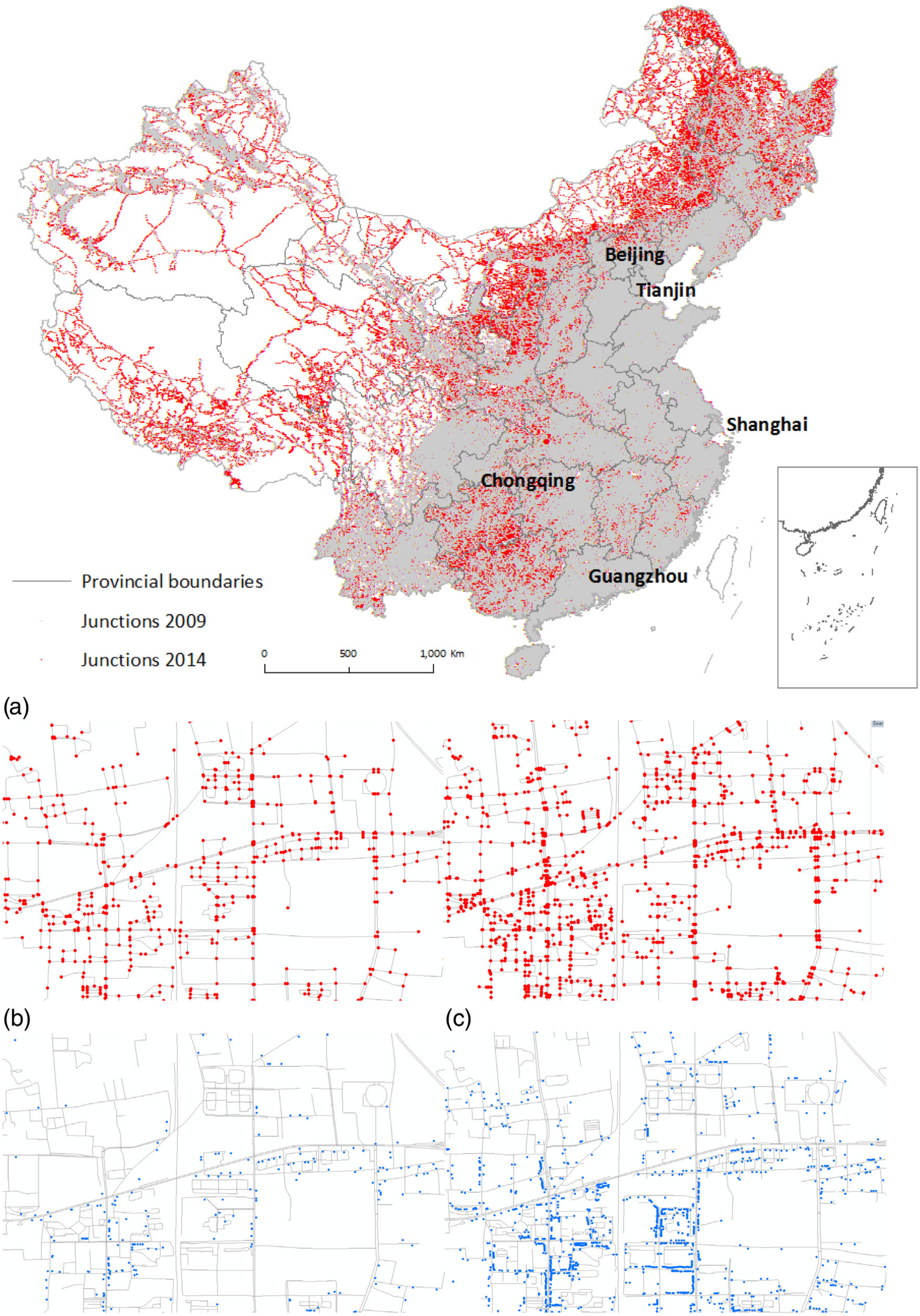


Fig. 2. Road junctions and POIs of China in 2014 (a) road junctions in the whole of China, (b) road junctions of 2009 in a small area in Beijing, (c) road junctions of 2014 in a small area in Beijing, (d) POIs of 2009 in a small area in Beijing, (e) POIs of 2014 in a small area in Beijing.

(Elvidge et al., 1999). A number of efforts have been made to successfully capture the robust positive correlations between DMSP-OLS night-time light data and demographic and socioeconomic variables at regional to global scales (Doll, Muller, & Morley, 2006; Ma et al., 2015). DMSP-OLS night-time light imagery data of 2004, 2008 and 2013 are derived from the National Oceanic and Atmospheric Administration's National Geophysical Data Center website (Version 4, downloaded from the website of http://www.ngdc.noaa.gov/dmsp/downloadV4composites.

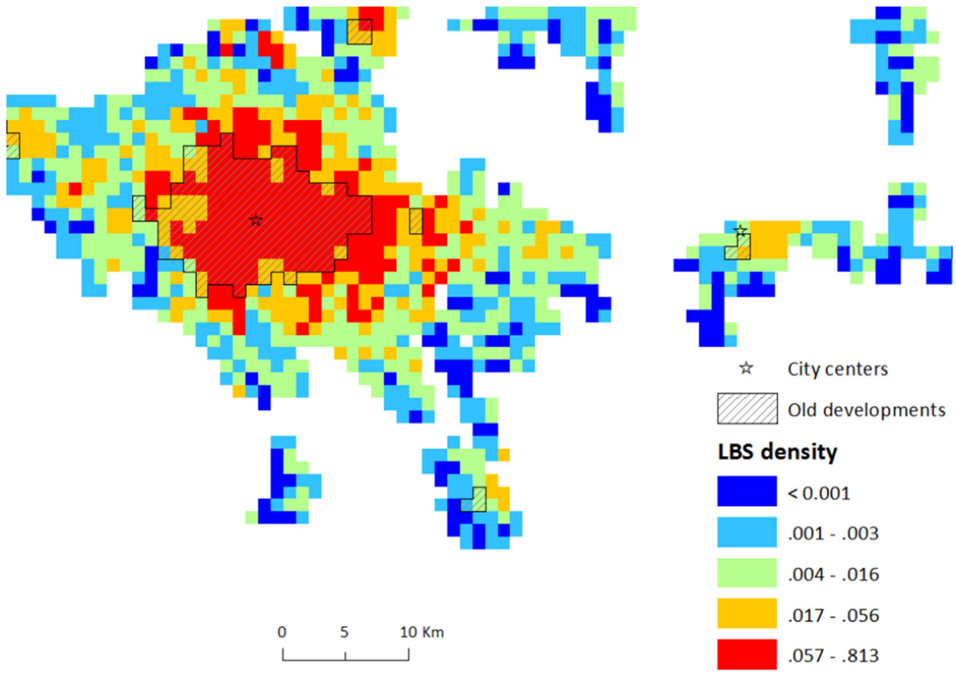


Fig. 3. LBS density of a small area in Jiangsu province. Note that the LBS density has been normalized and does not indicate the real population.

html). These image products provide gridded, cell based annual, cloud-free composited stable night-time lights with a digital number (DN) value ranging from 0 to 63. The above-mentioned data are obtained from three individual sensors: F15 (2004), F16 (2008) and F18 (2013), which are selected by following Elvidge, Erwin, Baugh, and Ziskin (2009) method to mitigate the errors arisen from varied sensor data in different years.

3. Method

3.1. Evaluating vitality of residential developments

We propose a straightforward method for evaluating the vitality of each residential project. First, we derive the kernel density surfaces for road junctions (J), POIs (P) and LBS based on human activity records (L) for China by using the Kernel Density toolbox in ESRI ArcGIS. To make the three layers consistent, the searching distance is set as 1000 m and the output raster is associated with a cell size of 200 m. We then generate three raster layers covering the whole of China. Second, we evaluate each residential project from the various dimensions of J, P and L by using the Sample toolbox in ESRI ArcGIS. Third, the vitality of each residential project is then evaluated by using Eq. (1), denoting that a residential project tends to be vibrant in places with denser roads, better developed urban functions and more human activities. We do not directly summarize the three dimensions to avoid the arbitrary setting on the weight for each dimension.

$$V = J * P * L \tag{1}$$

3.2. Identifying ghost cities via aggregating the vitality of residential projects at the project level

We then aggregate the project level results on vitality evaluation to the city level. We use the urban areas from the year 2000 to distinguish residential projects in old or new urban areas by using all residential land transaction records. The average vitality of residential developments in new urban areas (V_{new}) and residential developments in old urban areas (V_{old}) can be calculated for each city by overlaying residential transactions with the administrative boundaries of cities. The ghost city index (G) for each city can then be calculated by using Eq. (2).

$$G = 1/(V_{\text{new}}/V_{\text{old}} * V_{\text{new}}) \tag{2}$$

According to Eq. (2), the degree to which a city belongs to a ghost city is related to vitality in new urban areas and the difference in vitality between old and new urban areas. The larger the difference and the lower the vitality in the new residential projects, the more likely the city to be a ghost city. The definition of G avoids the urban physical, urban function and Internet development differences among cities as we compare new and old urban areas for each city. We have a careful examination on the residential development sizes in new and old areas and find that all cities are associated with a considerable size of developments. There are no cities are with zero development.

We can then rank all cities in terms of the G values. Those cities with a large G can be regarded as ghost cities if they meet the minimum residential development threshold. That is, if a city's G is very high, but its development scale is very small, we cannot regard this city as a ghost city. We have to admit the potential limitations of the G indicator, considering there are no better presentation for the indicator at the moment of preparing this paper. First, we haven't proposed a threshold for distinguishing truly “ghost” cities. Second, the G index does not take the total amount of residential projects in new and old areas into account. Third, the time lag between new and old areas may influence the indicator. These limitations are reserved for our future studies.

4. Results

4.1. Vitality of residential projects

Evaluating each residential project is the precondition for identifying ghost cities. Among all the 535,523 residential projects, 46.7% of the projects are within the 2000 urban areas (old urban areas). The overlaying residential projects and city boundaries' results denote that 51.1% of the residential projects are beyond all city boundaries (in counties or towns), and 30.0% in prefectural cities (not municipalities and provincial capitals).

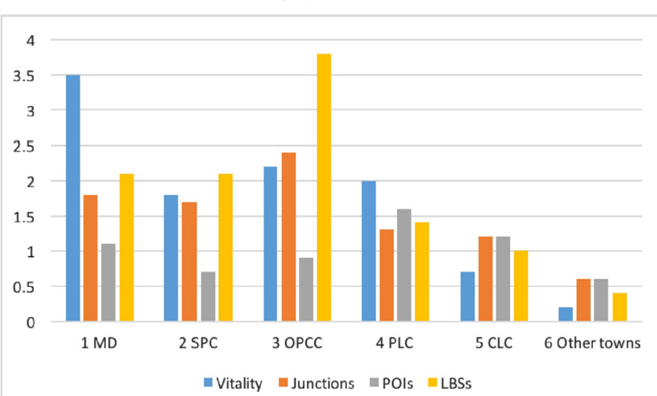
To retrieve a big picture of residential projects in old and new urban areas, we compare the vitality and its three components. The results indicate that the residential projects in new urban areas only account for 8.8% vitality of those in old urban areas, suggesting that the residential projects in new urban areas have very low vitality compared with those in old urban areas. This provides us enough evidence to show that it is a legitimate way to identify ghost cities, by focusing on newly developed areas and comparing them with old ones. In addition, this is also supported by the three vitality component evaluation results, which show that residential projects in new urban areas are associated with 39.4% road junction density, 21.5% POI density and 24.1% LBS density when compared with those in old urban areas. The comparison analysis provides us a profile on the vitality gap between residential projects in new and old urban areas.

We further profile the vitality and its three components of residential projects in each administrative level of cities. The results in Table 2 reveal that the vitality beyond existing city boundaries is very weak, only accounting for 20% of the average level. For the morphological dimension, the road junction density generally increases with the city tier and the other provincial capitals have the highest road junction density. This indicates that county level cities are associated with the largest urban blocks. For the functional dimension, lower tier cities have a higher POI density compared with upper tier cities, and prefectural level cities have the highest POI density. Lastly, for the social dimension, upper tier cities have a higher human activity density than lower tier cities, which is on the contrary of the condition for the POI density. This suggests that although residential projects in small cities have more highly accessed urban functions, their human activities are not great due to the developing scale of each project.

4.2. Impact factors for vitality of residential projects

Considering various factors contribute to the vitality of each residential project, we use linear regression for identifying each factor's impact on vitality. The dependent variable in the regression is the normalized vitality and its three components of each residential project (0–1), respectively. The independent variables which is selected according to urban vitality theory like Zijderveld (1998) ranging from URBAN (urban or not in 2000, 1 for urban and 0 for rural), YEAR (land transaction year), CENTER (distance to city center), LEVEL (the administrative level of a city in a descending order, 1 for municipality, 5 for county level city and 6 for non-city administrative area), to AREA (the land transaction area). The regression results are listed in Table 3. We find that a residential project in an old urban area with a small land area and issued recently which is close to the city center in an administratively higher tier city tends to be more vibrant. Among all the variables, URBAN and LEVEL are the most important factors contributing to the vitality. We find the condition for morphological and social dimensions is the same with that of vitality. For the functional dimension, we find that URBAN and AREA are the most important impact factors, indicating that a larger residential project tends to have less accessed urban functions.

Table 2
The evaluation results for residential projects in each administrative level of cities.



Note: The vitality and its components have been normalized by dividing the raw value with the corresponding mean value to indicate the differences. 1 MD = cities directly led by the nation (with 4 cities, tier 1), 2 SPC = sub-provincial cities (with 15 cities, tier 2), 3 OPCC = other provincial cities (with 17 cities, tier 3), 4 PLC = prefecture-level cities (with 250 cities, tier 4), and 5 CLC = county-level cities, and 6 Other towns means that the projects are beyond the administrative boundaries of cities in China, and this applies to our following context.

Table 3
Regression results for the vitality and its three components of residential projects (N = 535.523).

Variable	Vitality	Junctions	POIs	LBSs
URBAN	0.126	0.352	0.307	0.286
YEAR	0.008	0.003	0.040	0.015
CENTER	−0.025	−0.103	−0.056	−0.089
LEVEL	−0.132	−0.353	−0.057	−0.336
AREA	−0.041	−0.051	−0.082	−0.064
Adjusted R^2	0.045	0.353	0.123	0.274

Note: All variables are significant at the 0.05 level. All coefficients have been normalized in the linear regression process. When we use the logarithm value of vitality as the dependent variable, the adjusted R^2 and the normalized coefficients do not change much.

4.3. Calculating vitality for cities and identifying ghost cities

We aggregate the evaluation results of all the residential projects of China to the city level and calculate the vitality index for old and new urban areas in each city, respectively. We first focus on the vitality in newly developed urban areas and map the results in Fig. 4. The results indicate that the cities in the middle region of China have the largest vitality values and those in north eastern China and western China are with lower values.

Based on the calculated vitality values in old and new urban areas, we further derive the ghost index for each city and plot the *G* values of cities in Fig. 5. The average *G* value among all cities is 28. Cities with a large *G* value, but few residential projects are not regarded as ghost cities in this study. We remove those cities with residential projects in new urban areas that are less than 452 ha (the mean value at the city level) from the ghost city identification pool. Considering that generally residential areas account for about 30% of all urban areas in a city as revealed by the national standard for land use planning in China, the threshold 452 ha for residential developments correspond to an urban area of 15 km^2($4.52km^2/30\%$), which is a large-sized area even in the Chinese context. We then sort all remaining cities and select the top 30 as ghost cities in China, and they cover about 5% of all Chinese cities (Fig. 5). They area Suzhou, Weihai, Chengde, Wuzhong, Bengbu, Chuzhou, Anshan, Fuxin, Yingkou, Jinhua, Ganzhou, Jilin, Taian, Longkou, Yuyao, Kaifeng, Linyi, Zaozhuang, Maanshan, Harbin, Xinyang, Yixing, Jingdezhen, Jiaozhou, Yantai, Zigong, Heze, Binzhou, Shenyang and Shouguang.

4.4. Benchmarking our results with existing media coverage and rankings

As we have mentioned in the introduction section, reports on ghost cities is not rare in western media with their increasing interests on urbanizing China. As the first media coverage on ghost cities in China, L'Agence France-Presse published, “In China, some of the new development areas become ghost towns” on 19 May 2011. The Times (China in numbers: ghost town is not a special case, 9 April 2013), CNN (Can China breathe life into ghost towns? 27 May 2013) and The Washington Post (How smartphones are solving one of China's biggest mysteries, 4 November 2015) are its following counterparts.

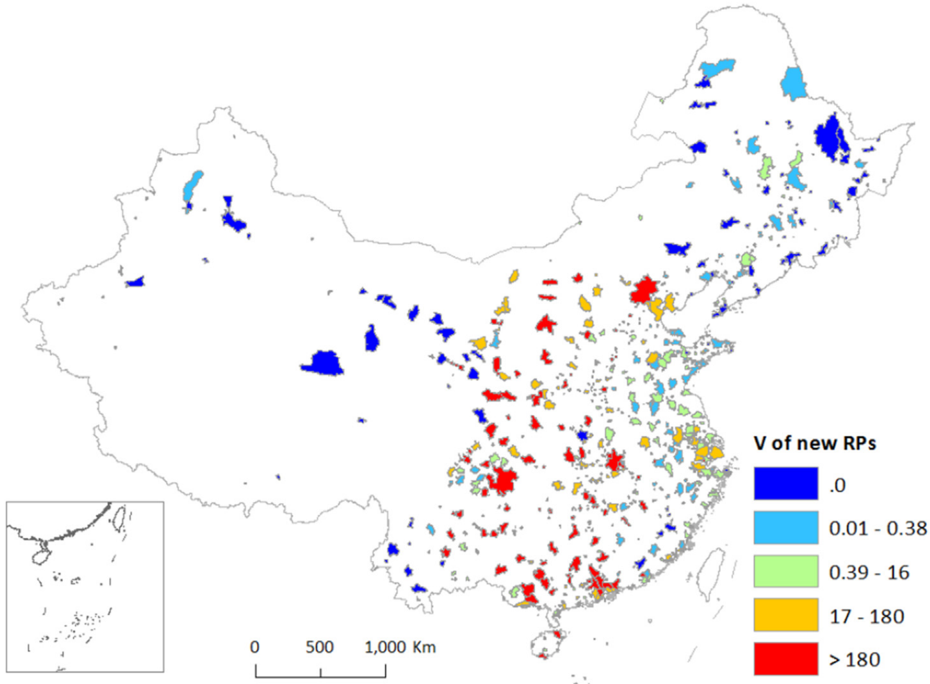


Fig. 4. The average vitality of residential projects (RPs) in new urban areas for all Chinese cities.

There is also much attention on ranking ghost cities in China from domestic media. Due to different definitions, indicators and basic data used for identifying ghost cities, the rankings are not consistent and even conflict with each other. We select three well known rankings for benchmarking against our ranking on ghost cities in China. The first is the Biaozhun Ranking, which uses the urban area per capita using yearbooks (http://biaozhun007.com/articles/city/422.html), the second is the Netease Ranking, which adopts an indicator that is calculated by using the city population's rate of increase divided by the urban land area's rate of increase (http://news.163.com/15/1209/01/BABTGM1O000014MTN.html), and the third one is the Fang Ranking which regards the extended price decline as an indicator (http://news.anshan.fang.com/2015-12-08/18506456_1.html). We situate our ranking among the three rankings, and the comparison results indicate the following findings (see Appendix 1 for details). Frist, all rankings differ a lot but also share some things in common. For instance, most of the cities ranked are dispersed throughout China and do not concentrate in few provinces or regions. It should be mentioned that, although a large number of ghost cities are in non-developed areas like Shandong and Hebei provinces, they also distribute in developed areas like Jiangsu province. Second, ten of our identified top 30 ghost cities in China appear in the other rankings. They are Weihai, Chengde, Wuzhong, Chuzhou, Yingkou, Taian, Xinyang, Yixing, Jingdezhen and Yantai. Third, the detailed ranks in the three existing rankings and our rankings, differ a lot and are even found inverted. The top 10 ghost cities in all four rankings do not even share any common city. The comparisons reveal that the existing three rankings on ghost cities in China are inconsistent with each other. Our ranking provides a new perspective on Chinese ghost cities with a straightforward method by using intensive micro data for describing Chinese residential development in the past years.

In addition, we aim to retrieve the public's sense on ghost cities in China and benchmark with our understanding in this study. For deriving this, we search each city and its province name as well as "鬼城" (ghost cities in the Chinese language) using the largest Chinese online search engine Baidu (www.baidu.com) and regard the searched item result count as the popularity/public's sense/media's interest of the city as a ghost city. We correlate the G indicator of each city with the total searched item count and find that both indicators are not correlated with each other. This indicates that our ghost city identification results do not follow the public's sense on ghost cities in China.

5. Discussion

5.1. Can night-time light images be used for identifying ghost cities?

As a complement for identifying Chinese ghost cities using project-level residential developments, we use night-time light images spanning several years for gaining ideas on ghost cities and their temporal evolution. We average the DN values of pixels for new (outer) urban areas after the year 2000 and for old urban areas within the 2000 (inner) urban areas for each Chinese city, using the remote sensing images in the year 2000 as introduced in Section 2.1. Both values of all cities are plotted in Fig. 6 (our identified top 30 ghost cities highlighted in red). We see a significant gap between new and old urban areas, and most cities were associated with much lower lighting in new areas than old urban areas. The cities with a higher administrative level are brighter than those cities with a lower administrative level. With the urbanizing process of China, we observe that the cities are getting brighter and the night light gap between new and old areas has become smaller from 2008 to 2013. We also notice that the light of most cities in 2013 is close to the maximum value and has been saturated, making it not easy to distinguish the old and new urban areas. The light in new urban areas is even brighter than that in old urban areas in some cities.

Although night-time light images can reveal the temporal evolution of urban developments in various periods, we find that the data are not suitable for identifying ghost cities due to the following points. First, the saturation effect makes the nigh-time light images being unable to be differentiated for well developed urban areas, thus being difficult to identify the gap between old and new urban developments in a city. Second, bright streets at night cannot guarantee real estate projects to be well occupied in newly developed urban areas in Chinese cities,

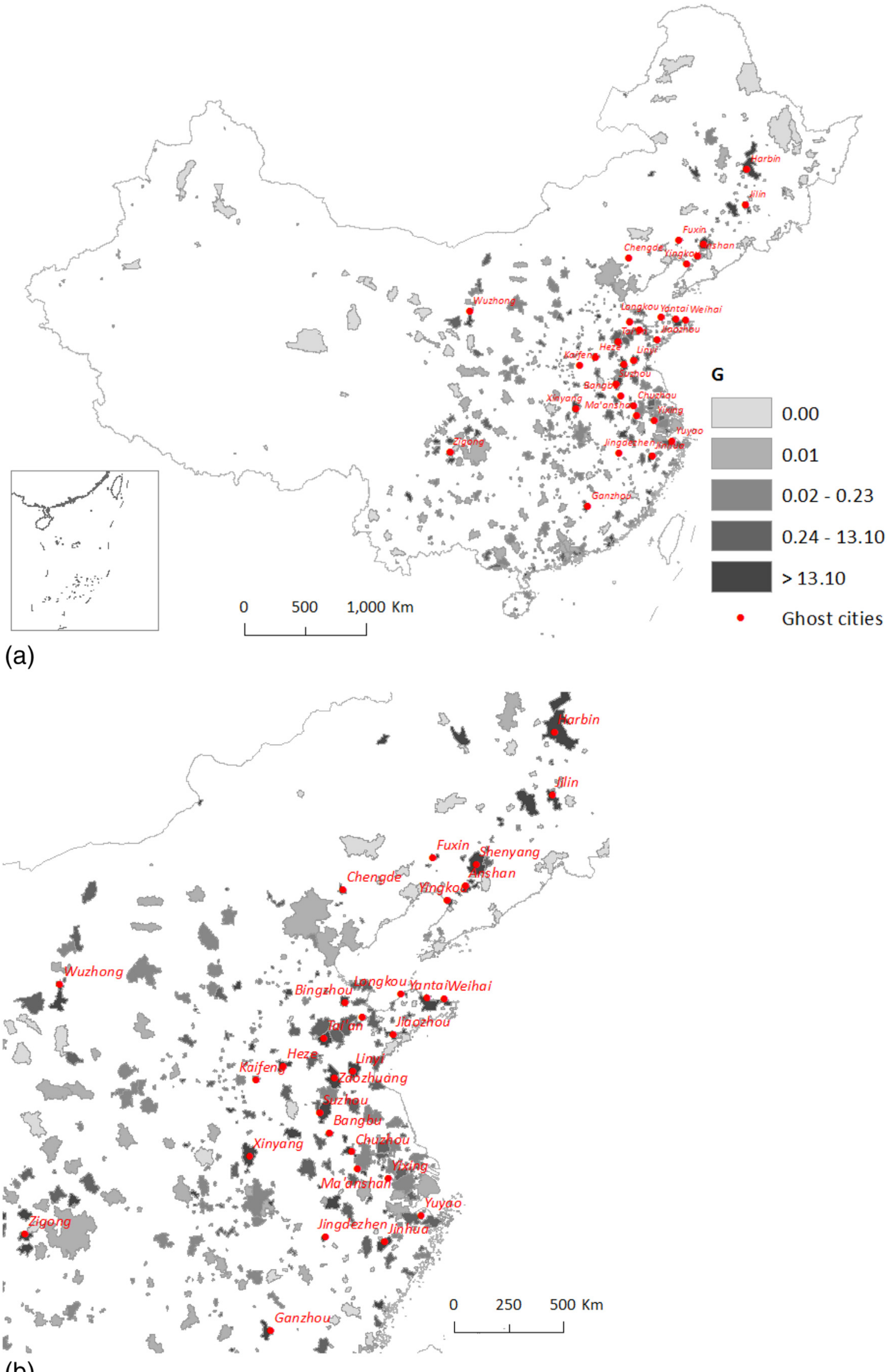


Fig. 5. The ghost index (G) for all Chinese cities (a) and a zoomed-in map for identified ghost cities (b). Note: The legend of (a) also applies to (b).

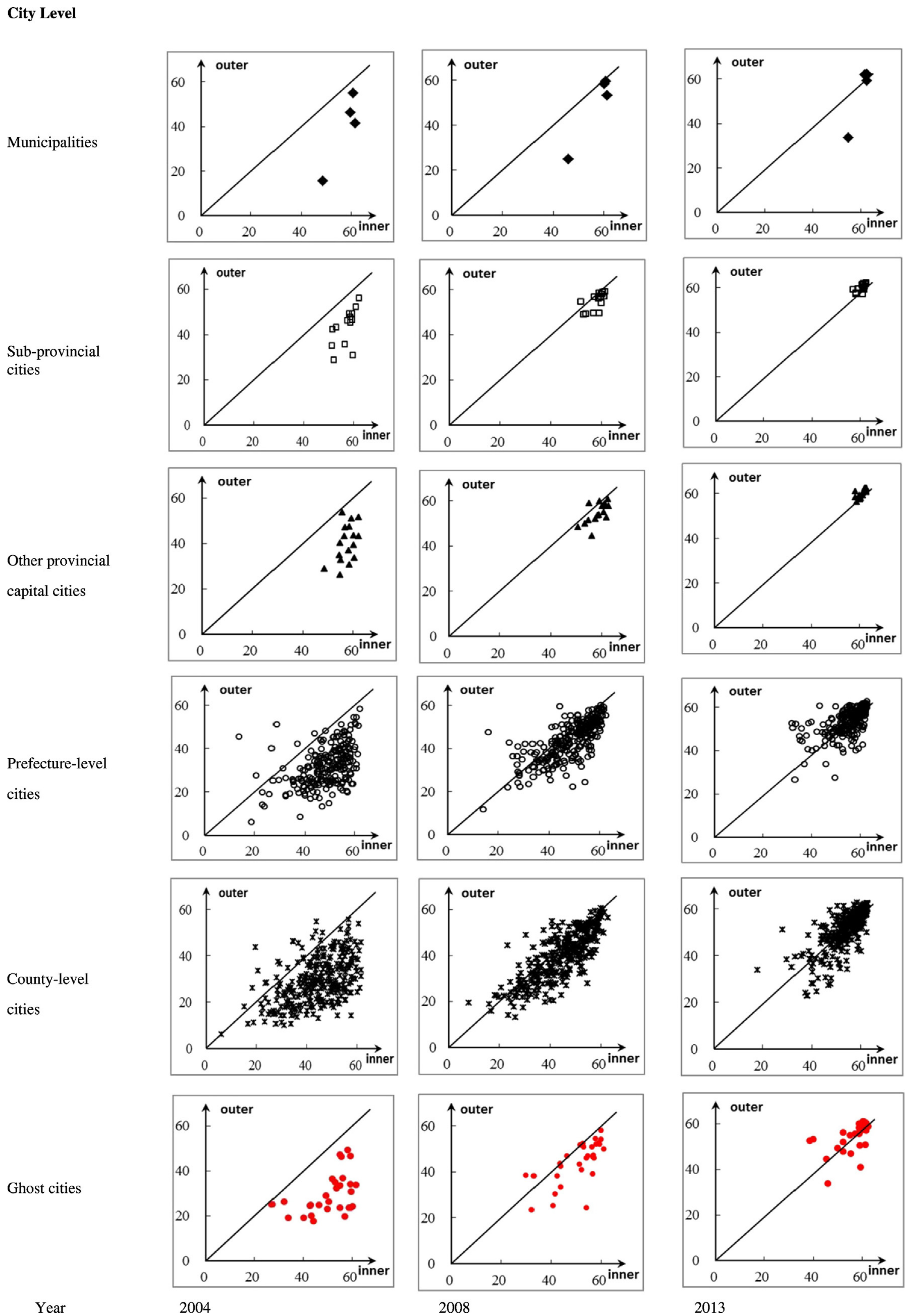


Fig. 6. The night-time light comparison for old and new urban areas of Chinese cities in various years.

considering road infrastructure (broad streets with bright lights) is generally constructed prior to the housing developments in China. That is, bright night light in new urban areas is not always associated with urban vitality. Third, the resolution of night-time light images is rather large in contrast to the residential projects, making it difficult to differentiate the small scale variations in terms of urban vitality.

5.2. Academic contributions

As one of the first overall and complete studies for detecting ghost cities in China, the contributions of our study mainly lie in the following aspects. First, considering the core of the ghost city concept, we identify ghost cities by evaluating residential development vitality from three dimensions, morphology, function and human mobility/activity. This may be more solid than solely from night-time light images or human activities. Second, we evaluate each city in a bottom-up manner by using ubiquitous and increasingly available big/open data from official websites, commercial internet companies and social networks. The collected residential projects have both inferred vitality and land transaction size in ha, enabling us to consider both "ghost" level and "ghost" size in our study. Third, we develop theoretical models to explain the contributing factors on vitality at the residential project level, which provides the possibility for proposing necessary policies to fight against ghost cities in modern China. Fourth, the proposed ghost indicator G considers not only the vitality in new urban areas, but also the gap between new and old urban areas, thus making it possible to overcome the gap of urban form, function and information communication technology (ICT) penetration across various cities. Last but not least, we hope this study can contribute to practical applications. The vitality evaluation results for all residential projects and the ghost level evaluation results for all cities can be used for informing local decision makers to deliver necessary policies. The national wide study also enables the understanding of regional variation conditions.

Both Chi et al.'s (2015) study and ours use intensive fine-scale data for profiling ghost cities in China, and both focus on residential developments in China. While admitting Chi et al.'s (2015) merits, we compare the differences between the two studies. First, Chi et al. use residential POIs as the proxy of residential developments, and POIs are lacking development size information of residential projects. Some residential communities are associated with several POIs, for example, each gate is a residential POI. In addition, the "gate" POI does not correspond to a residential area's center. Our study uses official residential land transactions with development size and accurate place information for evaluating ghost cities, thus making it more objective for reflecting the ground truth of China. Second, Chi et al. (2015) pay almost all attention to the human activity (social dimension) of Chinese cities. In our study, we have extended this to three dimensions (spatial morphology, urban function and human mobility/activity) contributing to city vitality and the resulting ghost cities. Our philosophy on a ghost city is that it should be associated with very large urban blocks, few urban functions accessed by residential development, as well as very sparse human mobility/activity density in and around the residential developments. This better meets the common sense on ghost cities in China. Third, we also develop models for explaining the possible reasons behind vitality development at the project level, in addition to identifying ghost cites in China. This is critically important for rethinking the ghost city phenomenon in China and redeveloping policies to combat with them and prevent the formation of more ghost cities.

5.3. Potential bias and future steps

This study profiles ghost cities in China and contributes to various aspects aforementioned. Nevertheless, several limitations still exist in the current study which will be highlighted in our future research. On one hand, although residential land transactions can better reflect the size and location of residential development projects, the access to the real boundary of each residential community may lead to more objective evaluation and identification results. On the other hand, land transactions stand for legal and official developments. Various studies have shown that there are unneglectable informal developments beyond the urban growth boundaries in China (Long, Gu, & Han, 2013; Long, Han, Tu, & Shu, 2015). The informal residential developments also contribute to the formation of ghost cities. This should be addressed in our next study as well.

6. Concluding remarks

Ghost cities have raised serious impacts in various aspects, ranging from social dimension (e.g. broadened social inequality), ecological dimension (wasted land resources) to economic dimension (e.g. slowed city transition). An in-depth evaluation on ghost cities in China may provide more opportunities for understanding urbanizing China. In this paper, we profile ghost cities in China from the view of residential development vitality, which is the core issue contributing to ghost cities at the micro level. A residential project's vitality is associated with three components, ranging from morphological, functional to social aspects. In total, 535,523 residential land transactions from 2002 to 2013 with a total area of 7770.2 km^2 are collected from an official website in China. We use the national-wide road junctions, points of interest, and location based on service records of 2014/2015 for measuring the morphological, functional and social vitality of each residential project. We propose a vitality index considering three major components and suggest the vitality of a residential project is equal to the combined result of the three dimensions. This enable us the opportunity to calculate all residential projects' vitality values. We further distinguish all residential projects with the existing urban areas in the year 2000 (within or beyond) and these projects are then classified into two types, either they are in old urban areas (developed before or in 2000) or new ones (developed after 2000). We then aggregate the project level evaluation results into the city level. The ghost index G is proposed for identifying ghost cities, and it considers the vitality gap between the average residential project vitality of old urban areas and the vitality of the new urban areas. The larger the gap is and the lower the average residential projects' vitality in new areas in a city, the more the city tends to be a ghost city (a larger G for the city). The ghost cities are then identified by sorting all cities' ghost values, removing cities with small-scale residential developments in new urban areas and selecting the cities with the largest G values. Considering the straightforward nature of our proposed framework for identifying ghost cities, we do not include a serious validation step in this study. Rather, we benchmark our findings with existing studies and verify our results using other datasets.

Our profiling results illustrate a big picture for Chinese past residential developments and then the ghost cities. We find the average vitality of residential projects in new urban areas is only 8.8% of that in old urban areas, denoting the potential existence of ghost cities in newly developed areas in Chinese cities. In addition, residential projects in new urban areas have much lower road junction, POI and LBS densities when compared with residential projects in old urban areas. We also analyze the vitality and three components across each administrative level of cities. The regression model for residential project vitality suggests that residential projects in old urban areas, being close to the city center in an administratively higher tier city, with a smaller development size and more recent development, positively contribute to a higher level of vitality. This finding explains the impact factors for vitality. Finally, thirty ghost cities are identified according to the G indicator evaluation results, and most of these cities are distributing in north eastern China, particularly in Shandong and Anhui provinces. Residential developments in new urban areas within these ghost cities have quite lower vitality compared with those in old urban areas, considering the definition of G. We have also benchmarked our identified ghost cities against existing rankings, the Baidu search engine, and night-time light images. Although we admit that ghost cities may exist in the particular urbanizing phase in China, and some cities that are ghost cities now may be well developed in future, this study provides a thorough evaluation on the ghost city condition in China. This may shed light on policy implications for Chinese urban development.

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Appendix 1. The rankings of ghost cities in China

	This study	Ranking according to Baidu search	The Biaozhun Ranking	The Netease Ranking	The Fang Ranking
Ranking title			Concludes the top fifty "ghost cities" of the future and a "Super star" county	The urban construction speed exceeds the population growth in many cities of China, a large number of "ghost cities" have appeared	Top 12 "ghost cities" of China in 2015
Evaluation indicators		By keyword searching, the retrieval condition is 'province name' + 'city name' + '鬼城'	Less than 5 thousand people per square kilometer in a city's built-up areas	Population growth less than or equal to zero, the change rate of population density less than or equal to zero, and the growth rate of urban area greater than or equal to zero	The pace of the decline in residential real estate
Data sources			http://biaozhun007.com/articles/city/422.html	http://news.163.com/15/1209/01/BABTGM1O00014MTN.html	http://news.anshan.fang.com/2015-12-08/18506456_1.html
Order	Top 30	Top 30	Top 50	No	No
1	Suzhou (Anhui)	Sanya (Hainan)	*Erlianhaote (Inner Mongolia)	Kiamusze (Heilongjiang)	Erdos (Inner Mongolia)
2	Weihai (Shandong)	*Tianmen (Hubei)	*Alar (Xinjiang)	*Anlu (Hubei)	Hohehot (Inner Mongolia)
3	Chengde (Hebei)	△Chongqing (Chongqing)	*Beitun (Xinjiang)	*Penglai (Shandong)	Bayan Nur (Inner Mongolia)
4	Wuzhong (Ningxia)	Zhangjiajie (Hunan)	*Aletai (Xinjiang)	*Hailin (Heilongjiang)	Erlianhaote (Inner Mongolia)
5	Bangbu (Anhui)	Luoyang (Henan)	Zhangye (Gansu)	Jixi (Heilongjiang)	Zhengzhou (Henan)
6	Chuzhou (Anhui)	#Nanjing (Jiangsu)	*Suifenhe (Heilongjiang)	*Tianmen (Hubei)	HeBi (Henan)
7	Anshan (Liaoning)	Lijiang (Yunnan)	Qinzhou (Guangxi)	*Longcheng (Shanxi)	Xinyang (Henan)
8	Fuxin (Liaoning)	*Emeishan (Sichuan)	Jiayuguan (Gansu)	Xuancheng (Anhui)	Yingkou (Liaoning)
9	Yingkou (Liaoning)	*Wuyishan (Fujian)	*Yumen (Gansu)	*Zhaoyuan (Shandong)	Changzhou (Jiangsu)
10	Jinhua (Zhejiang)	Rizhao (Shandong)	Shigatse (Tibet)	*Macheng (Hubei)	Zhenjiang (Jiangsu)
11	Ganzhou (Jiangxi)	*Conghua (Guangdong)	*Golmud (Qinghai)	*Xiantao (Hubei)	Shiyan (Hubei)
12	Jilin (Jilin)	Yangzhou (Jiangsu)	*Ruili (Yunnan)	*Laohekou (Hubei)	Chenggong (Yunnan)
13	Taian (Shandong)	^Guiyang (Guizhou)	*Turfan (Xinjiang)	*Qixia (Shandong)	
14	*Longkou (Shandong)	*Dali (Yunnan)	*Mishan (Heilongjiang)	*Jieshou (Anhui)	
15	*Yuyao (Zhejiang)	Jingdezhen (Jiangxi)	Weihai (Shandong)		
16	Kaifeng (Henan)	Langzhong (Sichuan)	*Changshu (Jiangsu)		
17	Linyi (Shandong)	Huizhou (Guangdong)	Wuzhong (Ningxia)		
18	Zaozhuang (Shandong)	Huangshan (Anhui)	*Kaiping (Guangdong)		
19	Ma'anshan (Anhui)	Zhuhai (Guangdong)	*Fukang (Xinjiang)		
20	#Harbin (Heilongjiang)	*Penglai (Shandong)	*Guixi (Jiangxi)		
21	Xinyang (Henan)	*Kaiping (Guangdong)	Yichun (Heilongjiang)		
22	*Yixing (Jiangsu)	#Lhasa (Tibet)	Shizuishan (Ningxia)		
23	Jingdezhen (Jiangxi)	Baishan (Jilin)	Chuzhou (Anhui)		
24	*Jiaozhou (Shandong)	Yichang (Hubei)	*Haining (Zhejiang)		
25	Yantai (Shandong)	Changzhou (Jiangsu)	Maoming (Guangdong)		
26	Zigong (Sichuan)	Luohe (Henan)	*Xilinhaote (Inner Mongolia)		
27	Heze	Mudanjiang (Heilongjiang)	Jinchang (Gansu)		

(*continued*)

	This study	Ranking according to Baidu search	The Biaozhun Ranking	The Netease Ranking	The Fang Ranking
	(Shandong)				
28	Bingzhou (Shandong)	Erdos (Inner Mongolia)	Fangchenggang (Guangxi)		
29	Shenyang (Liaoning)	Yichun (Jiangxi)	Chengde (Hebei)		
30	*Shouguang (Shandong)	*Yixing (Jiangsu)	*Taicang (Jiangsu)		
31			Zhoukou (Henan)		
32			*Dehui (Jilin)		
33			Laiwu (Shandong)		
34			Quzhou (Zhejiang)		
35			*Chongzhou (Sichuan)		
36			*Donggang (Liaoning)		
37			*Heshan (Guangdong)		
38			*Shulan (Jilin)		
39			Yantai (Shandong)		
40			*Korla (Xinjiang)		
41			*Kashi (Xinjiang)		
42			Sanya (Hainan)		
43			Erdos (Inner Mongolia)		
44			Hulun Buir (Inner Mongolia)		
45			Tai'an (Shandong)		
46			Yichang (Hubei)		
47			Xianning (Hubei)		
48			Lhasa (Tibet)		
49			Lianyungang (Jiangsu)		
50			*Huolinguole (Inner Mongolia)		

Notes: (1) Cities marked △, #, ^, and * indicate that they are municipality level, sub-provincial level, other provincial capital level, and county level respectively. Other cities are prefecture level cities. (2) The name inside the brackets represents the province where the city is located.

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