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Spatial-Temporal Dynamics of Population Aggregation during the Spring Festival Based on Baidu Heat Map in Central Area of Chengdu City, China

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Abstract

The application of location-aware devices and location-based services enables big data to provide a convenient and efficient way to study the dynamics of urban population distribution. Based on the Baidu heat map data, the spatial-temporal population aggregation in the main urban areas of Chengdu City was explored in the context of the Spring Festival. The results suggested that population aggregation showed regular fluctuation within a day, consistent with the commuting activities. Also, population mobility showed difference before, during and after the festival; population density during the holiday was significantly lower than that on the other two working days, meanwhile the heat value on the working day before the festival was slightly higher than that after the festival. The conclusion showed that the Spring Festival affected the population distribution density. Chinese government's emergent measures taken to suppress the nationwide spread of COVID_19 at early 2020 also had great influence on the low population aggregation during and after the Spring Festival, indicating the effectiveness of emergency control of human interactions. Better understanding of Spatial-temporal dynamics of population aggregation during the Spring Festival is of great value for optimizing the city expansion and structure planning.

Keywords: population aggregation, the Spring Festival, Baidu heat maps, Spatial-temporal dynamics

1. Introduction

With the increasing urbanization and modernization in the rapid growth of cities, urban planners are confronted with challenges of heavily congested traffic, mounting pollution and so on. To optimize the urban spatial layout and population distribution can help solve the problems effectively in the process of city expansion. Based on the application of location-aware devices and location-based services, big data provides a convenient and efficient way to study the dynamics of urban population as well as the use of public facilities.

As visual analytic tool, heat maps are effective for showing density information (Shrader, 2012) and gained great concerns from researchers for its easily interpreted mapped distribution, though the mapping method could be problematic due to some incorrect representation (DeBoer, 2015). Baidu Heat Map, a big data visualization product launched by Baidu Inc., China's leading Internet search company, in 2011, describes mobile phone users' information of geographical coordinate in the special form of highlighting when they get access to any of Baidu products, becoming a new tool to study the mobility of urban population. It's graphical representation of data where the individual values contained in a matrix are represented as colors. Specifically, the Baidu heat map collects the spatial location data of mobile phone users, reflecting the density degree of urban population by visualizing the heat value with colors which move from yellow to orange and then to red as the value increases, signaling the population concentration getting hotter in certain areas. Thus, the distribution map of urban population is obtained, offering real-time information of population mobility. In addition, Baidu map updates every 15 minutes, which meets the real-time dynamic data requirements. Providing real, effective and real-time dynamic data of population distribution, the Baidu heat map can give clues to the decision-making information for urban planners.

As the largest search engine in China, Baidu search gained great popularity among mobile search engine users, accounting for about 62.2% among the mobile search traffic market share. Baidu Map has over 300 million users and processes millions of position requests per day, which makes it reliable and effective to help detect urban population mobility.

The Baidu heat map data describes the real-time distribution, density and dynamics of population. Better understanding of the regular daily flow of urban residents is of great value for urban planning (Becker et al., 2011). Therefore, recent years saw the popularity and wide use of the Baidu heat map data for urban structure research (Wu &Ye, 2016), bus travel (Yu et al.,2017), and space use in given parts of the city including metro station (Ye et al., 2017), urban parks (Lyu & Zhang, 2019) and commercial centers (Zhang et al., 2019). Using the Baidu heat map, 69 polycentric cities among 658 Chinese cities were identified, and their developing level helped explore the proper patterns for small cities (Li et al., 2016). Leng et al. (2015) focused on the job-residence relation in Chongqing, revealing that multi-centric spatial structure of the city eases the pressure of long-distant commuting. Most studies focused on the population characteristics in urban central districts, illustrating their multi-dimensional relationship with land use function, traffic accessibility or historical protection elements and so on, helpful for the improvement of old urban districts and the construction of new parts in urban expansion.

Analyzing the spatial-temporal population distribution revealed by the Baidu heat maps, the flow patterns of residents' activity in different parts of a city can be easily and clearly identified. Based on the real-time population spatial distribution data of Baidu map, this study attempts to analyze the spatial-temporal population aggregation in the main urban areas of Chengdu City, so as to provide the basis for the optimization of Chengdu stock space. By monitoring the patterns of Chengdu residents' lifebeat and detecting any anomalies like overcrowding surroundings in case of emergencies, the typical mobility of people between different areas over time could be potentially modeled, thus revealing the current deficiency of spatial structure, population distribution and public facility allocation, and providing potential suggestions for urban planners.

Residents' flow activities are affected by demographic characteristics, time and places (Li et al., 2019). It's usually accepted that working people and adolescents' commuting behavior tend to be regular and periodic (Yu, 2017). Working days and off days showed differences in spatial-temporal population distribution (Ahas, 2010), and the peak period of population aggregation lagged behind on off days (Wang, 2018). Previous studies mostly focused on the disparity of population distribution between working days and rest days, but no research has been found on the flow dynamics of urban population during the Chinese traditional Spring Festival. In order to make clear of the impact of the Spring Festival during which large-scale population mobility occur annually, this study was set in the context of the Chinese traditional lunar New Year, the most solemn traditional festival for family reunion in China, which the Chinese people attach great importance to and have the tradition of going home to celebrate, no matter how far away they are. Thus, there is great population migration during the Spring Festival transport season. A large number of migrant workers would flow out of the city returning to their hometown, whereas urban residents flow from their residence places to home cities, and other large-scale population including tourists also pour in, bringing huge pressure on urban transportation, public facilities and so on. This paper set the time before (January 21), during (January 28) and after (February 6) the Spring Festival, aiming to elucidate the impact of the Spring Festival on the population dynamic distribution for the insight into urban planning and construction.

2 Data Description

2.1 Research Area

This research is based on the Baidu heat map data in Chengdu (latitude 30°05′ to 31°26′N, longitude 102°54′ to 104°53′E), the capital of Sichuan Province, one of the important industrial, financial, cultural and educational center in the southwest areas of China, attracting large amounts of Chinese and overseas tourists each year. The city had 16.33 million permanent residents in a total area of 14,335 km^2, with the urbanization rate of population up to 73.12%. This study targeted the urban central area of about 885.6 km^2 for the population distribution analysis to give some clues for urban planners.

According to the overall urban planning (2016-2035), Chengdu city plans to form a multi-center urban spatial structure of "one center, two wings and three axes", with the central urban area being expanded to 11 municipal districts and high-tech zones. With the strategic orientation of National Central City and the world cultural city, the urban population will be 13.6 million in 2035, and the urban construction land area will be 1388 km^2.

2.2 Dataset

The Spring Festival Holiday issued by the State Council was scheduled from January 24 to 30 (delayed to February 2 due to novel Coronavirus contagion). In order to elucidate the dynamics of population distribution in the main urban areas of Chengdu before, during and after the Spring Festival, three days of January 21, February 6, 2020 as working days, and January 28, 2020 as off days were selected. The real-time data of the Baidu heat maps in the three selected days were tracked and collected at one-hour intervals from 7:00 in the morning to 24:00 in the evening. In total, 54 maps were obtained for analysis (18 maps for each day) (Figure 1).

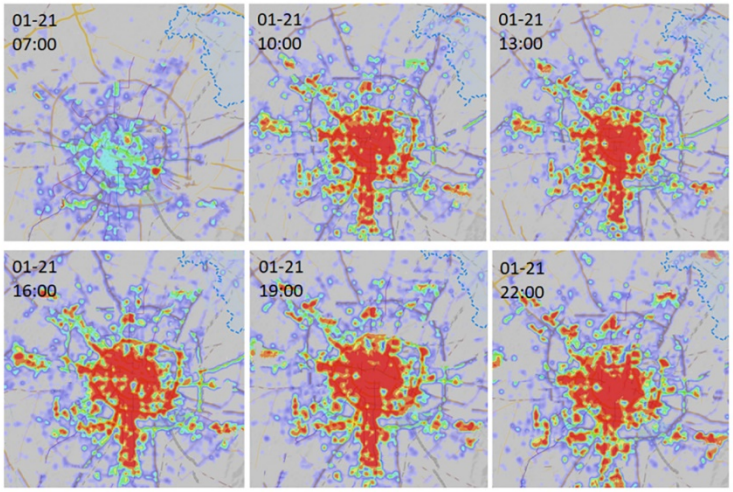

Figure 1. Real-time Baidu heat maps

2.3 Data Process

Based on the ArcGI S10.2 tool, the projection is defined as WGS - 1984 – UTM- zone- 50N. The coordinates and projection of the Baidu heat maps and Baidu Map are corrected, and then the Baidu heat map is georeferenced in batches based on the georeferencing link of Baidu road map. The Baidu heat map data is in PNG format, which consists of four channels, of which the fourth one (originally named band 4) is Alpha channel that uses 256 gray levels to represent picture information. Compared with the other three RGB channels, it is not interfered by pure white and black, which is more convenient for classification. Therefore, the fourth channel is loaded in ArcMap and reclassified according to the natural interruption method based on heat value. The original heat value is divided into 1-9 levels assigned to different color zones, in which the 8-9 level is defined as super heated area, and the 6-7 level is defined as heated area. The higher the level is, the higher the population density is, and vice versa. Data cleaning is completed (Figure 2).

In the ArcGIS tool, the average value of the thermal value at each time of the day is calculated by using the raster calculation:

$H = \sum Hx / 18$

Where h is the average thermal value of a day, Hx is the thermal value at x point, x = 7:00, 8:00, 9:00……24:00 (18 time slots). This is how to depict the space-time track and the aggregation of urban population flow.

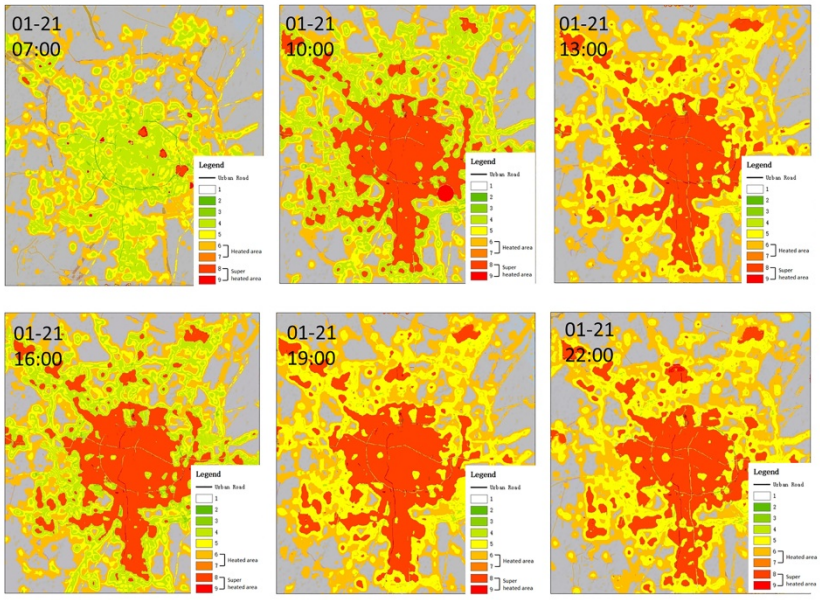

Figure 2. Data-cleaned real-time Baidu heat maps

3. Results and Analysis

3.1 Analysis of Population Distribution Dynamics in Super Heated Area

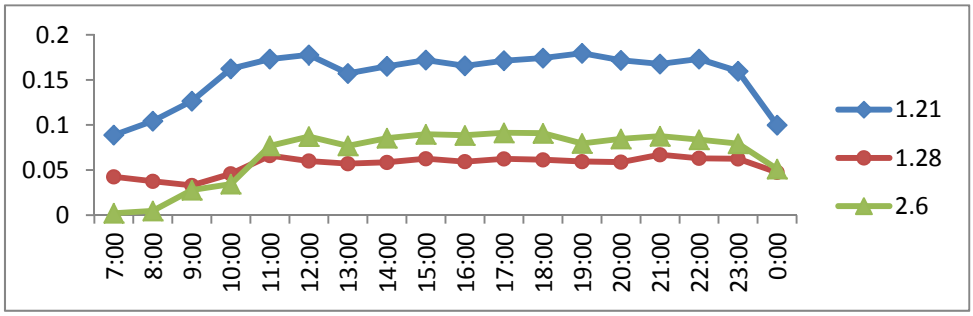

Figure 3. Population distribution dynamics in super heated area

The super heated area of high population concentration presented regular fluctuation change in the three days, showing similar trend of "rise-stability-decrease", which was consistent with people's daily activity habits of daytime aggregation and nocturnal dispersion (Figure 2). In terms of working days, the hot area kept rising rapidly during the period of 7:00-12:00, and reached the peak at about 12:00, which indicated that a large number of people gathered from residential areas to working places or commercial area in the morning. In particular, the area grew dramatically from 9:00 to 10:00, so it was speculated that this time slot was the early rush hour, and the urban traffic situation might face large-scale congestion. At 13:00, the super heated area slightly decreased, and then rebounded at 14:00 after a small trough. The decrease in this time slot may be related to the lunch break at noon while people dine out. During the period of 14:00-19:00, the super heated area was relatively stable, and a wave peak appeared at 20:00-22:00, and then declined after 23:00. Thereafter, it indicated the relatively stable population aggregation in the afternoon when people were engaged in work and in the evening when people enjoyed leisure and entertainment activities. As it was shown that the population in the urban center was more concentrated, and the significant density began to decline until 23:00, reflecting that Chengdu is a city with rich nightlife. On off days the super heated area showed very slight fluctuation, with its peak in the morning at 11:00, earlier than on working days, which was different from the findings of previous studies holding that the activity time of off days was delayed compared to working days(Wang, 2018; Li et al., 2019).

In terms of the overall within-day dynamics of population mobility from morning to evening, the super heated area on the working day before the lunar New Year (1.21) was significantly higher than that on the other two days, while the heated area on the working day after the New Year (2.8) was slightly higher than that during the Spring Festival holiday (1.28).

3.2 Analysis of Population Distribution Dynamics in Heated Area

The dynamics of population density in heated area within a day showed a certain consistency on working and off days with violent fluctuation in the morning and evening, though not as significant as that of the super heated area (Fig. 4). On working days, the population mobility fluctuated sharply in the time slots of 7:00-9:00, 12:00-14:00, and 18:00-23:00. The first peak appeared in the period of 7:00-9:00, followed by a relatively stable level until the noon, whereas the population density in super heated area began to increase rapidly from 9:00 to 10:00. This conformed to the daily migrant activity of urban people who began to move gradually from 7:00 to their working places, thus the first population density peak in heated area appeared; with people's increasing aggregation, the heated area gradually transformed to super heated ones, consequently, the sharp increase of population density in super heated area lagged behind the former. Another peak occurred in the period of 12:00 to 14:00, when a small part of the population transferred from working places to surrounding areas for lunch break, which resulted in the decrease of super heated area and the increase of heated area. Also, the time slot from 14:00 to 19:00 saw a relatively stable trend, but the trend of the working day after the New Year (2.6) maintained a significantly high level than that after the New Year, which was obviously different from the other two days. The reason for this anomaly may be related to the production recovery of some enterprises during the epidemic occurrence before February 10th. The time slot of 20: 00 to 23:00 on both work and off days underwent through a fluctuation, which was consistent with the population dynamics in super heated area. Therefore, it can be seen that the residents in Chengdu city generally gather and enjoy colorful life with abundant entertainment activities at night. On off days (1. 28), the fluctuation of heated area was slight, with two relative peak slots at 9:00 in the morning and 21:00 in the evening, which was obviously different from the previous studies in which the density peak appeared in daytime (Wang, 2018; Ye 2017).

In terms of the overall within-day dynamics of population mobility from morning to evening, the heated area during the Spring Festival holiday (1.28) was significantly lower than that on the other two working days, meanwhile the heat value on the working day before the Lunar New Year (1.21) was slightly higher than that after the New Year (2.8).

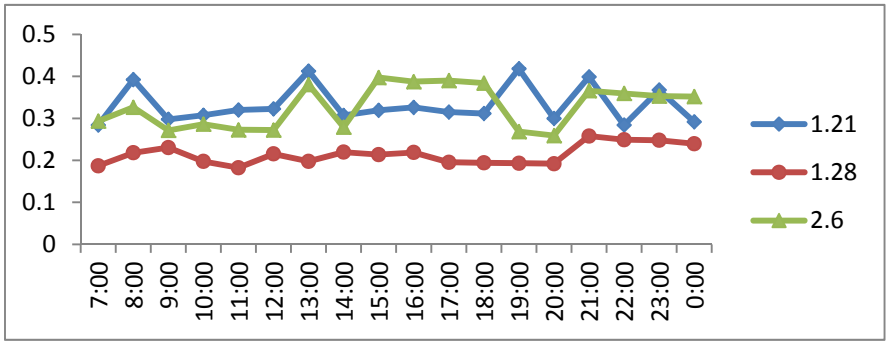

Figure 4. Population Distribution Dynamics in Heated Area

3.3 Comprehensive Analysis of Population Distribution Dynamics in Urban Central Area

3.3.1 Analysis of the Average Percentage of Super Heated and Heated Areas

By comparing the average percentage of the heat areas in three days, it was found that the ranking of the super heated area was consistent with that of the heated area (Table 1). That is to say, when the day showed the highest percentage of super heated area, it also correspondingly had the highest proportion of heated area, and vice versa. The off day during the Spring Festival holiday (1.28) showed the lowest area of super heated and heated areas, obviously lower than on the working days before and after the festival. Therefore, the degree of urban population aggregation during the Spring Festival is not high relatively, which may be related to the fact that working places are no longer high aggregation area since most people stop commuting between residential and working places; also, the population migration out of the city during the statutory Spring Festival holiday attributes to the decrease, during which Chinese people will choose to go back to their hometown for the family reunion in such a traditional festival. Especially, a large number of migrant workers from the rural areas will move to the countryside, thus it is reasonable that the degree of population aggregation in city will be greatly reduced. In addition, the outbreak of novel coronavirus infection in China is also an important cause, greatly affecting people's mobility.

Noticeably, the average proportion of both super heated and heated areas on the working day after the Spring

Festival (2.6) was apparently lower than before the New Year (1.21), which was surely affected by the nationwide spread of COVID_19 in China at the beginning of 2020. As in other urban and rural areas, the relevant policies of isolation stopping human-to-human contagion were promulgated in Chengdu city, under which most urban residents chose to stay at home and some companies postponed the resumption of work. Consequently, the population density of commercial districts and working places was lower in February than in January, with the super heated area being significantly lower than on usual working days.

Table 1. Average percentage and rankings of super heated and heated areas

Day	Super heated area		Heated area	
	Average proportion	Ranking	Average proportion	Ranking
1.21	0.154991	1	0.331989	1
1.28	0.055749	3	0.213797	3
2.6	0.067835	2	0.327702	2

3.3.2 Spatial Analysis of Average Population Distribution Dynamics

It can be seen that the average heat level was highest on working days before the Lunar New Year and much lower after the Festival, and that both the average super heated and heated areas greatly declined, reflecting the obvious decrease in the degree and areas of population aggregation during this period (Figure 5). In response to the outbreak of COVID-19, the first-level public health emergency measures were taken nationwide to control the mobility and aggregation of population so as to reduce the spread of infection caused by human contact. This reasonably explains why the average heat level after the Spring Festival holiday in Chengdu city was much lower than that before the holiday. Also, this indirectly reflects the effectiveness of the government's quick response to contain the epidemic. As further progress in control of the epidemic situation, more enterprises shall recover gradually, thus the heat value on work days in February was higher than on off days (1.28).

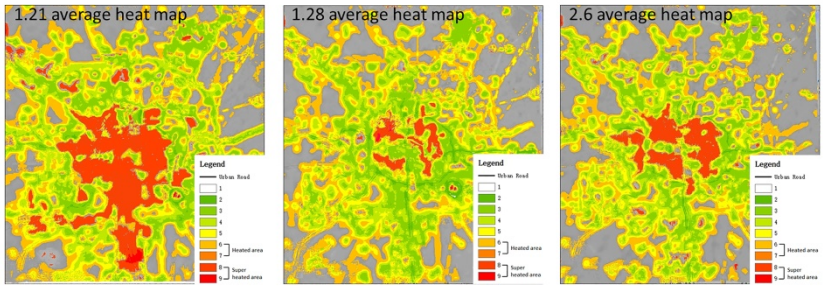

Figure 5. Heat maps of average population distribution dynamics before, during and after the Spring Festival

On the whole, the spatial location of high heat value in Chengdu city was mainly distributed in the central downtown area, where the enormous population flow brings much pressure on public transportation and service facilities. How to optimize the urban spatial structure and avoid a series of problems caused by excessive population aggregation is a great challenge in urban development and expansion. In the overall urban planning, it is planned that Chengdu will form a "multi-center" structure composed of eight regional central cities. The layout of the central urban area will show the mode of fan leaf, shifting the development center eastward and southward. The population dynamics depicted by Baidu heat maps also calls for the development of multi centers and further expansion of main urban areas in Chengdu city's planning and development strategy.

4. Conclusion

The real-time nature of Baidu heat maps can help to study the population mobility in a day, offering a dynamic perspective for the observation of people's activities and the use of urban space. This study showed that the heat value of Chengdu had a sharp increase trend in the morning and evening, reflecting that the demand for work commuting or entertainments in this time slots will bring greater pressure to the traffic. Through the growth rate of heated area, we can roughly infer the peak hours in the morning and evening, thus corresponding measures shall be taken to alleviate traffic congestion, such as implementing relevant restrictions along some roads on given time slot, adding temporary public transporting vehicles and so on. Besides, the super heated and heated areas maintained at relatively high level from noon to afternoon, revealing the lasting population aggregation in urban central area. We hold that it is necessary to convert the single mode of business circle and entertainment

centers to a networked, multi-central and ecological urban development pattern, to balance the population capacity of urban areas. In addition, Chengdu had a high degree of population aggregation at night, revealing its rich leisure and entertainment activities. Therefore, the catering and entertainment industry may consider extending the business hours appropriately to meet residents' needs, easing the high aggregation at the same time.

Based on the data before and after the Spring Festival, we found that both heated and super heated areas in Chengdu city was significantly reduced during the Festival, which proved that the urban population distribution dynamics was closely related to the date, and that the Spring Festival had a greater impact on the degree of population aggregation. During the seven-day holiday, many Chinese people would like to transfer from work places back to their home for family reunion, which meant that the population density in residential areas was far higher than in business area. In addition, many migrant workers in Chengdu would flow out to other cities or rural areas, greatly decreasing the density of urban population, even though some outsiders flowed in the city. Therefore, in order to facilitate the population output before the Spring Festival and input after the festival, it is suggested that special public transport shifts and special channels for Spring Festival transportation at the start and end of the holiday be set up to meet the needs of passenger increase. Due to the impact of the epidemic, the data collected during the Spring Festival in 2020 shows certain particularity. Some emergency measures taken to contain the epidemic, however, are instructive in effectively reducing population aggregation such as staggered peak return after the Spring Festival holiday. The model, however, does reflect the effect of COVID_19 on population dynamics and the effectiveness of Chinese government's quick response to control population migration in short time. And we predict the growth of population density when the epidemic vanishes. This study shall give some clues to other similar domains or emergencies, in which quick population evacuation are necessary and optimization of land use and transportation facilities requires for planning. Further study is necessary for a better understanding of the impact of the Chinese traditional Spring Festival on urban population aggregation.

Sample selection biases shall be taken into consideration. According to the statistics of 2018 China Mobile Search Market Research Report, the mobile search users are mainly young people, with the age range of 18 – 40 accounting for 63.7%; the gender distribution of mobile search was uneven, with the male users being 52.2%, higher than the females. Besides, the market share of Baidu search, though the largest, represented 62.2%, failing to cover all the urban population. Further study is necessary to expand the sample selection to all the mobile phone users for better constructive suggestions in the improvement of public facility allocation and spatial structure arrangement.

References

Ahas, R., Aasa, A., Silm, S., & Tiru, M. (2010). Daily rhythms of suburban commuters' movements in the Tallinn metropolitan area: Case study with mobile positioning data. *Transportation Research Part C: Emerging Technologies, 18*(1), 45–54. https://doi.org/10.1016/j.trc.2009.04.011

Becker R. A., Cáceres R., Hanson K., Loh J. M., Urbanek S., Varshavsky A., & Volinsky C. (2011). A tale of one city: using cellular network Data for urban planning. *IEEE Pervasive Computing, 04*, 18-26. https://doi.org/10.1109/MPRV.2011.44

DeBoer M. (2015). Understanding the Heat Map. *Cartographic Perspectives, 80*, 39-43. https://doi.org/10.14714/CP80.1314

Leng B. R., Yu Y., Huang D. Q., & Yi Z. (2015). Big data based job-residence relation in Chongqing metropolitan area. *Planners, 31*(05), 92-96.

Li J., Li M.Y., Long Y., & Dang A. R. (2016). China polycentric cities based on Baidu heatmap. *Shanghai Urban Planning Review, 03*, 30-36.

Li J. G., Li J.W., Yuan Y.Z., Li G. F. (2019). Spatiotemporal distribution characteristics and mechanism analysis of urban population density: A case of Xi'an, Shaanxi, China. *Cities, 86*, 62–70. https://doi.org/10.1016/j.cities.2018.12.008

Lyu F. N., & Zhang L. (2019). Using multi-source big data to understand the factors affecting urban park use in Wuhan. *Urban Forestry & Urban Greening, 43*, 1-9. https://doi.org/10.1016/j.ufug.2019.126367

Shrader W. (2012). GooGle heat MaPs. *Cartographic Perspectives, 72*, 85-89.

Wang L. C. (2018). Spatial-temporal characteristics of urban population aggregation based on Baidu heat map in central areas of Wuhan city. *Journal of Human Settlements in West China, 33*,

52-56.

Wu Z. Q., & Ye Z. N. (2016). Research on urban spatial structure based on Baidu heat map: a case study on the central city of Shanghai. *City Planning Review, 40*(04), 33-40.

Yu C., & He Z. C. (2017). Analysing the spatial-temporal characteristics of bus travel demand using the heat map. *Journal of Transport Geography, 58*, 247-255. http://dx.doi.org/10.1016/j.jtrangeo.2016.11.009

Ye Z. N., Chen Y. H., & Zhang L. (2017). The analysis of space use around Shanghai metro stations using Dynamic data from mobile applications. *Transportation Research Procedia, 25C*, 3151-3164. https://doi.org/10.1016/j.trpro.2017.05.353

Zhang X.D., Han H.Y., & Shu X. F. (2019). Influencing factors on the vitality of five commercial complexes in Hangzhou: Based on the heat maps analysis. *Journal of Geo-information Science, 21*(11), 1745-1754.