Sensors and Materials, Vol. 35, No. 3 (2023) 871–887
MYU Tokyo

S & M 3215

Commuting Characteristics of Peripheral Clusters around a Central City Based on Mobile Phone Signaling Data —A Case Study of Tianjin, China

Zifei Liu, Peng Guo,* Yanling Sun,** Junrong Li, and Xinrui Pei

School of Geography and Environmental Science, Tianjin Normal University,
No. 393 Binshui West Road, Xiqing District, Tianjin 300387, China

(Received October 29, 2022; accepted February 14, 2023)

Keywords: commuting, peripheral clusters, job–housing separation, central city, mobile phone signaling data, Tianjin

Commuting has been the focus of research on urban spatial structure in recent years. Owing to the lack of information about employment locations in Chinese census data, commuting research has typically relied on traditional data sources such as surveys and questionnaires. With the advancement of communication and geographic information technology, new ideas and technical means for commuting research have emerged. The peripheral clusters of a central city are an essential part of urban functions and are critical areas that affect residents' commuting. We present a framework for analyzing the commuting characteristics of peripheral clusters around a central city based on mobile phone signaling data. We used the peripheral clusters around the central city of Tianjin as the research area for a case study based on this framework. The results show that the proportion of commuting within peripheral clusters around the central city of Tianjin is significant, and the overall commuting situation is excellent. Most peripheral clusters around the central city of Tianjin are in a relatively balanced state of employment and residence. The Xinli Cluster and Airport Logistics Park Cluster have slightly fewer residences. The Dongli Lake Cluster has a moderate shortage of job opportunities and a slight separation between job and housing availability.

1. Introduction

Commuting refers to the movement of people between residences and employment locations in an urban area.(1) It is inextricably linked to the spatial layout, land use planning, transportation structure, and residents' social life. Commuting characteristics are critical in determining the rationality and livability of an urban area. Moreover, the differences in commuting characteristics within various urban spatial distributions and built environments become the focus of commuting research, which usually involves the study of the spatial distribution of houses and sites of employment, commuting time, and commuting mode.(2) Thorough research into the commuting characteristics of urban residents can shed light on the internal workings of organic

*Corresponding author: e-mail: pguo@tjnu.edu.cn
**Corresponding author: e-mail: sunyanling@tjnu.edu.cn
https://doi.org/10.18494/SAM4207

ISSN 0914-4935
https://myukk.org/

urban development, streamline land resource distribution, boost the efficiency of urban operations, and guide the pursuit of high-quality urban growth.[3]

The current focus of scholars who study commuting characteristics is the investigation of residents' commuting time, distance, efficiency, transportation mode, route planning, and other aspects, as well as the analysis of the factors influencing commuting characteristics. Some scholars use the ratio of commuting time spent at work to describe commuting features.[4–7] From the perspective of improving the urban traffic system to alleviate traffic congestion and rationally optimizing the urban spatial layout, scholars have used various methods such as the structural equation model, the multinomial logit regression model, the discrete choice model, and the multi-level mixed effect model to systematically and thoroughly discuss the spatial characteristics of residents' commuting, commuting time, commuting distance, commuting mode, carbon emissions due to commuting, and factors influencing these characteristics, and put forward policy suggestions for optimizing the urban spatial structure and encouraging low-carbon transportation.[8–10] The most common research method is to select specific employment locations or residences for case analysis or comparative analysis.

Owing to the absence of information on employment locations in Chinese census data, scholars initially relied on traditional data such as questionnaires and activity logs, which were inefficient, offered tiny sample sizes, and were sluggish with respect to updating data.[11] In today's era of big data, the rapid development of information technology provides new ideas and technical means for analyzing commuting characteristics. Datasets that included relatively specific spatial-temporal attributes and had high accuracy, such as bus swipe card data, media check-in data, and micro-blog user data, had been used earlier. However, the drawback of these datasets is that their scope limited the research to card users and micro-blog users.[12–14] The emergence of mobile phone signaling data brings a new opportunity to study residents' commuting characteristics, which can portray residents' spatial distribution and movement more realistically and effectively through real-time positioning information from mobile phones. The broad spatial and temporal coverage, high rate of ownership, and large quantity of mobile signaling data are important data supplements for studying commuting characteristics.[15–18]

Even though numerous researchers have studied commuting characteristics and produced outstanding results, most of their attention has been focused on mega-cities such as New York, Tokyo, Beijing, and Shanghai. More research is needed on the peripheral clusters around central cities. Peripheral clusters around central cities are the outlying regions that can meet the basic living needs of residents and support the migration of various functions from the central city.[19] The establishment of peripheral clusters can effectively control the irrational expansion of a central city and relieve the pressure of population and employment, which is an essential strategy for coordinating regional development, help in the optimization of a city's spatial layout, and assist in realizing sustainable urban development.[20] However, the lack of synchronization between places of employment and residences in the construction of peripheral clusters has resulted in a large number of "sleeping cities" and "empty cities," exacerbating the imbalance between available jobs and housing, increasing the commuting costs of residents in peripheral clusters, and impacting their daily lives. Analyzing the commuting characteristics of peripheral clusters around a central city is necessary for optimizing the spatial layout of an area, enhancing

the efficiency of resource utilization within an area, and attaining high-quality urban development. As a result, we propose a framework for analyzing the commuting characteristics of peripheral clusters around a central city based on mobile phone signaling data. We used Tianjin's peripheral clusters in a case study to provide a reference for the improvement of peripheral cluster planning in Tianjin.

2. Data and Methods

2.1 Study area

The study area was the peripheral cluster around the central city of Tianjin. According to the document "Tianjin Urban Master Plan (2005–2020),"[21] Tianjin has developed as a four-tier town system consisting of primary and secondary centers, new towns, central towns, and general towns to promote urbanization and steadily raise the level of urbanization. As the urban functions of Tianjin continued to spread beyond the central area, residential areas and industries in the former central urban districts were gradually relocated to the suburbs. In locations along the outer ring outside the main city center, peripheral clusters of various scales and purposes were developed, including Xiqing New Town and 9 clusters in Dasi, Shuanggang, Xinli, Airport Logistics Park, Dongli Lake, Dabizhuang, Xiaodian, Shuangjie, and Qingshuang (Fig. 1). The building of the Xiqing New Town and the 9 clusters were primarily completed by 2017.

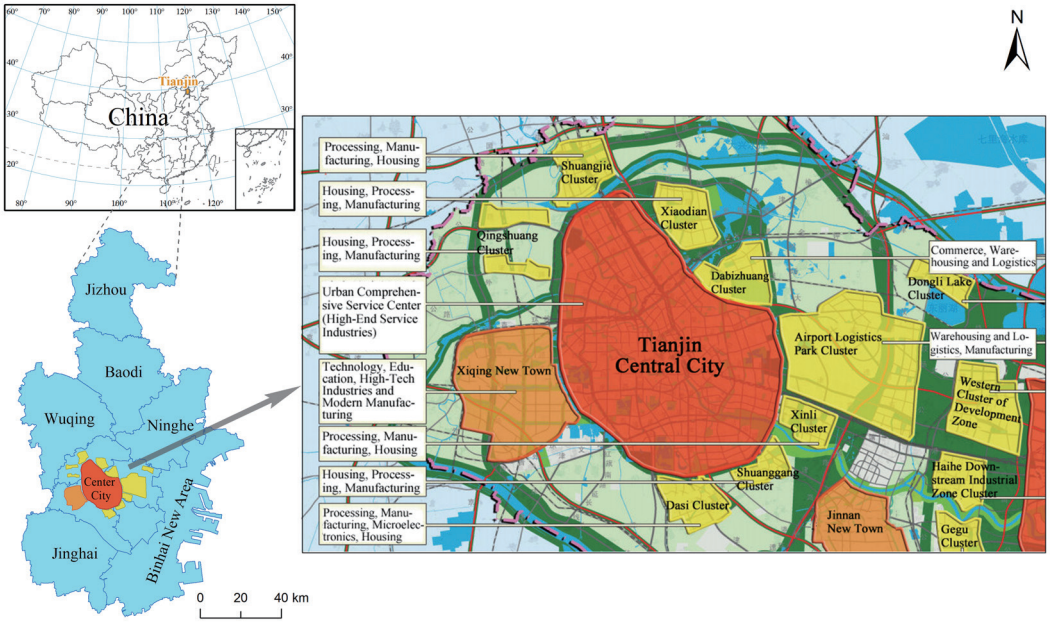

Fig. 1. (Color online) Layout structure of "central city + peripheral clusters" for the central city of Tianjin. [Source: Tianjin Urban Master Plan (2005–2020)]

2.2 Methods

Anonymized mobile phone signaling data from China Mobile operators in Tianjin between Oct. 18 and Nov. 23, 2017, were used in this study. Specifically, anonymized user identification (ID) numbers, time, base station ID numbers, and signaling types were included. During the active period, mobile phones were used to connect with the mobile signal base station, and information was recorded approximately every 4 min between the hours of 6:00 and 22:00. Each mobile phone produced nearly 131–171 signals per day on average. According to statistics, by the end of 2017, China Mobile subscribers accounted for 62.4% of all mobile subscribers. Furthermore, there was no significant difference in the spatial distribution of users in choosing communication operators. To a certain extent, the data reflected the commuting characteristics of residents. On the basis of the information and the technical framework shown in Fig. 2, an analysis was carried out.

2.2.1 Identification of locations of employment and housing

The adjacent time intervals generated by each signaling data are not fixed, and there is a possibility of recording time longer than 1 h or shorter than 1 min. As a result, we used the cumulative time method proposed by Niu and Xie to analyze signaling data from Oct. 18 through Nov. 23, 2017, to identify locations of mobile phone subscribers and eliminate the irregularities

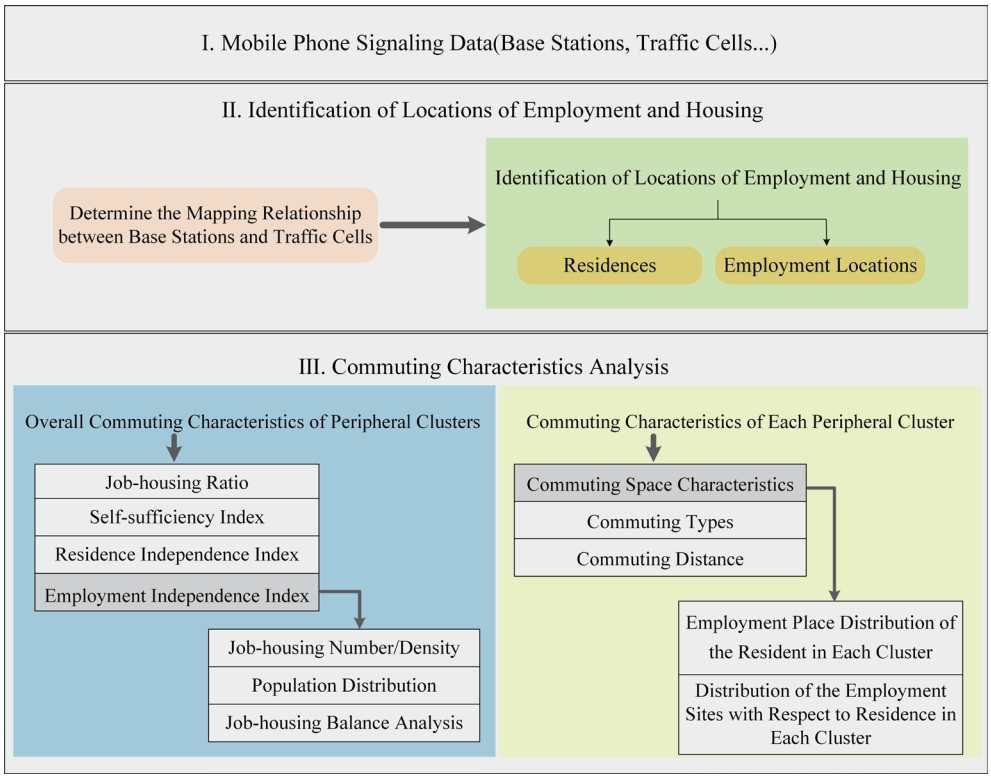

Fig. 2. (Color online) Diagram of the technical framework.

in the signaling recording time.[22] The locations where users spent the most cumulative time during the day from 9:00 to 18:00 were labeled as employment locations, while the locations where they spent the most cumulative time during the night from 20:00 to 8:00 were labeled as residences. Finally, in the regional scope of the peripheral clusters in the central city of Tianjin, approximately 341000 residences and 385000 employment locations were identified. Comparing the number of residents in each block identified by mobile phone data with the data from the sixth nationwide population census showed that the two types of data have a high consistency in spatial distribution. Although mobile phone records and identification rules have an impact on the results of the identification of the resident population, the method of using mobile phone signaling data to identify the resident population is still considered feasible.

2.2.2 Origin destination (OD) analysis

The OD survey refers to a survey of traffic volume between an origin and a destination. When using the mobile phone signaling data to identify the locations of residences and employment of mobile phone users, the spatial mapping relationship between the base station cell and each traffic cell was obtained, and an OD table of mobile phone users' travel was constructed.[23] By analyzing the OD travel of mobile phone users, both the commuting flow and type of mobile phone users were determined. The balance between their places of employment and residences, referred to as the job–housing balance, was calculated as a result.

2.2.3 Analysis of commuting between sites of employment and residences

The ratio of the number of jobs to the number of residents in an area and a self-sufficiency index were chosen to measure the spatial relationship between sites of employment and residences. On the quantitative level, this ratio represents the balanced relationship between the number of jobs and the number of residents in a particular area; on the qualitative level, the self-sufficiency index represents the degree of independence of employment locations and residences in a particular area.

(1) Job–housing ratio. The job–housing ratio is the ratio of the number of jobs in an area to the number of residents in that same area.[24] The specific calculation formula is

$$Z_i = \frac{A_i}{B_i}, \tag{1}$$

where Z_i is the job–housing ratio in region I, A_i is the number of jobs in region i, and B_i is the number of residents in region i. As reported by Cervero,[25] a balanced job–housing relationship in a region is indicated by a ratio ranging from 0.8 to 1.2. Therefore, the range of 0.8–1.2 was used as a standard for a balanced job–housing ratio in this study.

(2) Self-sufficiency index. The self-sufficiency index reflects the potential of job–housing balance in a particular region. Xu and Wu modified Thomas's "independence index" and proposed a self-sufficiency index.[26] The specific calculation is

$$C_{fi} = \frac{Y_i}{Avg\left(Y_i\right)}, \tag{2}$$

$$R_{si} = \frac{N_i}{Avg\left(N_i\right)}, \tag{3}$$

$$E_{si} = \frac{B_i}{Avg\left(B_i\right)}, \tag{4}$$

where Y_i is the ratio of people who work and live in region i to the total number of people living there, N_i is the ratio of people who live in region i but do not work to the total number of people who live there, and B_i is the ratio of people who work but do not live in region i to the total number of people who work there.

The self-sufficiency index (C_{fi}) measures the level of integration between jobs and housing in a region. A higher C_{fi} value indicates a higher degree of integration and a weaker separation between jobs and housing. On the other hand, a higher value of the residence independence index (R_{si}) suggests greater housing independence in the region, with a higher proportion of people who work elsewhere and limited employment opportunities. The employment independence index (E_{si}) reflects the employment independence of a region, with a higher value indicating a higher proportion of people who live elsewhere, more abundant employment opportunities, but a shortage of housing.

3. Analysis of Results

3.1 Residence and employment

3.1.1 Population distribution of residences and employment

Table 1 shows the resident population, the number of employed people in the population, and the residential density and employment density of the clusters in the peripheral clusters around Tianjin's central city identified through mobile phone signaling data. From the resident population, the number of residents in Xiqing New Town is much larger than in other clusters, followed by the Airport Logistics Park Cluster and the Dasi Cluster; the number of residents identified in Xiaodian, Shuangjie, Shuanggang, and Xinli clusters is similar; the Qingshuang and Dabizhuang clusters have a small number of residents, and the Dongli Lake Cluster has the smallest number of residents. Considering the number employed people, Xiqing New Town is still far more populated than other clusters, and the Dongli Lake Cluster is the least populated. The difference in ranking in terms of the number of residents is that, while the Xinli Cluster's residents are not as numerous as those in the Shuanggang Cluster, the Dongli Economic Development Area within the Xinli Cluster may cause the number of employed people in the Xinli Cluster identified by mobile phones to exceed that of the Shuanggang Cluster.

Table 1
Number and density of employment and residents in peripheral clusters in the central city of Tianjin.

Cluster name	Resident population (person)	Employment population (person)	Cluster area (km^2)	Density of residences (person/km^2)	Density of employment (person/km^2)
Xiqing New Town	131526	139241	90.00	1461.38	1547.10
Airport Logistics Park Cluster	52946	73080	111.96	472.92	652.76
Dasi Cluster	35666	39278	19.91	1791.78	1973.23
Xiaodian Cluster	22745	26077	23.54	966.27	1107.83
Shuangjie Cluster	22320	23683	22.45	994.37	1055.10
Shuanggang Cluster	21001	21588	11.03	1903.33	1956.53
Xinli Cluster	18575	25025	14.29	1299.85	1751.21
Qingshuang Cluster	14545	16391	15.93	913.06	1028.94
Dabizhuang Cluster	13732	14225	23.02	596.59	618.01
Dongli Lake Cluster	8053	6497	11.81	681.91	550.15

Because of the large area of the cluster, Xiqing New Town has the most people and a relatively high density of residences. Furthermore, Zhangjiawo Town, Yangliuqing Town, Zhongbei Town, and other densely populated areas are part of the Xiqing New Town. The high density of residences and employment in the Airport Logistics Park Cluster is also related to the large size of the cluster, although the density of residences and employment is very low. The Dasi Cluster and the Shuanggang Cluster have a relatively high number and density of residences and employment, which is related to the fact that the Dasi Cluster has two economic and technological development zones, and the Shuanggang Cluster has the Shuanggang Industrial Zone. The number and density of residences and employment in the Dongli Lake Cluster are low due to the development of tourism in the vicinity of Dongli Lake, which has leisure and entertainment venues such as resorts and Happy Valley.

The kernel density analysis of the resident population distribution (Fig. 3) and the employment population distribution (Fig. 4) identified by mobile phone signaling data in the peripheral clusters of Tianjin's central city reveal that the resident population distribution is relatively concentrated in each cluster, while the employment population distribution is relatively dispersed and balanced. Areas with a resident population density of more than 5000 people per km^2 are roughly located in Zhongbei Town, Yangliuqing Town and Zhangjiawo Town of Xiqing New Town, Beichen Science and Technology Park of Shuangjie Cluster, Jinzhong Street of Dabizhuang Cluster, and Tianjin Airport Economic Zone of Airport Logistics Park Cluster. The pattern of residential concentration shows a decline in population density in concentric circles radiating from the center. Meanwhile, the distribution of the employed population is more dispersed and balanced across the region. However, there are still certain areas with a relatively high concentration of employed individuals, such as the high-tech zones in Xiqing New Town, Yangliuqing Town, the Airport Economic Zone in the Airport Logistics Park Cluster, the Xinli Street in the Xinli Cluster, and the Dasi Town in the Dasi Cluster.

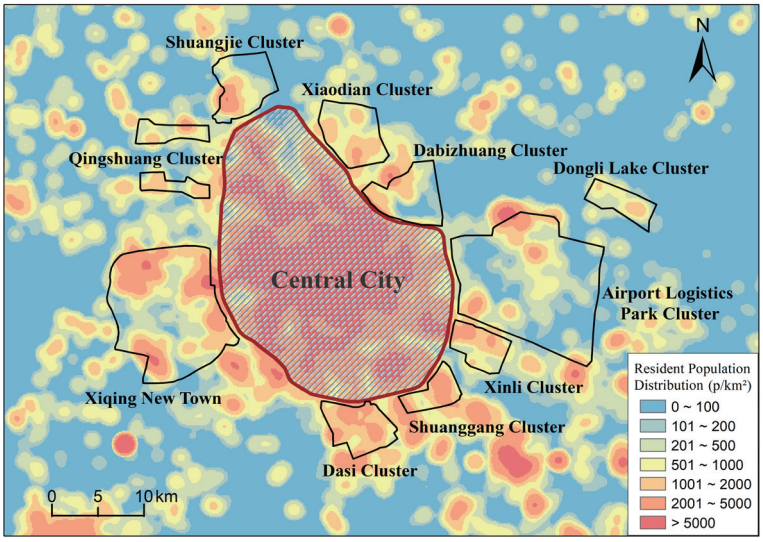

Fig. 3. (Color online) Kernel density of the resident population distribution in peripheral clusters in the central city of Tianjin.

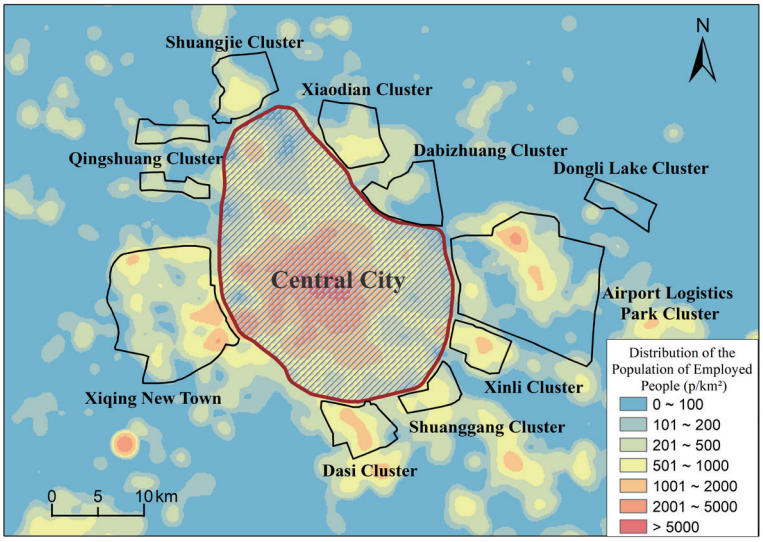

Fig. 4. (Color online) Kernel density of the distribution of the population of employed people in peripheral clusters in the central city of Tianjin.

3.1.2 Job–housing balance analysis

The table describing the balance between jobs and residential housing for the peripheral clusters in the central city of Tianjin (Table 2) shows that most of the clusters are in a balanced state in terms of the number of residents and jobs, but the ratio of jobs to residences in the Airport Logistics Park Cluster and Xinli Cluster exceeds the maximum value of 1.2 in terms of the balance between jobs and the number of residents, indicating that the number of jobs in these two clusters is greater than the number of residents. From the perspective of the self-sufficiency

Table 2
The assessment of the balance between jobs and housing in the peripheral clusters in the central city of Tianjin.

Cluster name	Jobs–housing ratio	Self-sufficiency index	Residence independence index	Employment independence index
Xiqing New Town	1.06	1.05	0.77	0.74
Airport Logistics Park Cluster	1.38	1.08	0.65	1.40
Dasi Cluster	1.10	0.96	1.18	1.13
Xiaodian Cluster	1.15	1.09	0.63	0.89
Shuangjie Cluster	1.06	1.00	1.00	0.91
Shuanggang Cluster	1.03	0.92	1.35	1.06
Xinli Cluster	1.35	1.03	0.88	1.46
Qingshuang Cluster	1.13	1.01	0.95	1.04
Dabizhuang Cluster	1.04	1.00	1.00	0.84
Dongli Lake Cluster	0.81	0.86	1.59	0.52

index, the Xiaodian Cluster, the Airport Logistics Park Cluster, and Xiqing New Town have relatively high self-sufficiency indexes, indicating a well-balanced relationship between jobs and residential housing. On the other hand, the Dongli Lake Cluster has a lower self-sufficiency index of 0.86, suggesting a less balanced job–housing relationship. In terms of the residence independence index, the Dongli Lake Cluster and the Shuanggang Cluster have higher residence independence, implying that these areas have adequate housing and a high proportion of residents who commute for employment. Meanwhile, the Xinli Cluster and the Airport Logistics Park Cluster have higher employment independence index values, which indicate that these clusters have a higher availability of employment opportunities and a higher proportion of people who commute from outside the region.

3.2 Commuting space characteristics

We obtained the travel OD table of users within each cluster using mobile phone signaling data to identify the locations of employment sites and residences. Furthermore, the employment whereabouts of the residents and the commuting directions of employees can be obtained by analyzing the travel OD of mobile phone users. On the basis of this, we examined the commuting characteristics of residents in the peripheral clusters in Tianjin's central city from four perspectives: distribution of employment sites of the residents, distribution of residential sites with respect to employment, commuting type, and commuting distance.

3.2.1 Employment site distribution of residents

The kernel density of the distribution of employment sites of residents in peripheral clusters of Tianjin's central city (Fig. 5) shows that majority of the residents in peripheral clusters in the central city of Tianjin are employed in a central street or a specific town within the cluster, such as Shuangjie Town in Shuangjie Cluster, Jinzhong Street in Dabizhuang Cluster, Xinli Street in Xinli Cluster, Shuanggang Town in Shuanggang Cluster, Dasi Town in Dasi Cluster, and Huaming Street in Dongli Lake Cluster. The vast majority of residents in each cluster congregate

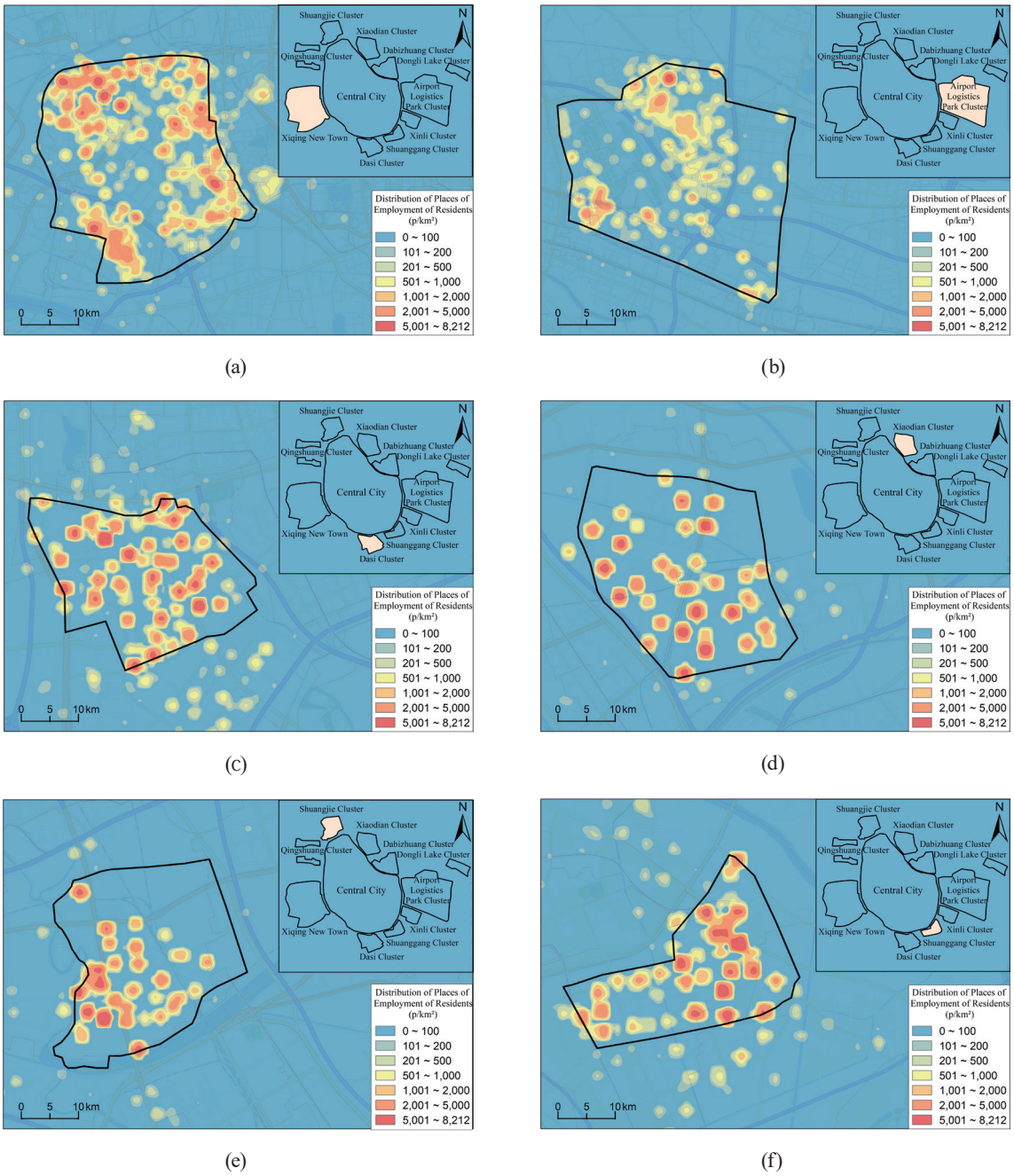

Fig. 5. (Color online) Distribution of places of employment of residents in the peripheral clusters of the central city of Tianjin: (a) Xiqing New Town, (b) Airport Logistics Park Cluster, (c) Dasi Cluster, (d) Xiaodian Cluster, (e) Shuangjie Cluster, and (f) Shuanggang Cluster.

on these streets or in these towns. In addition, some clusters have jobs more evenly distributed among several towns or streets, such as Zhangjiawo Town, Yangliuqing Town, and Zhongbei Town in Xiqing New Town, Qingguang Town and Shuangkou Town in Qingshuang Cluster, Yixingbu Town and Xiaodian Town in Xiaodian Cluster, and Huaming Street, Xinli Street, and Junliangcheng Street in the Airport Logistics Park Cluster.

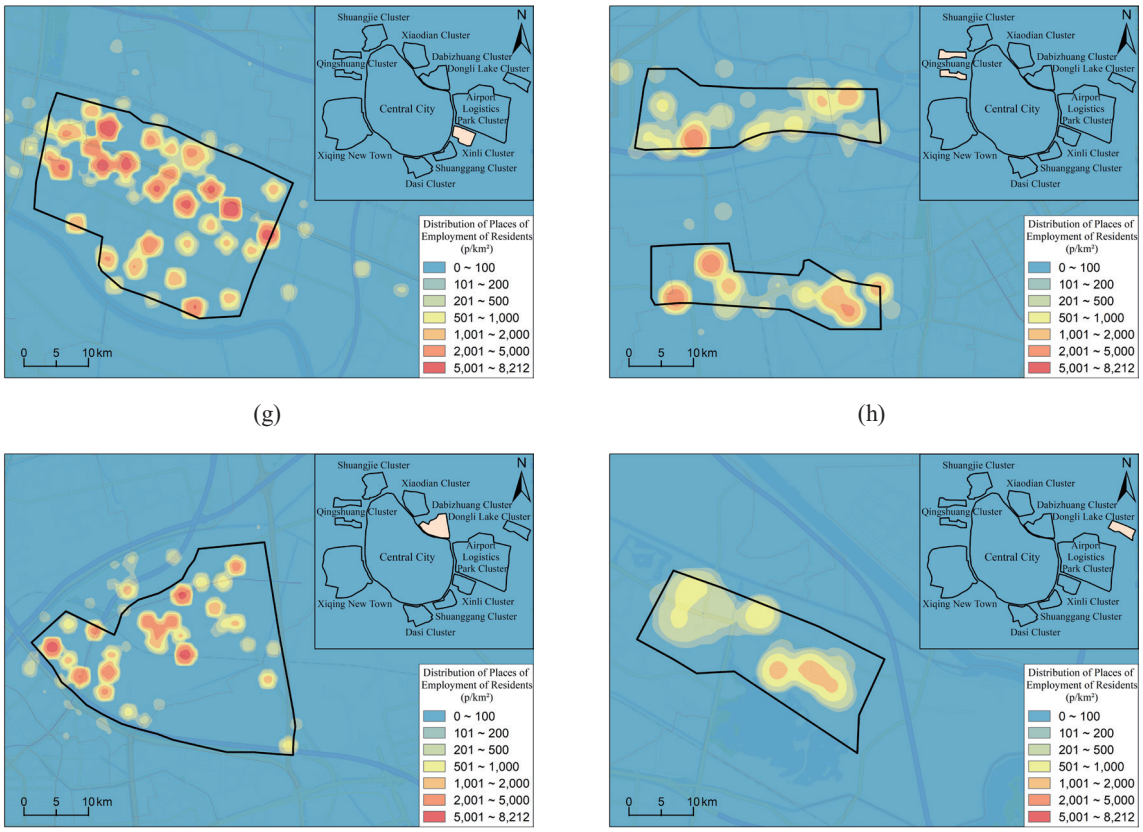

Fig. 5. (Continued) (Color online) Distribution of places of employment of residents in the peripheral clusters of the central city of Tianjin: (g) Xinli Cluster, (h) Qingshuang Cluster, (i) Dabizhuang Cluster, and (j) Dongli Lake Cluster.

3.2.2 Distribution of employees with respect to residence

The kernel density of distribution of residential areas of employees in peripheral clusters of Tianjin's central city (Fig. 6) indicates that the majority of the residences of employees in these peripheral clusters are also primarily concentrated within their respective clusters. Analysis and comparison revealed that the distribution of the residential locations of the employees and the distribution of their employment sites are largely the same within each cluster. The streets with the highest concentrations of employees also have the highest concentrations of residents. The consistency of spatial distribution between workplace and residence is relatively high.

3.3 Commuting types

The types of commuting are classified into internal and external commuting according to the relationship between locations of employment and residences in each peripheral cluster. Internal commuting refers to living and working in the same cluster, whereas external commuting refers to working in a cluster but not living there. The ratio of commuting types for each cluster is

Fig. 6. (Color online) Distribution of residential areas of employees in peripheral clusters of the central city of Tianjin: (a) Xiqing New Town, (b) Airport Logistics Park Cluster, (c) Dasi Cluster, (d) Xiaodian Cluster, (e) Shuangjie Cluster, and (f) Shuanggang Cluster.

shown in Table 3. The internal commuting ratio within a peripheral cluster is ranked similarly to the self-sufficiency index. The highest commuting ratios are found in the Xiaodian and Airport Logistics Park clusters, while the lowest ratio is in the Dongli Lake Cluster. The ranking of the external commuting ratio corresponds to the ranking of the employment independence index.

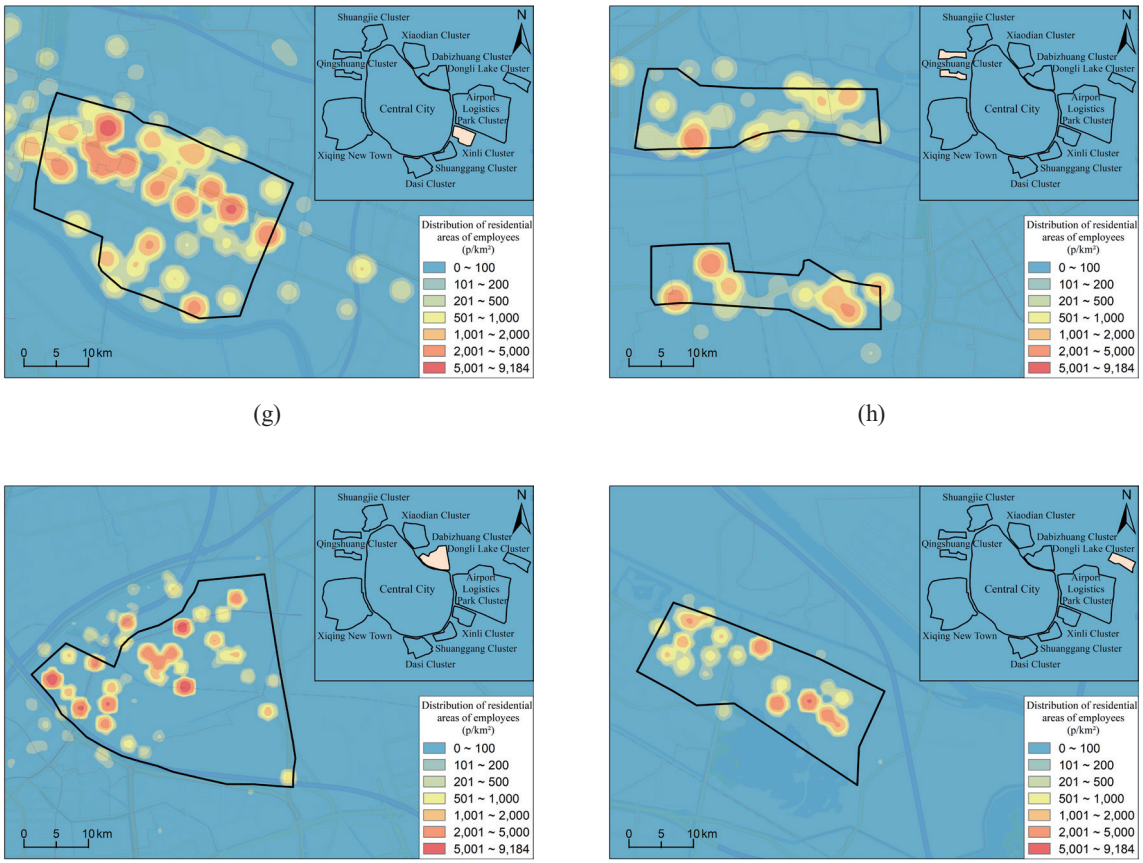

Fig. 6. (Continued) (Color online) Distribution of residential areas of employees in peripheral clusters of the central city of Tianjin: (g) Xinli Cluster, (h) Qingshuang Cluster, (i) Dabizhuang Cluster, and (j) Dongli Lake Cluster.

Table 3
Proportion of commuting types in peripheral clusters in the central city of Tianjin.

Cluster name	Internal commuting (%)	External commuting (%)
Xiqing New Town	85	19
Airport Logistics Park Cluster	88	37
Dasi Cluster	78	30
Xiaodian Cluster	88	23
Shuangjie Cluster	81	24
Shuanggang Cluster	74	28
Xinli Cluster	83	38
Qingshuang Cluster	82	27
Dabizhuang Cluster	81	22
Dongli Lake Cluster	70	14

The Xinli Cluster and Airport Logistics Park Cluster ranked highest, with the Dongli Lake Cluster ranking lowest. The internal commuting ratios of the peripheral clusters in Tianjin's central city are all 70% or higher. The other peripheral clusters, except the Airport Logistics

Park and Xinli clusters, all have 30% or lower external commuting ratios. Except for the Airport Logistics Park Cluster and Xinli Cluster, which have a higher proportion of external workers, the other peripheral clusters in Tianjin central city maintain a balance between jobs and residents, consistent with the results of commuting characteristics obtained from the analysis of the ratio of jobs to residents.

3.4 Commuting distance

The commuting distance for the peripheral clusters in the central city of Tianjin (Table 4) shows that the average commuting distance within each cluster is relatively short, and most clusters have an internal commuting distance of 300 m or less. The internal commuting distance exceeds 500 m in Xiqing New Town and Airport Logistics Park Cluster because of the large area of the clusters. The commuting distance from the inside out of each cluster is quite different, and the commuting distance from the inside out of Xiqing New Town, Airport Logistics Park Cluster, Shuangjie Cluster, and Dongli Lake Cluster exceeds 10 km. The commuting distance back from the outside of each cluster is roughly equivalent to the commuting distance from the inside out. The average commuting distance of residents in each cluster is reasonable for most clusters and lies between distances of 1 km and 2.5 km, but the average commuting distance of residents in the Dongli Lake Cluster is more than 4 km, which is related to the fact that Dongli Lake Cluster has a small number of jobs and the commuting distance from the inside to the outside is long. The attractiveness of employment is closely related to the commuting distance to locations of employment. If the average commuting distance to employment locations in a particular region is significantly greater than the average commuting distance of residents, the attractiveness of employment in the area is higher. According to Table 4, the Airport Logistics Park Cluster and the Xinli Cluster are very attractive in terms of employment, while the Dongli Lake Cluster is less attractive.

Table 4
Commuting distance in peripheral clusters in the central city of Tianjin (unit: m).

Cluster name	Internal commuting distance	Commuting distance from inside out	Commuting distance back from outside	Average commuting distance of residents	Average commuting distance of employment locations
Xiqing New Town	582	11357	10360	2171	2486
Airport Logistics Park Cluster	501	11871	13480	1909	5241
Dasi Cluster	242	7498	9974	1870	3119
Xiaodian Cluster	290	8628	8986	1296	2316
Shuangjie Cluster	282	11357	10616	2402	2741
Shuanggang Cluster	173	8814	7789	2393	2284
Xinli Cluster	219	9489	8870	1777	3528
Qingshuang Cluster	128	6629	6785	1304	1946
Dabizhuang Cluster	140	7553	6256	1559	1482
Dongli Lake Cluster	156	14339	13186	4450	1925

4. Discussion

Analyzing the commuting characteristics of peripheral clusters in a central city can help improve the efficiency of urban operations and play a positive role in the planning and construction of the city. The framework proposed in this study analyzes the commuting characteristics of peripheral clusters in a central city using mobile phone signaling data. The sample size based on mobile phone data is large, so it reflects the commuting characteristics quantitatively. The results of identifying the locations of employment sites and residences by mobile phone data are consistent with the census data. We compared our results of the case study on the peripheral clusters in the central city of Tianjin with Qiqi Xiao's research on the distribution of jobs and housing in Tianjin.[27] The latter research results pointed out that the distributions of residential agglomeration areas and employment agglomeration areas in Tianjin are highly similar, and the distributions of employment sites and residences are relatively balanced. The internal commuting characteristics of areas such as Dongli District and Xiqing District are more prominent, with many residents commuting within the same cluster. We also compared our results with those from the study on the relationship among commuting, employment, and housing in Tianjin by Baidu Huiyan and Taupd Joint Innovation Lab. The latter research results pointed out that the number of jobs in places such as the Airport Development Zone is relatively high, which are mainly located in industrial clusters, while the Dongli Lake Cluster has a modest shortage of jobs.[28] These results are basically consistent with the results of this study, which suggests that it is feasible and reasonable to use mobile phone signaling data to analyze the commuting characteristics of peripheral clusters around a central city.

According to our results, the overall situation involving jobs and housing in the peripheral clusters around the central city of Tianjin is excellent, but there is still much potential for improvement. The Xinli Cluster and the Airport Logistics Park Cluster have high employment rates and cannot meet the housing needs of employees. We suggest that these two clusters strengthen their construction of housing and infrastructure, improve living conditions, and solve the housing problems of the employees. There are few jobs in the Dongli Lake Cluster, and the average commuting distance of residents is relatively long. The cluster's industrial structure and the long commuting distance of the residents should be improved, the development of industries other than tourism and vacationing should be emphasized, and the number of jobs should be increased to provide more job options closer to residential areas for the residents of the Dongli Lake Cluster. Improvements in the study of these issues could also be made. For example, the individual characteristics of mobile phone user data should be taken into account when studying the commuting characteristics of peripheral clusters around a central city. Because of limitations in the data, the users' age range was not taken into consideration in this work, so we failed to separate the employed residential group from the unemployed residential group. We also did not include the gender, occupation, and income level of users and did not thoroughly analyze the reasons for the differences in commuting characteristics of the residents. We also did not examine factors influencing the commuting characteristics of each cluster. These aspects should be considered in future work.

5. Conclusions

We proposed a framework for analyzing the commuting characteristics of peripheral clusters based on mobile phone signaling data and took the peripheral clusters in the central city of Tianjin as the study area to conduct an analysis. The main conclusions are as follows.

(1) The overall commuting situation in the peripheral clusters around the central city of Tianjin is excellent. Most of the clusters have a high proportion of internal commuting, and the average commuting distance is relatively short.

(2) The relationship between the number of jobs and the number of residents in a particular area can be characterized as balanced in most peripheral clusters in the central city of Tianjin. However, some clusters may experience slight imbalances in either housing or employment, leading to a slight separation of the job–housing distribution.

These research results may help optimize the spaces for employment sites and housing in the peripheral clusters around the central city of Tianjin, save commuting costs, and improve the commuting efficiency of residents, thus alleviating urban traffic conflicts and improving urban operation efficiency. We have identified aspects that need to be improved in the planning and development process of peripheral clusters around the central city of Tianjin and have suggested improvements to provide references for the planning of peripheral clusters around the central city of Tianjin.

Acknowledgments

This work was supported by the 2021 Open Project of Key Laboratory of Intelligent Transportation Industry of Urban Public Transport (2021-APTS-02) and the National Natural Science Foundation of China (Grant Nos. 41001022 and 41971306).

References

1 Z. Li and Y. Chai: Hum. Geogr. (2000) 67. https://doi.org/10.13959/j.issn.1003-2398.2000.06.015
2 J. Tian, D. Wang, D. Xie, and W. Zhu: Geogr. Res. **36** (2017) 134. https://doi.org/10.11821/dlyj201701011
3 S. Zhou and L. Yang: Urban Transport China **3** (2005) 62. https://doi.org/10.13813/j.cn11-5141/u.2005.01.017
4 M. Wachs, B. D. Taylor, N. Levine, and P. Ong: Urban Stud. **30** (1993) 1711. https://doi.org/10.1080/00420989320081681
5 T. Schwanen, F. M. Dieleman, and M. Dijst: Growth Change **35** (2004) 304. https://doi.org/10.1111/j.1468-2257.2004.00251.x
6 M. Kawabata and Q. Shen: Urban Stud. **44** (2007). https://doi.org/10.1080/00420980701426616
7 T. Schwanen and M. Dijst: Transp. Res. Part A Policy Pract. **36** (2002) 573. https://doi.org/10.1016/S0965-8564(01)00023-4
8 X. Zhang, J. Song, W. Yu, and Z. Wang: Acta. Geogr. Sin. **76** (2021) 383. https://doi.org/10.11821/dlxb202102010
9 C. Zhang, Z. Cheng, X. Yu, Y. Wang, and C. Shen: Prog. Geogr. **39** (2020) 111. https://doi.org/10.18306/dlkxjz.2020.01.011
10 W. Yang, F. Liang, and X. Cao: Geogr. Res. **39** (2020) 1625. https://doi.org/10.11821/dlyj020190566
11 D. Gan, D. Wang, and W Zhu: Geogr. Res. **34** (2015) 1481. https://doi.org/10.11821/dlyj201508007
12 B. Liu and C. Feng: Urban Plann. Forum (2012) 59. https://doi.org/10.3969/j.issn.1000-3363.2012.04.009
13 Y. Long, Y Zhang, and C. Cui: Acta Geogr. Sin. **67** (2012) 1339. https://doi.org/10.11821/xb201210005
14 Y. Xu, N. Ta, and X. Li: Hum. Geogr. **32** (2017) 93. https://doi.org/10.13959/j.issn.1003-2398.2017.03.012
15 H. Shao, C. Jin, Y. Zhong, and W. Mao: Hum. Geogr. (2022) 37 (in Chinese). https://doi.org/10.13959/j.issn.1003-2398.2022.05.016

16 W. Liu and J. Chen: Tropical Geogr. **42** (2022) 965. https://doi.org/10.13284/j.cnki.rddl.003494
17 M. Wang, X. Hou, L. Si, and F. He: JGGS (2022) 162. https://doi.org/10.13474/j.cnki.11-2246.2022.0159
18 D. Wang, D. Li, and Y. Fu: Acta. Geogr. Sin. **75** (2020) 1585. https://doi.org/10.11821/dlxb202008003
19 M. Yang, J. Wang, Y. Wu, H, Qiu, and M. Mao: Urban Dev. Stud. **26** (2019) 12. https://doi.org/10.3969/j.issn.1006-3862.2019.10.002
20 W. Xu, X. Zhang, and Y. Long: Urban Dev. Stud. **26** (2019) 48. https://doi.org/10.3969/j.issn.1006-3862.2019.10.006
21 Tianjin Urban Master Plan (2005–2020): https://ghhzrzy.tj.gov.cn/ywpd/cxgh_43015/ghgb/202012/W020201206136705242211.pdf (accessed August 2006).
22 X. Niu and C. Xie: Urban Transport China **17** (2019) 19. https://doi.org/10.13813/j.cn11-5141/u.2019.0303
23 Z. Lu, Z. Long, and Q. Yu: Modern Urban Res. (2019) 50 (in Chinese). https://doi.org/10.3969/j.issn.1009-6000.2019.03.007
24 Y. Bai and P. Zhao: J. Northwest Normal Univ. (Nat. Sci.) **54** (2018) 89. https://doi.org/10.16783/j.cnki.nwnuz.2018.04.016
25 R. Cervero: J. Am. Plann. Assoc. **55** (1989) 136. https://doi.org/10.1080/01944368908976014
26 B. Xu and X. Wu: Urban Plann. Forum (2010) 87. https://www.cnki.com.cn/Article/CJFDTOTAL-CXGH201005014.htm
27 Q.Xiao: https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD202202&filename=1022481869.nh (accessed February 2021).
28 Baidu Huiyan and Taupd Joint Innovation Lab: https://baijiahao.baidu.com/s?id=1601253733444976729 (accessed May 2018).

About the Authors

Zifei Liu received her B.S. degree from Tianjin Normal University, China, in 2021. She is currently working on her M.S. degree at Tianjin Normal University. Her research interests are in climate change and urban regional development. (liuzifei_0801@163.com)

Peng Guo received his B.S. and M.S. degrees from Southwest Agricultural University in China in 2001 and 2004, and his Ph.D. degree from Wuhan University, China, in 2008. Since 2008, he has been at Tianjin Normal University, China, and currently serves as an associate professor. His research interests are in the analysis of geographic big data. (pguo@tjnu.edu.cn)

Yanling Sun received her B.S., M.S., and Ph.D. degrees from Southwest Agricultural University, China, in 2001, 2003, and 2006, respectively. From July 2006 to May 2008, she was a postdoctoral fellow at the Key Laboratory of Regional Climate-Environment for East Asia, Institute of Atmospheric Physics, CAS. Since 2008, she has been at Tianjin Normal University and currently serves as an associate professor. Her research interests are in remote sensing of resources and environment and global change. (sunyanling@tjnu.edu.cn)

Junrong Li received her B.S. degree from Taiyuan Normal University, China, in 2020. She is currently working on her M.S. degree at Tianjin Normal University, China. Her research interests are in climate change and urban regional development.(lijunrong98@163.com)

Xinrui Pei received her B.S. degree from Tianjin Normal University, China, in 2020. She is currently working on her M.S. degree at Tianjin Normal University. Her research interests are in climate change and urban regional development. (pei_xinrui@163.com)