

Measuring spatial accessibility and disparity to county hospitals in western China: based on the web map navigation data

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Abstract

Background

The Chinese government proposed the initiative of "XIAO BING BU CHU CUN, DA BING BU CHU XIAN" in 2016, which means the rate of health care service provided by county hospitals should reach 90%. The prerequisite for achieving this goal is that residents can access to county hospitals' services conveniently and impartially. However, little research reported the level of spatial accessibility of county hospitals in western China. Therefore, we aim to measure the spatial accessibility to county hospitals of county residents and identify regional disparities in Shaanxi Province in western China.

Methods

We implemented a novel method – navigation data of the AutoNavi map (known as Gaode map in Chinese) – to assess time and distance from villages and neighborhoods to county hospitals. The navigation data was collected by requesting an application-programming-interface using a web crawler in Python. The minimum driving time and distance were extracted from the navigation data. The travel impedance to the nearest provider was used to measure spatial accessibility.

Results

The results show that county residents in northwestern China's Shaanxi Province have poor spatial accessibility to county hospitals. Only 68.8% of villages and neighborhoods can reach the county hospitals within 60 minutes, while 13.4% of them are reachable beyond 90 minutes. Moreover, a significant within-province disparity exists, with residents in the central area most accessible to county hospitals, while the north and south areas still need improvement.

Conclusions

Health resource planning is required to improve spatial accessibility and eliminate the regional disparity. Further studies are called for to integrate navigation data of web map with GIS methods to measure spatial accessibility of health facilities in more complex contexts.

Introduction

The Chinese government issued the "Healthy China 2030" Planning Outline on October 25, 2016, which aims to improve people's health and re-emphasizes the need to "provide an equal and accessible, systematic and sustainable health service" [1].

Equity and accessibility have become two of the important goals of China's health system. Equity and accessibility refer to no differences between urban and rural areas, different regions, and populations in terms of health service utilization, health outcomes, and access to health resources [2]. Accessibility generally refers to spatial accessibility (the convenience to reach a health care institution) and economic accessibility (affordable or not) in China [6]. Spatial accessibility not only measures the utilization of health services but affects residents' health status and health service needs [7, 8]. Measurement of spatial accessibility of health resources may provide effective evidence for health resource reallocation and regional health planning.

Existing studies on the spatial accessibility of health resources in China can be mainly summarized into two aspects. First, studies have assessed the spatial accessibility of residents to different types of health institutions from the perspective of health system research. These studies find that the distribution of hospital beds at the county level has been highly spatially clustered [9]. There has been gaps of spatial access to primary health care within Sichuan Province in China [10], 69% of villages have lower spatial accessibility of health services comparing with the average of the county in Jiangsu Province [11], spatial accessibility of public hospitals in Beijing was improved by referral reform that was launched at 2015 and increased the inequality of access to medical resources between towns and streets [12]. Second, some studies have implemented various methods to evaluate the feasibility of using these methods to measure special accessibility. Such as the "two-step optimization for spatial accessibility improvement" has been verified can balance the dual goals of efficiency and equality by combining the two steps for a true hybrid optimization model [13], the two steps floating catchment area method was verified to be able to reveal detailed spatial distribution differences in larger areas (such as cities) [14]. In conclusion, spatial accessibility of health resources is popular research filed in China, where researchers measure spatial accessibility from the perspective of health systems and methodologies. However, studies from the perspective of health systems are not enough, especially in terms of county-level hospitals.

China's health care delivery system showing an urban-rural dual structure, three-tier health care delivery system plays the most important role of providing accessible and sustainable basic health services in rural areas of China [1, 10]. County-level hospitals are the highest level of health care institutions in the county regions, the appropriate accessibility to county-level hospitals is an important prerequisite for the guarantee of rural residents' health [15]. The Chinese government proposed the initiative of "XIAO BING BU CHU CUN, DA BING BU CHU XIAN" in 2016, which means the rate of health care service provided by county hospitals should reach 90% [16]. The prerequisite for achieving this goal is that residents can access health care services from county hospitals conveniently and impartially. However, there is a lack of research that documents the level of spatial accessibility of county hospitals in China.

The commonly used methods to measure residents' spatial accessibility to public services are provider-to-population ratios (PPR), nearest-neighbor analysis (NNA), two-step floating catchment area (2SFCA) and a series of modified methods [3, 10, 17–19]. There are two problems in the measurement of spatial accessibility: i) identification of the population distribution, ii) accurate calculation of time and distance between the residential areas and the health care institutions. The widely used solutions to obtain population distribution include 1) using population census [8, 11, 20–22]; or 2) using GIS package to cut the map into grid cells with different areas and evenly assign the total population of the area to each grid unit and treat its center as the population distribution coordinate point [7, 9, 23]. The most common method to measure time and distance between points is to use road networks in the GIS package with information on speed limit criteria [7, 9, 23]. The limitations of this approach include that the census was conducted with intervals and therefore hysteresis, that there were errors by cutting the map, and that using road network maps may lead to rough estimates.

Therefore, this study aims to measure spatial accessibility to county hospitals and its disparity for county residents in 73 administrative counties in Shaanxi Province of western China. We firstly used navigation data of online digital maps to assess the time and distance from residents to county hospitals in China. The navigation data was collected from AutoNavi, a Chinese web mapping, navigation, and location-based services provider, via our request to open an application programming interface (API) using web crawler technology.

Data Collection And Methods

Research area

Shaanxi Province is the most developed province in northwest China, the area was 205,800 square kilometers with a total of 38,350 thousand populations in 2017 [24]. Geographically, the central, south, and north regions of Shaanxi Province differ significantly. The central part is a plain and the wealthiest area in Shaanxi Province, the south part is the Qinling Mountains, the north part is the Loess Plateau. The economy is less developed with a relatively small population density in the south and north part. This study divides Shaanxi Province into three regions based on the condition of geography and economy.

Data Collection Scheme

In order to measure spatial accessibility of health resources, three aspects of data were basically needed: geographical distribution of population, the geographical location of hospitals, and time and distance between residents and hospitals. Therefore, we collected data in three steps.

Firstly, considering the uneven distribution of population, we used the geographical location of the villages and neighborhoods to identify the population distribution. Two strategies were adopted in our study:

- i) for villages and neighborhoods with village clinic: we selected the coordinates of the village clinics to represent the population distribution since the village clinics should be in a relatively concentrated area of the village population to cover the population of the village to the greatest extent when they were set.
- ii) for the villages and neighborhoods whose village clinic cannot be acquired or have multiple village clinics, we selected the default coordinates provided by web map navigation service. This coordinate usually defaults to the location of the villages and neighborhoods' office that is usually located in a populated area.

Secondly, we collected the name of county hospitals from the Health Commission of Shaanxi Province, and then we directly used the name of hospitals to get the geographical location from the web map.

Thirdly, the time and distance between each village and neighborhood to the county hospitals were collected from the results of navigation of the web map navigation service. Chose the fastest but not the highway route (because China's highway import and export are usually set around the county) to get the time and distance from villages and neighborhoods to the local county hospital by using the real-time navigation data of AutoNavi map under the driving mode. The reason why only the local county hospitals were selected is that the Chinese new rural cooperative medical insurance implemented in rural areas is at the county level. In this study, we assumed that due to the medical insurance reimbursement strategy, residents were less likely to visit a doctor in another county-level hospital outside the county [11].

Data Collection Method

Firstly, we obtained the names of village clinics and county hospitals in overall Shaanxi Province from the Shaanxi Provincial Health Statistics Annual Report in 2017 that was provided by the Health Commission of Shaanxi

Province. In addition, we also obtained the name of village and neighborhood committees in overall Shaanxi Province from the website of the National Bureau of Statistics [25].

Secondly, we used the geocoding interface of AutoNavi map to collect the coordinates of villages and neighborhoods and county hospitals. The requests for the API of geocoding of AutoNavi map were conducted by using a web crawler in the Python 3.6 program [26]. The URL of this geocoding interface can be found here. AutoNavi map known as Gaode in Chinese is founded in 2011 and is one of the largest web mapping, navigation, and location-based services providers in China. It offers map services at Amap.com and a mobile app.

Thirdly, navigation data, including driving time and distance, were collected by using the path planning interface by setting the coordinates of the villages and neighborhoods as the starting point and the coordinates of a county hospital in the district as the endpoint. The URL of path planning interface can be found here. Considering the influence of traffic conditions at different times, this study was performed four times randomly: the morning (10:00 to 11:00) and afternoon (14:00 to 15:00) on November 23, 2018 (Friday) and November 27, 2018 (Tuesday). During the time period, 4 times crawling requests by Python were made to the AutoNavi map, and took the average value of 4 times. Finally, data on 10,350 villages and neighborhoods (total 13,074 villages and neighborhoods) from 73 counties of Shaanxi Province were obtained in our study (Fig. 1).

Analysis Method

The travel impedance to a nearest provider (TINP) was used to evaluate the spatial accessibility in this study. TINP measured the spatial accessibility by using indicators such as the distance, time, or cost from the place of residence to the nearest medical institution, it was expressed in terms of straight Euclidean distance (straight line) [3]. Distance and time are indicators that directly reflect spatial accessibility, the closer the distance is, the shorter the time and the higher the accessibility. Although TINP ignores the supply of health resources, this method is applicable to the situations that the choice of seeking healthcare service is relatively simple in rural areas. In addition, we used more precise traffic distance downloads from a web map instead of Euclidean distance in this study.

We calculated Getis-Ord G_i^* statistics for the spatial association of each county to explore the disparity of spatial accessibility [27, 28]. The G_i^* statistic returned for each county is a z-score [29]. A high positive z-score and small p-value for a county represent a spatial clustering of high values (hot spot). A low negative z-score and small p-value represent a spatial clustering of low values (cold spot). The higher or lower the z-score, the more intense the clustering. A z-score close to zero means no significant spatial clustering. Getis-Ord G_i^* statistics were calculated by 'spdep' package of R language [30]. The spatial relationships of counties were defined as Queen's Case. The distance and time of counties were the averages of distance and time of villages and neighborhoods.

Results

Level of spatial accessibility

From the perspective of villages and neighborhoods level, the average driving distance from the villages and neighborhoods to the county hospitals is 28.4 kilometers, and it costs an average minimum of 49.7 minutes. Only

68.9% of villages and neighborhoods can arrive at the county hospitals within 60 minutes, and 13.4% of residents need to take more than 90 minutes (Table 2 and Fig. 2).

Table 1
Spatial accessibility to county hospitals in villages and neighborhoods level

	Central Shaanxi	Northern Shaanxi	Southern Shaanxi	Overall	F	p
N	4119	3306	2925	10350		
Distance(km), mean(sd)	19.2(12.1)	35.2(21.0)	33.8(20.2)	28.4(19.3)	935.7	< 0.001
Shortest time(minutes), mean(sd)	33.5(19.3)	59.5(32.7)	61.5(35.5)	49.7(31.9)	1060	< 0.001
Time range, %(CI 95%):						
Under 15 minutes	13.8(12.8–14.9)	7.6(6.7–8.5)	6.6(5.7–7.5)	9.8(9.2–10.4)		
Under 30 minutes	48.7(47.1–50.2)	21.6(20.2–23)	22.6(21.1–24.1)	32.6(31.7–33.6)		
Under 45 minutes	79(77.7–80.2)	38.3(36.6–39.9)	38.9(37.2–40.7)	54.7(53.7–55.6)		
Under 60 minutes	91.6(90.8–92.4)	54.0(52.3–55.7)	53.6(51.8–55.4)	68.9(68.0–69.8)		
Under 90 minutes	98.3(97.9–98.7)	80.2(78.9–81.6)	77.3(75.8–78.9)	86.6(86.0–87.3)		
Under 120 minutes	99.6(99.4–99.8)	95.7(95–96.4)	91.9(90.9–92.9)	96.2(95.8–96.5)		

Table 2
Spatial accessibility to county hospitals in county level

Areas	The number (%) of counties in which 80% villages or neighborhoods can access to county hospital	
	Under 60 minutes	Under 90 minutes
Overall Shaanxi (N = 73)	29(39.7%)	52(71.2%)
Central Shaanxi (N = 29)	24(82.8%)	27(93.1%)
Northern Shaanxi (N = 20)	3(15.0%)	11(55.0%)
Southern Shaanxi (N = 24)	2(8.3%)	14(58.3%)

From the perspective of the county level, we calculated the percentage of villages and neighborhoods that can reach county hospitals within 60 minutes and 90 minutes per county. Figure.3 shows that the number of the county that all villages and neighborhoods can access to the county hospitals within 60 minutes and 90 minutes are 3 and 16, respectively. Therefore, we assumed that 80% of the villages and neighborhoods could arrive at the county is a standard. We further calculated the frequency and percentage of counties in which 80% of villages or neighborhoods can access to county hospital within 60 minutes and 90 minutes, respectively, and found that only 39.7% and 71.2% of the counties in Shaanxi Province meet the standard (Table 2).

Disparity Of Spatial Accessibility

In terms of sub-regions, there is a large disparity of spatial accessibility in the central, north, and south regions of Shaanxi Province (Fig. 4). Meanwhile, we summarized the distance and time of villages and neighborhoods into county-level, the values of each county are the average of local villages and neighborhoods. Getis-Ord G_i^* statistics show that the north and south regions of Shaanxi Province are hot areas, while the central regions are cold area (Fig. 5)., which means longer distance and time clustered in north and south regions. In other words, the worst spatial accessibility areas clustered in the north and south regions. The central region has the best spatial accessibility due to its location in the plain and rich areas, the average driving distance from residential areas to county hospitals is 19.2 kilometers with an average minimum of 33.5 minutes, and 91.6% of the residents can arrive at the county hospital within 1 hour (Table 1). The proportions of residents that can arrive at the county hospitals within one hour in the north and south region were 54.0% and 53.6%, respectively (Table 1). In county level, the proportions that 80% of the villages and neighborhoods in the counties can arrive at the county hospitals within 60 minutes were 82.8% in central, 15.0% in the north, and 8.3% in southern regions. The figures based on within 90 minutes are only 55.0% in the north and 58.3% in south regions (Table 2).

Discussion

There are two key findings in our study. First, residents in county areas in Shaanxi Province has poor spatial accessibility to county hospitals, only 68.8% of villages and neighborhoods can reach the county hospitals within 60 minutes, while 13.4% of that still need more than 90 minutes. Second, there is a large disparity inner Shaanxi Province, the residents in the central area have the best spatial accessibility to county hospitals, the north and south area still need improvement in the accessibility. Moreover, our study proved that using navigation data of a web map to measure spatial accessibility to health resources is feasible.

Our study shows that Shaanxi Province has a low-level spatial accessibility to county-level hospitals. In fact, we think the spatial accessibility would be worse, because we selected the driving mode to calculate the distance and time in the process of crawling navigation data. The original intention of selecting driving mode was to simplify the data collection process, however, the ownership of vehicle per 100 urban households was 29.7 in 2017 in China [31], which means China has not yet developed a stage that every household has a vehicle at the current stage, especially in the county area. Therefore, the spatial accessibility in the county area may be overestimated. On the other hand, since Shaanxi is the most developed province in northwestern China, we have reason to infer that other northwestern provinces (Gansu and Ningxia, etc.) with less developed economic levels and worse geographical environments may have worse spatial accessibility to county hospitals.

Good spatial accessibility is an important prerequisite for residents to use health care services in a timely manner, low-level spatial accessibility may cause several problems. A research reported that asthma mortality showed a significant trend with the increase of travel time to hospital and the relative risk was 1.07 for each additional 10 minutes [32]. Mortality of other time-critical diseases, like stroke, may have the same risk. Another study showed that geography obstacles were one of the four major factors that persons with disabilities were unable to access primary health care [33]. Moreover, we found an obvious regional disparity in spatial accessibility to county hospital exist across the Shaanxi Province. This disparity should be taken seriously, the regional disparities of spatial accessibility were also observed at primary health institutions in Sichuan Province and public hospitals in Beijing City [10, 12]. Regional variations are also commonly existed in the world. Such as, there are significant geographic disparities in access to primary stroke centers in the United States [34], in access to health care facilities between urban and suburban seniors in Montreal Island [35], in access to community resources particularly between urban and rural areas of New Zealand [36]. It is well known that spatial accessibility influences health services utilization. Strong evidence has proved that there is a strong pro-rich inequality of maternal health services and inpatient utilization in rural western China [37, 38]. Therefore, we have reasons to infer that the disparity of spatial accessibility may cause or aggravate the pro-rich inequality of health services utilization in western China. Therefore, China should also pay attention to the equity of spatial accessibility to health care, although the Chinese government has advocated that residents in every region should have equal access to health care resources.

How to improve the spatial accessibility to county hospitals in rural areas? Some cities in China have begun to set a goal of “15-minute health circle” for primary health care services [39]. Our study identified that it could be reasonable to set the residents’ spatial accessibility to county hospitals as “1 hour” in western China. In addition, the most direct approach to improve spatial accessibility is to improve transportation facilities in rural areas, but spatial accessibility should not be limited to improve from a real distance. Establishing video telemedicine and timely drug distribution system by using internet technology to strengthen the flow of superior resources between the three-level (county-township-village) service networks, the spatial distance between residential areas and health care services in county hospitals could be effectively improved.

Finally, one previous study analyzed the time and space accessibility of urban parks by using the path planning API provided by Gaode map [40] as we used in our study, which confirmed the feasibility of using the navigation data of the web map to conduct spatial accessibility research. There are two advantages of this method: i) the accuracy of the data extracted from navigation is significantly higher than that roughly estimated by the road network map. The measurement accuracy is unsatisfactory whether using linear Euclidean distance or road network traffic distance. An accurate method to measure distance is very important since the measurement accuracy of the distance directly affects the accuracy of the assessment of spatial accessibility. ii) the navigation data provided by the web map realizing real-time updates, considering the road traffic situation, is more in line with the actual situation. In summary, combining the navigation data from web map and two-step floating catchment area modified methods to measure spatial accessibility of health resources has high feasibility and application prospects.

We still can't avoid some limitations in this study. First, since it is very difficult to collect specific population in villages and neighborhoods level, only the relatively simple nearest distance method was used to evaluate the spatial accessibility, which ignored the supply and demand of health resources. Second, distance and time data were only extracted under the driving mode, the figure within public transportation or other modes was not

analyzed, which may not be consistent with the actual mode of travel of rural Chinese residents. Lastly, not all villages and neighborhoods in Shaanxi Province were involved because of the small amount of data were unobtainable.

Conclusion

We found that county residents in northwestern China's provinces represented by Shaanxi Province have lower spatial accessibility to county hospitals, and significant regional disparity exists inner province. Health policy and health resource planning are needed to improve the spatial accessibility and eliminate regional disparity. Moreover, our study demonstrates the feasibility of using navigation data provided by the web map to measure spatial accessibility to health resources. Further research is needed to verify whether this new method is more accurate than using GIS for evaluation. We encourage further research to combine the navigation data of the web map with the two-step floating catchment area modified methods to measure the spatial accessibility of health facilities in more complex situations.

Abbreviations

API
Application Programming Interface
NNA
Nearest-Neighbor Analysis
PPR
Provider-to-Population Ratios
TINP
Travel Impedance to a Nearest Provider
2SFCA
Two-Step Floating Catchment Area

Declarations

Ethics approval and consent to participate

The data used in this study did not collect from human subjects.

Consent for publication

Not applicable.

Availability of data and materials

The data were collected from AutoNavi map, a Chinese web map and navigation service provider. This web map provides an open application programming interface for freely using data after registering as a developer. The application programming interface can be found here:

(<https://lbs.amap.com/api/webservice/guide/api/georegeo#geo>) &
(<https://lbs.amap.com/api/webservice/guide/api/direction#driving>).

Competing interests

All authors declare no competing interests.

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Authors' contributions

CS, ZLZ and XC contributed to the framework and design of this study. CS and XYW wrote the python script to collect the data and performed the data analysis. CS, LL and SL drafted the manuscript. WYD, JZ, MS and QWD provided assistance in data collection and analysis. YRC provided significant advices in design and analysis. All authors contributed significant intellectual content in this study and approved the final submission.

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Figures

Comparison of number of village/urban committees between overall and sample

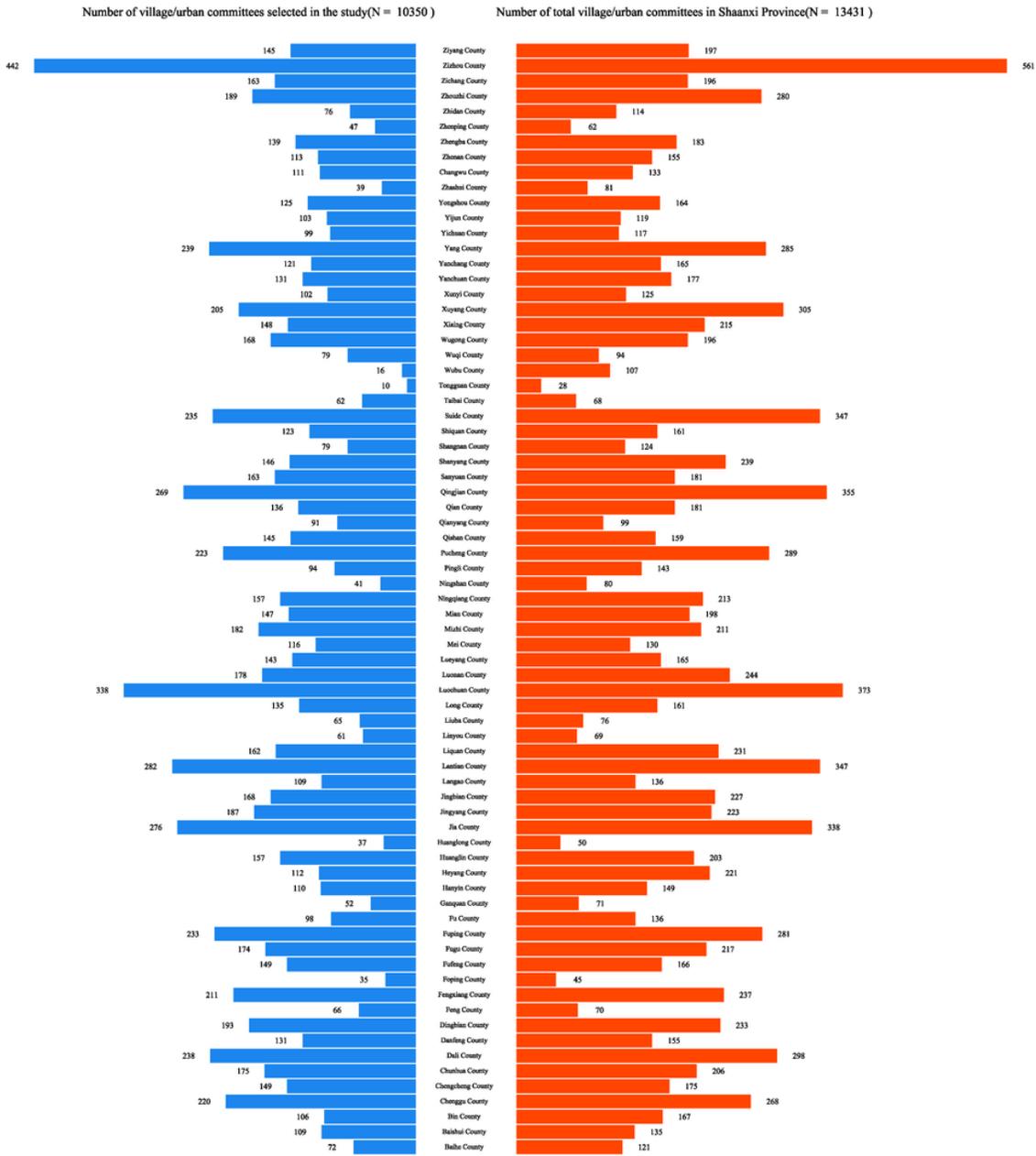


Figure 1

Sample information about villages and neighborhoods

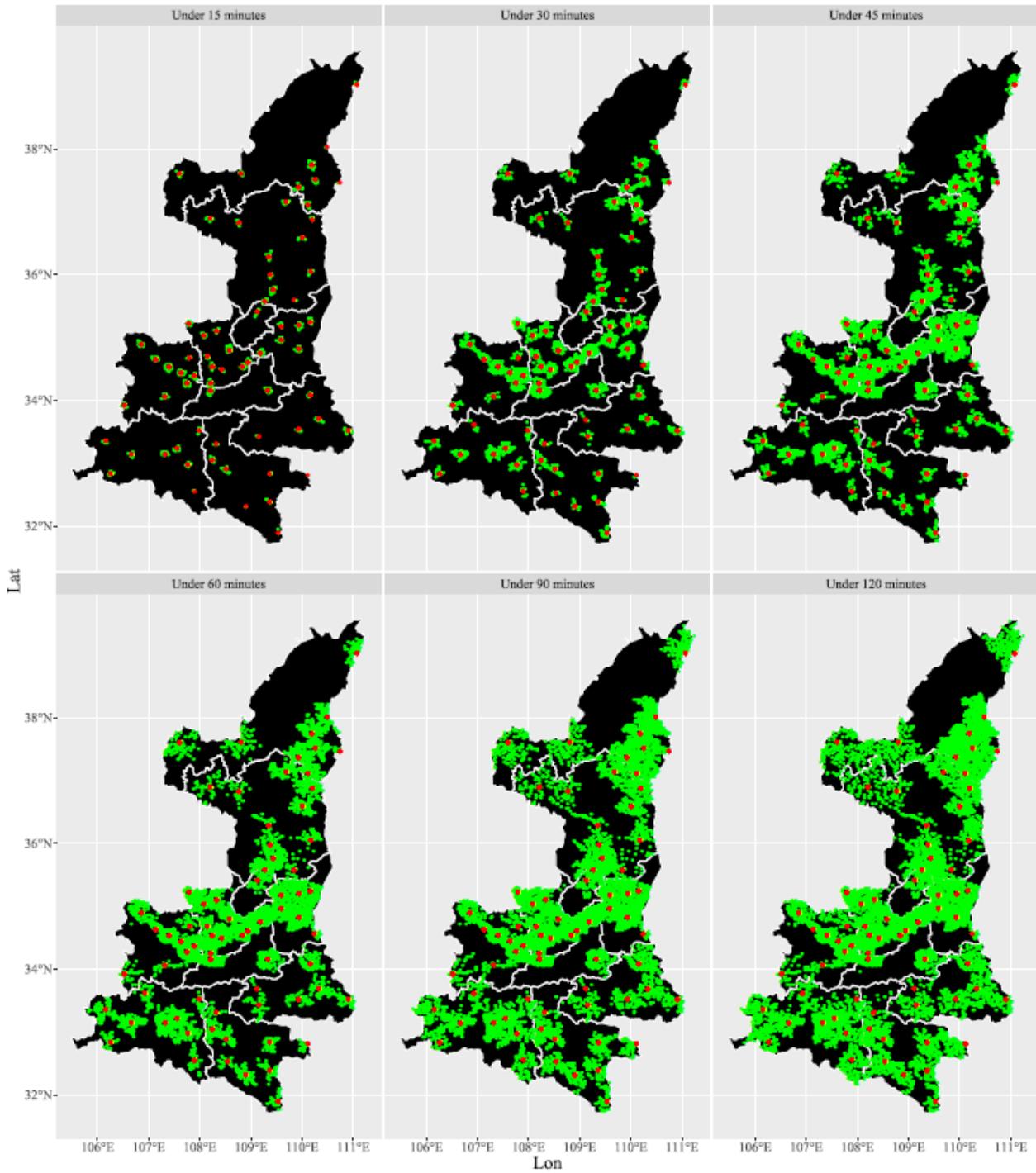


Figure 2

The distribution of villages and neighborhoods that can reach county hospitals under different time in Shaanxi Province. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

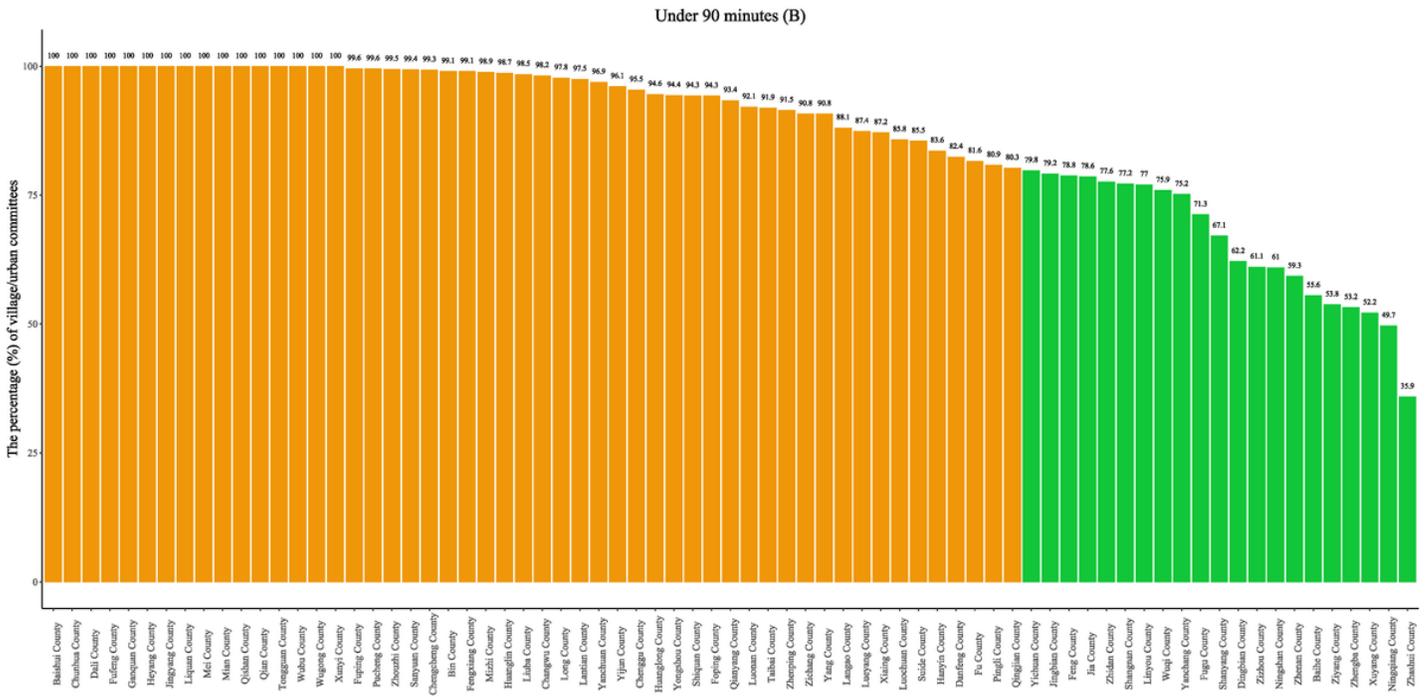
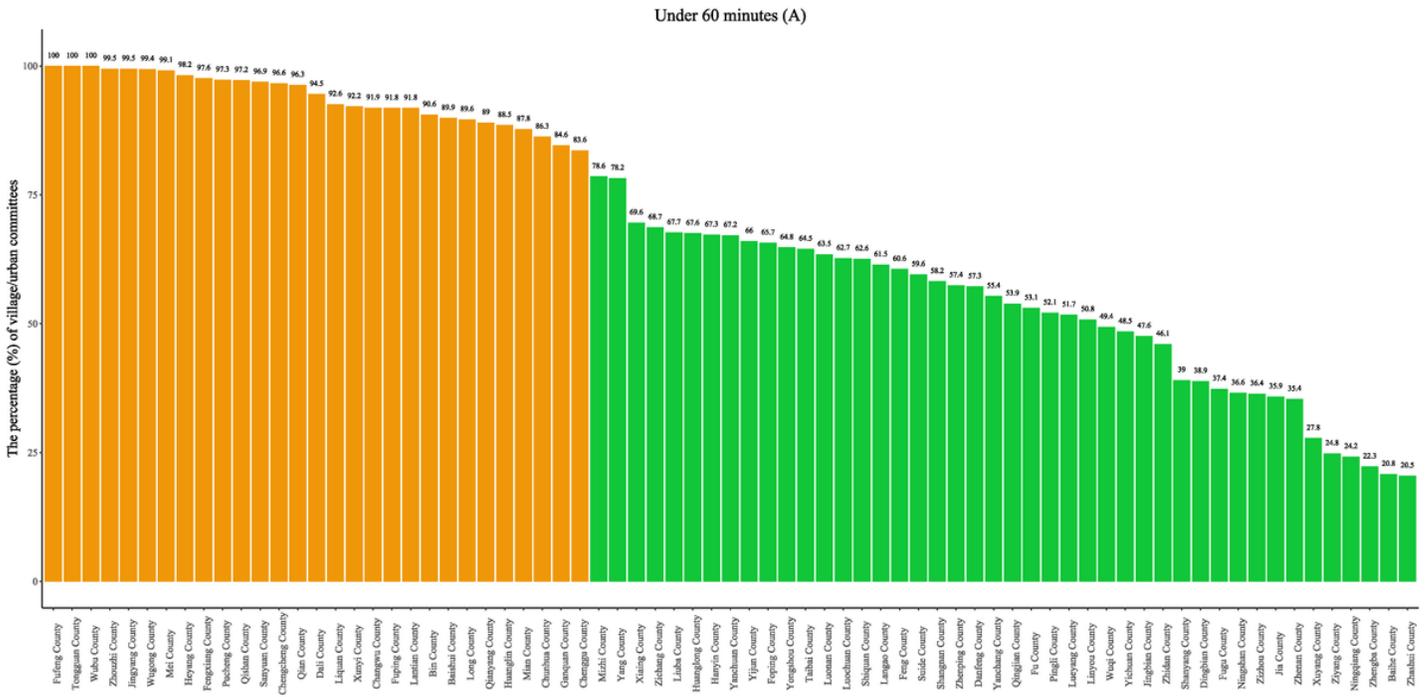


Figure 3

The percentage of villages and neighborhoods that can reach county hospital under 60 or 90 minute per county in Shaanxi Province

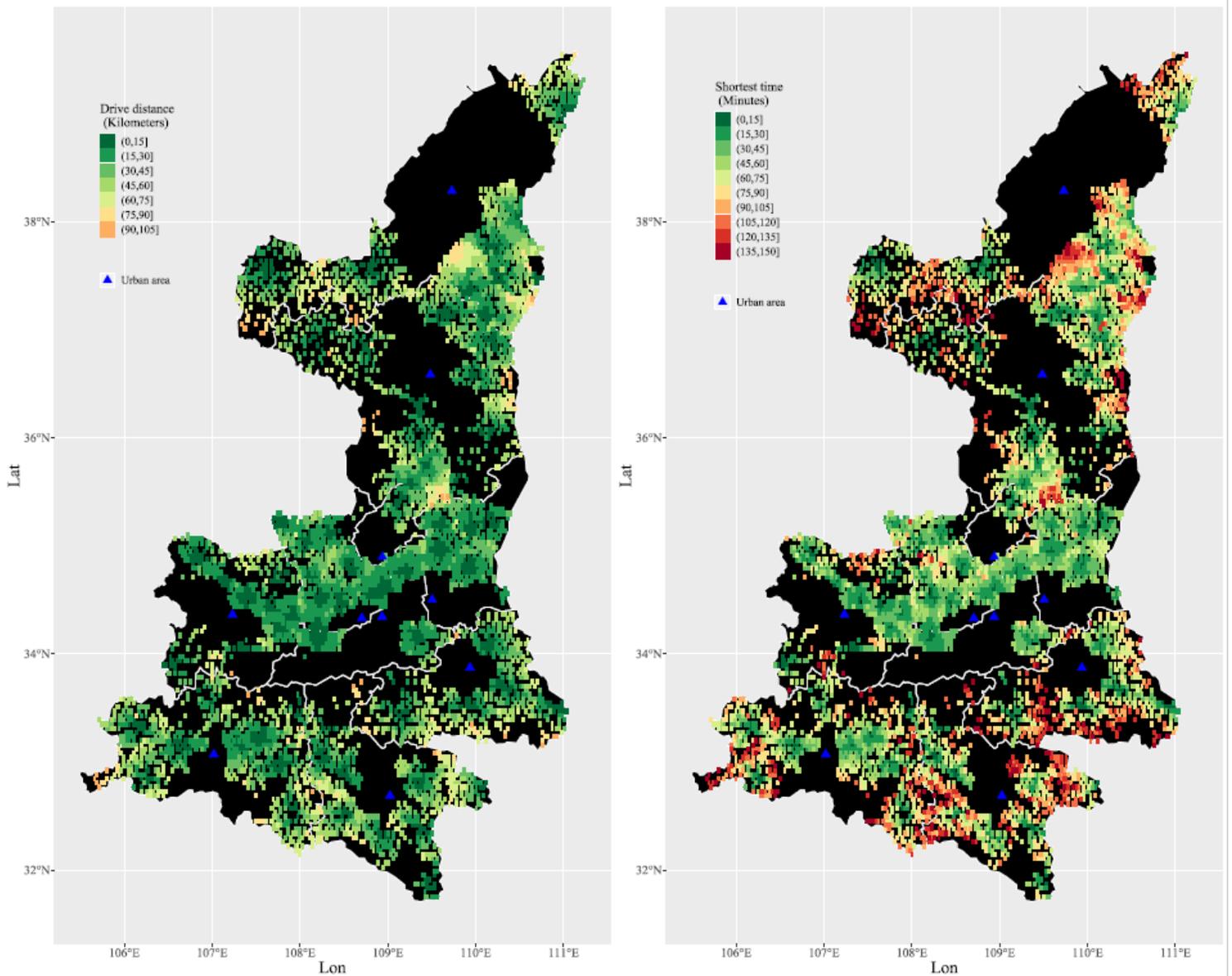


Figure 4

The regional disparity of minimum driving time and distance inner Shaanxi Province. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

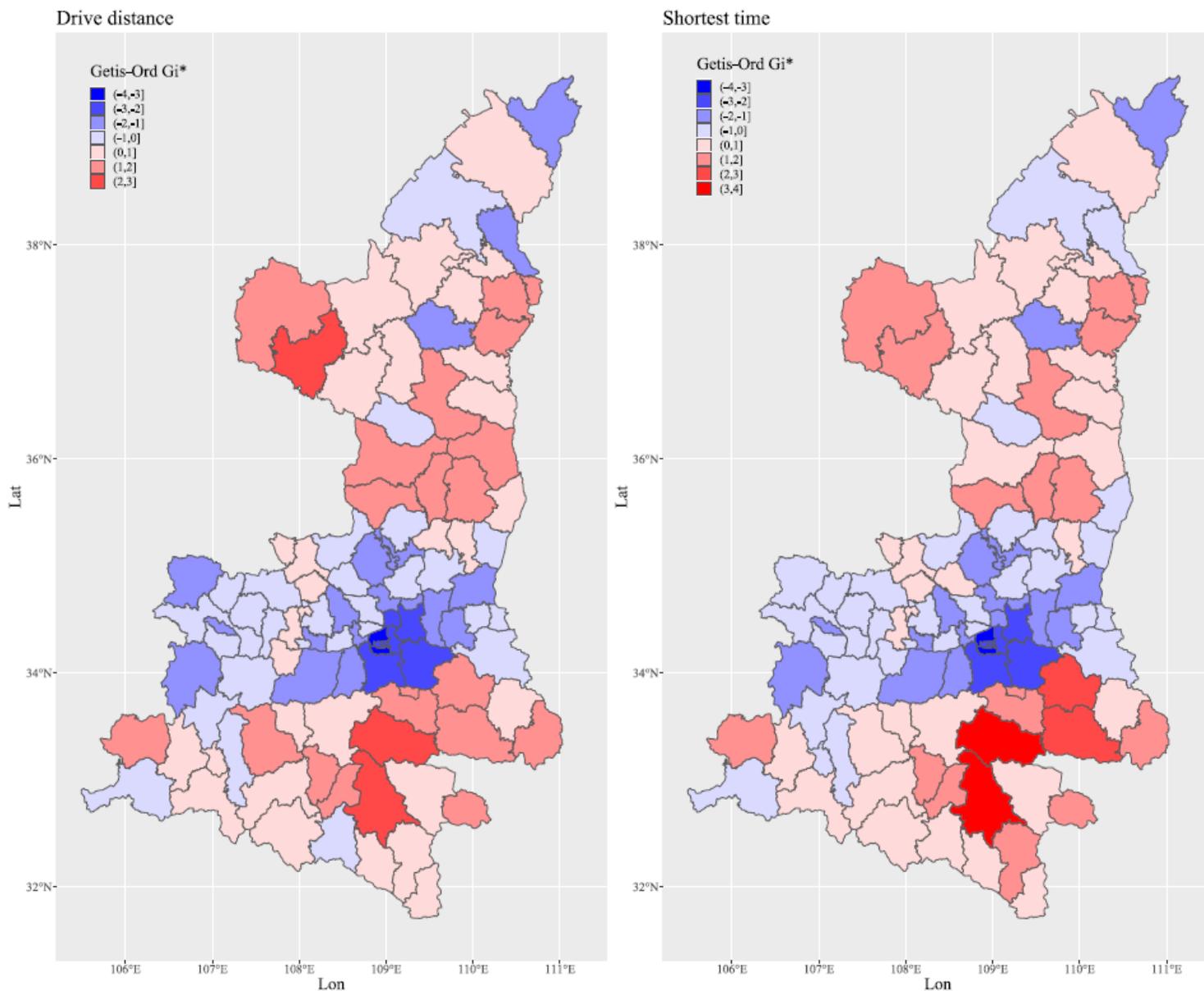


Figure 5

The Getis-Ord G_i^* statistics of minimum driving time and distance in county-level inner Shaanxi Province. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.