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Study on Urban Resilience Based on the Analysis of Supply Guarantee Facilities during Epidemic Closure

—A Case Study of Shanghai in 2022

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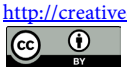

Abstract

In the case of major public emergencies, the ability of cities to resist shocks becomes very important and reflects urban resilience. This paper selected the supply guarantee facilities during the city-wide lockdown of Shanghai during March-May 2022 due to COVID-19 pandemic as the research object. In this research, the per capita supply guarantee capacity and supply guarantee overlay intensity were analyzed based on the official list of facilities, and the actual role of the supply guarantee facilities was investigated through a public research questionnaire. The thermodynamic diagram map that was generated based on phone visits reflected the actual distribution of the population. Then the level of "supply guarantee resilience" was evaluated and graded for each district of Shanghai. It was concluded that the overall level of supply guarantee resilience was high in the central city, divergence in the near suburban districts, and generally low in the remote suburban districts. Based on this, the paper summarized the problems of supply guarantee revealed in Shanghai during the epidemic lockdown as well as proposed strategies to improve the resilience of similar scenarios in the future. With the help of big data and public research tools, this paper aimed to provide ways and methods to evaluate the resilience of cities under major public emergencies.

Keywords

Epidemic Lockdown, Supply Guarantee Facilities, Urban Resilience

1. Introduction

The outbreak of COVID-19 in 2020, as a major global public health emergency

with rapid spread, wide impact, and great difficulty in prevention, had brought the cumulative number of cases to more than 600 million worldwide till December 2022. It undoubtedly not only threatened human life and health, but also had a huge impact to the global trade market, industrial supply chain, international trips, social stability and other aspects. As such, it posed a major challenge to the response and sustainability of individual cities all around world. A number of cities were lockdown due to the COVID-19 pandemic outbreak. It broke out from the lockdown of Wuhan China in January 2020, then the lockdown of Japanese cities such as Tokyo in February, the lockdown of US cities such as New York in March, and then the London, UK in December. Over the past two years, the epidemic had caused most cities around the world to adopt varying degrees of "lockdown" polices.

The fierce and rapid spread of the COVID-19 epidemic always caught the city off guard. On 1st March, 2022, one local COVID-19 case was reported in Putuo District Shanghai, followed by 16 cases in succession from 6th March to 10th in Xuhui District Shanghai. Since then, the epidemic in Shanghai had broken out. In the next 10 days, the cumulative number of confirmed cases had increased tenfold from 1000 to more than 10,000. By early-April, the number had risen to more than100,000[1]. Under emergency, Shanghai had to start "lockdown", calling off all urban operations, implementing a series of "reverse" measures such as neighborhood isolation, traffic control, logistics shutdown, as well as quarantines and restrictions on people's activities to "effectively interrupt or reduce the spread of COVID-19". In this context, the economic, cultural and political lives, social activities, transportation and recreational functions of the city were greatly affected.

For a time, the restrictions on travel, logistics and communication directly cut off the access to urban food, daily necessities, production materials and other sources, which disrupted the original urban operation order and the normal life of citizens. The guarantee on the life quality of citizens dropped, resulting in food and medicine shortage, inability to seek medical attention when sick, exhaustion of daily necessities, etc. Meanwhile the life satisfaction plummeted. Negative emotions such as anxiety, burnout and depression had been growing up. According to related statistics, since the lockdown in Shanghai in March 2022, the number of searches for "psychological counseling" and related keywords by Shanghai residents had increased by nearly 250% year on year[2]. It was not only the epidemic itself that posed a threat to human health, but also the social unrest caused by it was a huge impact and test on both physiology and psychology for citizens.

In a word, it was an urgent problem need to be explored that how citizens could still secure food safety, medical treatment and medicine, consumable supplies and other daily necessities to maintain their basic living standards during

[1]Data source: Shanghai Municipal Health Commission, Daily Epidemic Notification.
[2]Data Source: DT financial research, 2079 valid samples, data statistics time as of April 15, 2022.

the lockdown. The emergency measures taken by the city and the actual effect of resilience in the face of such major emergencies directly determined the impact on the urban citizens.

Therefore, this paper took the city-wide lockdown of Shanghai from March to May 2022 as an example to evaluate the response measures and operation of the city in major public health emergencies based on the "urban supply guarantee capacity". From this, it could find out the problems and deficiencies in the resilience of urban security and supply. Moreover, we try to explore the general improvement strategies for most cities by getting much from little, which aimed to minimize the impact of major public health emergencies on the life of citizens and even the disturbance to the order of city in the future.

2. Literature Review

The concept of "resilience", which originated in the field of mechanical physics to express the ability of a material to recover from plastic deformation, was introduced to the field of ecology by Holling in the 1970s [1]. With this introduction, the focus of the concept was extended from the ability to recover from external forces to the ability to resist and buffer external forces, to express the equilibrium maintenance and adjustment of the resilience of ecosystems, and to expand the description from a single subject to the whole system-wide coordination and adaptation [2]. Since the 1990s, the research of "resilience" has been extended from the field of "natural ecology" to "human ecology". As urbanization trends in recent decades, the increasingly close relationship between humans and cities has naturally led to the disaster prevention, mitigation, and risk resilience of cities. Along with this, the concept of "resilience" has been introduced into the field of urban research, giving the concept of "urban resilience", which emphasizes the ability of urban systems to maintain normal functions in the face of external shocks. In this process, the connotation of "resilience" itself has been expanded from "engineering resilience" and "ecological resilience" to "evolutionary resilience", emphasizing a dynamic, constantly moving forward to find a new equilibrium point, learning and innovation of self-adjustment ability [3].

At an earlier time, a large number of studies on urban resilience construction focused on urban environmental aspects such as global climate change adaptation and natural disaster risk mitigation, while the consideration of urban emergency management such as public health and social security was generally lacking. From the perspective of measurement and evaluation indicators of urban resilience at home and abroad, it could be divided into "Single Field Assessment" and "Comprehensive Field Assessment". The "Single Field Assessment" referred to the assessment of resilience elements at a single level of the city, which had been widely used in specific areas such as urban flood control and urban traffic [4]. While the "Comprehensive Field Assessment" combined multiple subsystem elements such as urban economy, politics, society, ecology and material, reflect-

ing the comprehensive adaptive carrying capacity of the city [5]. Adhere to the research on the construction of urban resilience assessment system by domestic and foreign researchers and organizations including Bergstrand Kelly [6], Rockefeller Foundation [7], Hudec [8], BaiLimin [9], Ribeiro [10], etc., it could be summarized that the most commonly involved dimensions of "Comprehensive Field Assessment" were society, economy, natural ecology, infrastructure and organizational environment. It was also because of its comprehensiveness, its indicator content was often left to be qualitative "extensive". Its direct guidance for specific improvement strategies was often not significant.

In 2021, the concept of "resilience" for the COVID-19 pandemic emerged internationally. This concept was used to determine the recovery ability of basic social, economic, cultural, political and other urban functions. It could be measured by the number of infections, deaths, vaccination status, economic production differential, logistics and traffic volume, quality of education and culture and other factors [11]. For example, Brazil (2021) measured the vulnerability of micro regions to COVID-19 through its hospital structure of doctors, intensive care units, respirators, etc. [12].

Basing on this, the paper put forward the concept of "resilience on supply". It referred to the ability of city to guarantee the basic life of citizens and the supply of materials, that was, the maximum extent of protecting the livelihoods of citizens from or against the impact of lockdown. It was measured by the distribution density of supply guarantee, the strength of supply guarantee facilities, the supply of materials, the quality of life of residents, the degree of security of residents, etc.

In terms of research on relevant assessment contents, scholars such as Wan Jiaqi (2022) had organized the characteristics of various assessment indicators of "resilient cities" in the context of COVID-19 pandemic, specifically summarized into four dimensions: infrastructure resilience, layout resilience, technological resilience, and economic resilience [2]. Among them, in foreign countries, regarding the construction of urban infrastructure, special attention is paid to the connectivity of transportation facilities to regulate the internal and external connectivity of the city, while in China, more attention is paid to the innovative application of facility construction, such as Hua Zhiya (2020) proposed "uncertainty thinking" instead of "certainty thinking" in the construction of urban facilities [13]. As for the distribution layout, the strong relationship between the form of urban construction distribution and population development had been noted both at home and abroad. Shi (2021) pointed out that the arrangement and control of population driven by urban layout determines the vulnerability and resistance of cities [14]. Accordingly, Wan Jiaqi *et al.* (2022) proposed an improved variant of the "3Ds theory" (aesthetic design, land diversity, and distance of services) from a demographic perspective, which focuses on the density of construction layout and distribution of facilities in urban design. It could be seen that the distribution density of resources, the distribution mode and the

construction intensity of facilities were often recognized as resilience factors. However, the city is a complex multidimensional system. Its development is not only affected by the objective physical and hardware resources, but also by the subjective thinking and behavior of residents. Therefore, the study of urban resilience should not only be focused on the physical facilities and resources of the city, but also consider its non-material factors, including residents' behavior, willingness feedback, trend orientation, etc.

In terms of research on emergency response strategy, according to the United Nations International Strategy for Disaster Reduction (UNISDR), to build an efficient and robust urban emergency system it required a combination of risk knowledge, monitoring and alerting services, distribution and communication, and emergency response capabilities [15]. Zhuang Guobo *et al.* (2019) further constructed the urban emergency system including management measures such as "pre prediction and early warning, emergency response in the event, and post-recovery and reconstruction" [16]. They found that ensuring the continuity between various links was the basis for improving urban resilience. Among them, "emergency logistics" was a key component and important element to ensure emergency supply, promote production, and enhance urban resilience [17] [18] to serve as a link to all emergency works [19]. Generally, they all pointed to the importance of "connectivity", "affordability" and "correspondence" for emergency supply guarantee. Moreover, Bukari Chei *et al.* (2021) confirmed that the urban pandemic had a graded adverse impact on family welfare through the research on poverty and food insecurity under the influence of the COVID-19 epidemic in Ghana, spotting that vulnerable groups' families tend to suffer greater livelihood impact [20], which implied the attention to urban food security and necessities support under the pandemic as well as the care for vulnerable groups.

According to above researches, this paper would focus on the dimension of supply and security under major public health emergencies, With the consideration on both objective material and subjective non-material factors, improve the compatibility between the evaluation content and the evaluation object, and pay attention to the timeliness, relevance and practicality, so as to make an evaluation that can provide direct guidance for future resilience improvement.

3. Research Area and Data Acquisition

3.1. Overview of the Research Area

The main actions of Shanghai against the outbreak of COVID-19 could be divided into four phases: grid management period, static management period, partition management period and normalized management period (refer **Table 1**).

Since 11th April, Shanghai had designated three zones in each district, namely "lockdown zone, control zone, and prevention zone", which were targeted for different prevention and control policies. For the areas where there are positive cases within the last 7 days, Shanghai has designated them as "lockdown zone",

Table 1. Phases of the outbreak prevention and control policy in Shanghai.

Phase	Time span	Phase description
Grid management	3.1 - 3.27	Grid-based nucleic acid screening in key areas after the outbreak
Static management	3.28 - 4.10	Pudong and Puxi areas have been blocked and controlled, and the whole city was lockdown
Partition management	4.11 - 4.21	Lockdown zones, control zones, and prevention zones are divided for differentiated management styles
Normalized management	Since 5.16	The resumption of work and production, the resumption of business and the market, the resumption of schools and classes, and the full implementation of the normalized management of epidemic prevention and control have been promoted according to priorities, and the normal production and living order in the city will be gradually restored.

Source: Author editor.

and implement "area lockdown, stay at home, door-to-door supply"; And for areas where are no positive cases in the past 7 days, Shanghai has designated them as "control zone" and implemented "7-day home health monitoring", where people can leave their homes but are strictly prohibited from gathering; While areas where are no positive cases in the past 14 days are "prevention zone", where people are allowed to carry out appropriate activities within their neighborhoods streets, but are not allowed to enter the lockdown zones and control zones.

From 28th March to 16th May, public places throughout the city were shut down, including most commercial, catering and entertainment facilities. Although citizens could purchase supplies through some e-commerce app (e.g. Dingdong, Meituan, Freshippo etc.), poor logistics also made the process very difficult since all e-commerce companies declared inventory shortages and adopt quota supply mode. In additional, some residential communities carried out group purchases to get supplies direct from manufacturers. But most people who were lockdown at home were in great inconvenience in terms of food, clothing, daily usage, medical needs etc. In view of this, Shanghai municipal government set up a varying number of "supply guarantee facilities" in each district to provide basic supplies to people.

In this paper, the effectiveness of the supply guarantee facilities was evaluated by taking the 16 districts of Shanghai as the scope of the research (The geographical location of Shanghai is shown in **Figure 1**, and the administrative division of Shanghai is shown in **Figure 2**), starting from the relationship between the distribution of supply guarantee facilities and the distribution of population and combining it with a questionnaire survey of the public. It was hoped that this research could give some suggestions for the urban supply guarantee system and enhance the resilience of the city in near future.

Figure 1. Geographical location map of Shanghai. Source: Self-drawn by the author.

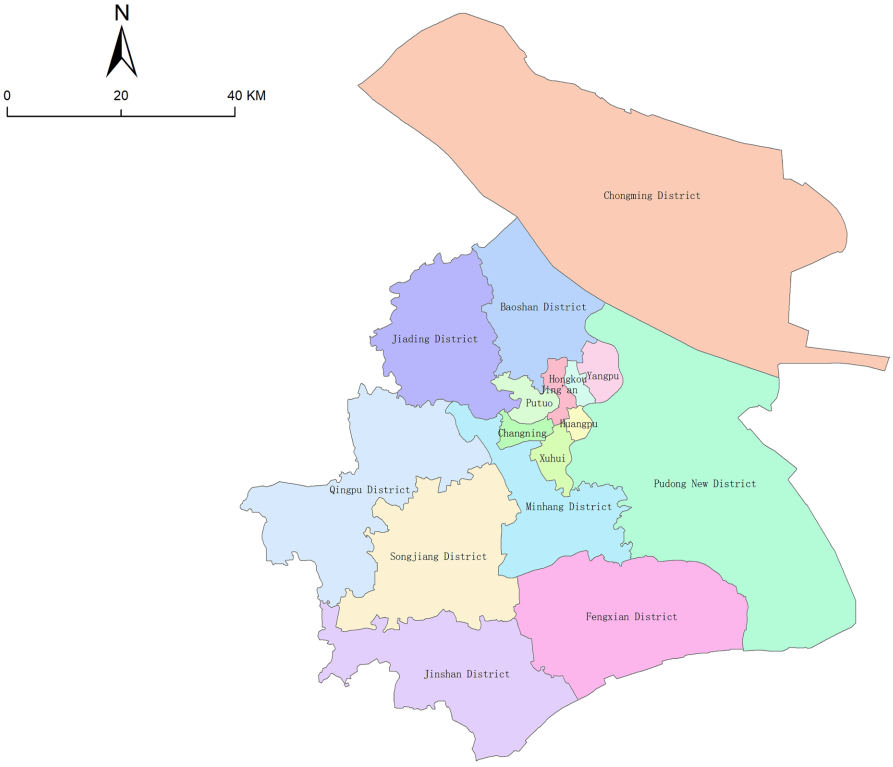

Figure 2. Administrative Map of Shanghai. Source: Self-drawn by the author.

3.2. Data Acquisition

3.2.1. Supply Guarantee Facility Data

According to the list of supply guarantee facilities[3] in each district published in

[3]"Shanghai Release", as the official new media certified by the Shanghai Municipal Government Information Office, is used to release authoritative government information and provide social services to the public. The summary data of the supply guarantee list of each district released on April 10 comes from the information of the commercial enterprises provided by each district business committee to guarantee the supply.

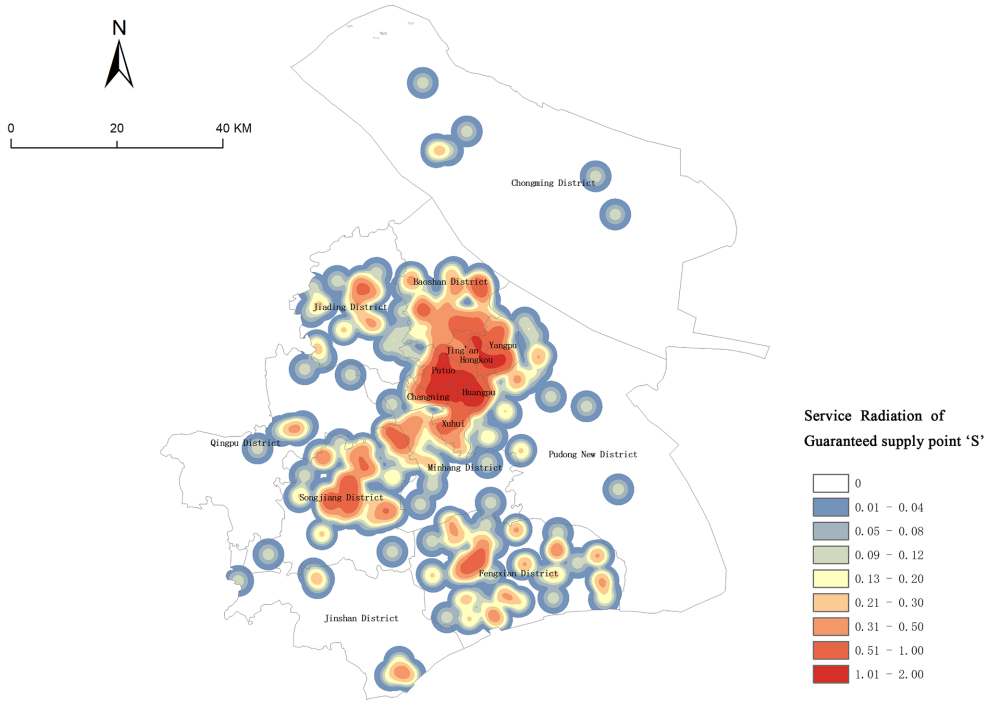

Figure 3. Distribution of regional supply guarantee facilities in Shanghai. Source: Self-drawn by the author.

the "Shanghai Release" on April 10, 2022, this paper compiled a total of 548 Supply guarantee facilities in the city. They were superstores, agricultural trade and e-commerce, which provide supplies covering fresh fruits and vegetables, snacks, rice, flour and oil, dairy products and bakery, daily necessities, mother and baby medicine, and pet department stores. Through POI data (from Map of AutoNavi) of the corresponding supply guarantee facilities (WGS84 coordinate system), the kernel density analysis was conducted with "3 km" as the service radius of the facilities (**Figure 3**). The regional supply guarantee facilities were measured in terms of their "density" to the surrounding residential districts. It could be used to measure the "immediate and direct" radiation effect of each facility on the surrounding residential districts and the degree of coverage.

Figure 3 shows the supply guarantee facilities in Shanghai, which are mainly concentrated in the center of the city. Accordingly, the stronger agglomeration effect generates stronger supply guarantee radiation capacity. As in the suburban areas there are also some aggregation points, which are located in Fengxian District, Songjiang District and Jiading District. As the scale and degree of agglomeration are weaker than those in the city center, the radiation power of supply guarantee facility is also relatively lower. The distribution of supply guarantee facilities in the rest of the district is more sparse and the agglomeration effect is correspondingly the weakest, especially in the outer areas of the suburban ring road.

3.2.2. Population Distribution Data

In this paper, the thermal map of population in Shanghai was collected at two

time points, 20:00 pm on April 15 and 10:00 am on April 16. Since people were almost staying at home during the lockdown period, the map of the two time periods of the 15th and 16th showed not differs conspicuously under the statistical caliber of 3 km range (Figure 4). The maps work based on the location information of billion scale cell phone users when they look through Baidu products (including Baidu map, Baidu search, weather, music, etc.). The number of population in each region is finally visualized on the map after density analysis. Although there remains some difference with the actual number of regional population, the comparative relationship of gathering degree can truly reveal the tendency and the real-time distribution of population. The darker the color, the higher the population concentration in the region and *vice versa*.

From Figure 4, we can find the population distribution characteristic in Shanghai. Most people are living in Jing'an District, Huangpu District, Hongkou District, Xuhui District, Changning District, Putuo District, Yangpu District and other districts within the inner ring road of Shanghai as the "high concentration center". Chongming District, Pudong New District and the western areas of Qingpu, Jinshan and Songjiang Districts are more sparsely populated.

Based on the population thermal data, the population distribution in Shanghai during the lockdown period was analyzed, and the local population density "d" in each district and the service population agglomeration degree "C" within the 3km service radius of each guaranteed supply facility were calculated respectively. The agglomeration magnitude "P" of the population served by each guaranteed supply facility was obtained by dividing "C" and "d". The calculation formula is as follows.

$$P_i = \frac{C_i}{d_i} \tag{1}$$

The calculation results are as follows in Figure 5.

3.2.3. Questionnaire Survey

To further analyze the role of supply guarantee facilities in each district in securing the basic livelihood of people nearby, a questionnaire survey was conducted via internet. The questionnaire was distributed in a grid format and was released on 20th April and collected on 30th April. The survey covered 16 districts of Shanghai, and a total of 1104 valid questionnaires were collected, with 100% effective rate (because of the online filling-in, all submissions are valid). Of which, 298 (26.99%) were from the prevention zone, 396 (35.87%) from the control zone, and 410 (37.14%) from the lockdown zone. The respondents were mainly 18 - 59 years old, accounting for 67.84%. Those aged below 18 and 60 and above accounted for 19.93% and 12.23%, respectively. The ratio of male to female was nearly 1:1.4.

The questionnaire is divided into three parts: ① the first is mainly about the

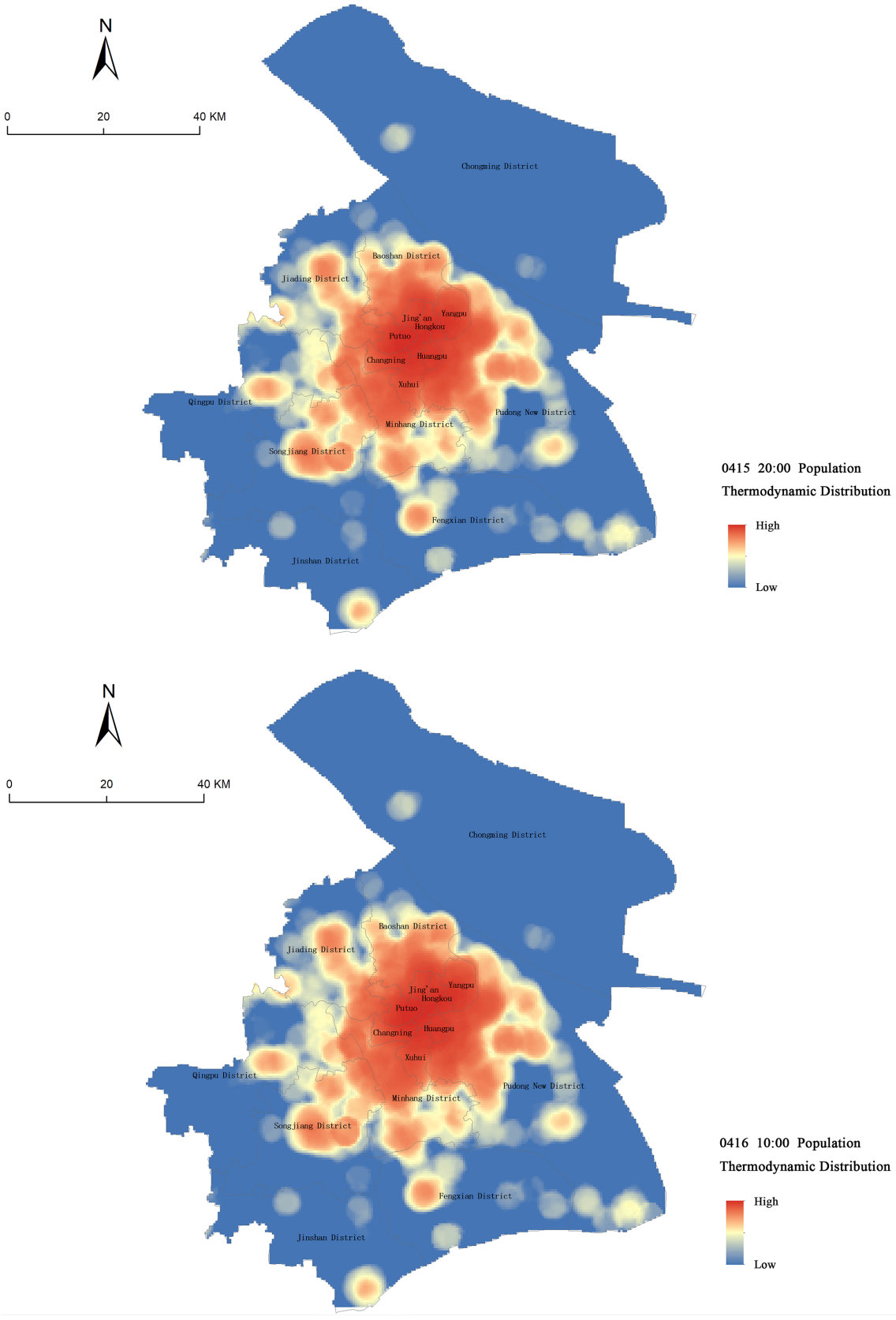

Figure 4. Population heat map of Shanghai on 15th April and 16th April. Source: Self-drawn by the author.

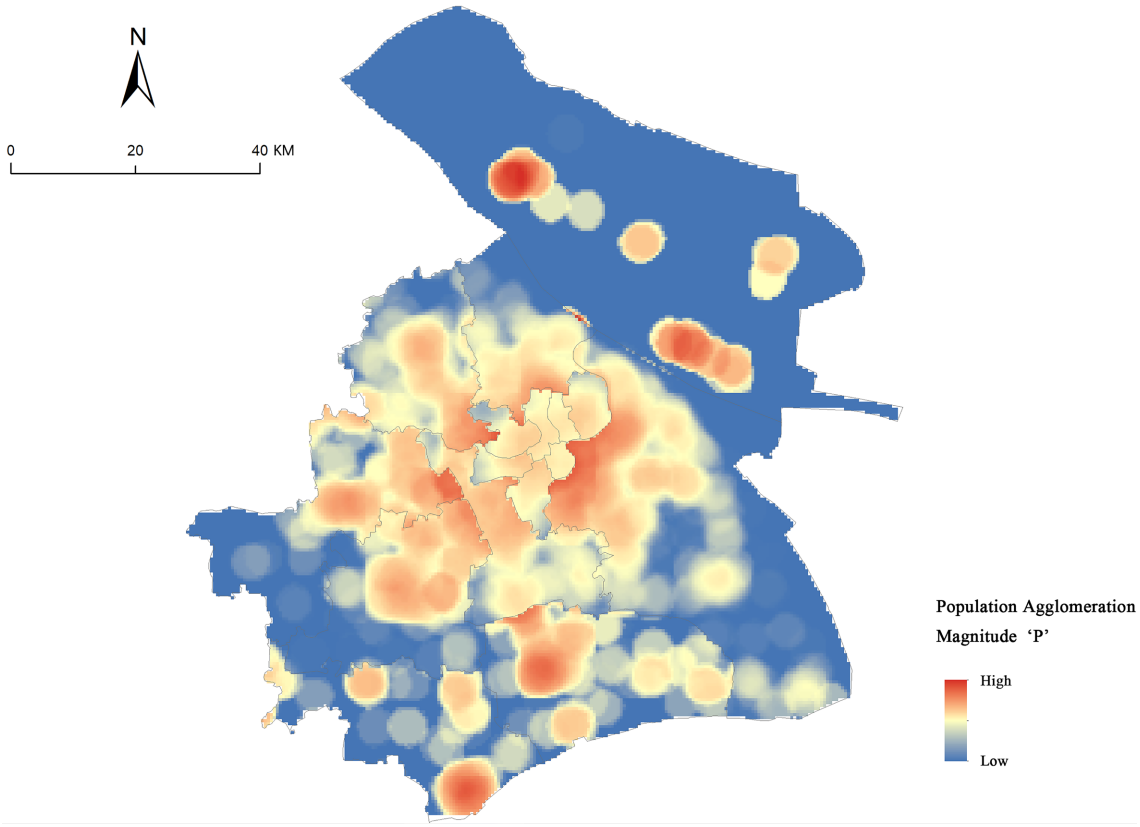

Figure 5. Population concentration level of each guarantee facility of Shanghai. Source: Self-drawn by the author.

personal information of the respondents, including the basic demographic characteristics and the district where they live during the lockdown period and the classification of the "three zones" they belong to; ② the second is about the level of living and the demand status during the lockdown period; ③ the third is about the facilities, including the choice of the guarantee facilities, the degree of knowledge of the guarantee information, and the evaluation of the guarantee situation.

The results reflect the influence of the epidemic lockdown on the lives of the residents to a certain extent. In the survey on whether basic life can be guaranteed, 26.72% of the respondents said that the basic living level cannot be guaranteed. Among which, 35.25% in the lockdown zones, 34.92% in the control zones, and 29.83% in the prevention zones (**Figure 6**). And we didn't see any significant differences among the three zones. This also confirms that even the majority of the city were set as prevention zones, but still managed as same as control zones during the period April 11-May 1[4].

From the analysis, the top three categories of items with the highest frequency of demand are fresh vegetables, snacks and beverages, and fruits. They are the most basic materials for daily life, followed by convenience foods, fresh meat,

[4]Shanghai released on April 12, 2022: For the prevention districts with many closed and controlled areas in adjacent districts and may generate cluster risks, each district may strengthen control measures and upgrade management according to the situation.

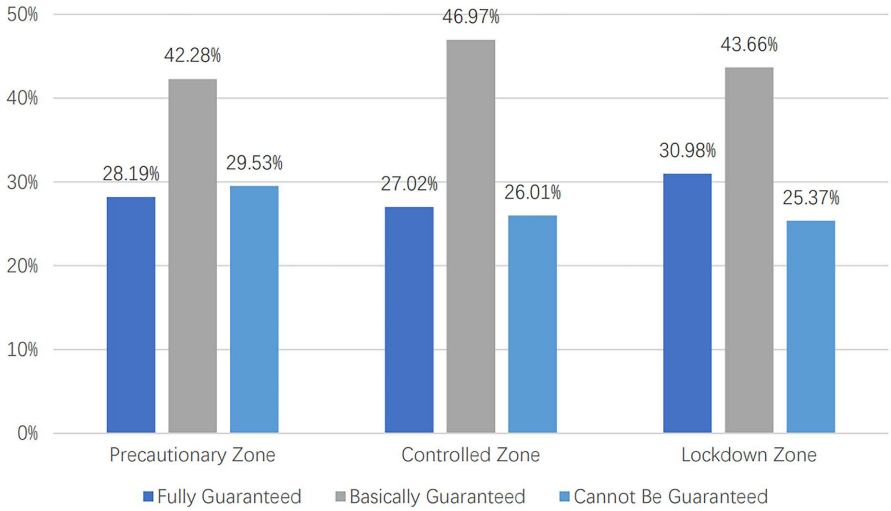

Figure 6. Basic livelihood guarantee levels of the local population in Shanghai during the epidemic lockdown period. Source: Self-drawn by the author.

eggs and fish. Through the composite score of the frequency and ranking of the demanded items (option composite score = (Σfrequency × weight)/the number of people filling in this question), the demand is significantly divided into two categories, high and low. The high demand category is vegetables, fruits, fresh food, snacks, rice, flour, grain and oil and other essential food items for daily life; while the low demand category is daily consumables, dairy products, pet department stores, mother and child products, medicine, etc. (**Figure 7**). The most basic foodstuffs such as rice, flour, oil are not at the top of the demand list, which shows that the most basic foodstuffs are guaranteed.

With regards to the access to living goods, the three kind of zones are also basically the same (**Figure 8**). The main means of accessing living goods for the local population during the lockdown period include community-based supply guarantee facilities, e-commerce platform, community group purchase, government/unit distribution, and neighborhood exchange and mutual aid. Similarly, by combining the ranking and frequency of the options, the combined scores of each option were 4.14 for community-based supply guarantee facilities, 3.96 for e-commerce, 3.85 for community group purchase, 3.71 for government/unit distribution, and 3.64 for neighborhood exchange and mutual aid. The supply guarantee facilities and e-commerce platforms are slightly more prevalent. They are the two main and common ways to obtain goods during the lockdown period. (**Figure 9**)

Regarding the evaluation of the effects of supply guarantee facilities: First, 20.83% of the residents know a lot about the supply guarantee facilities in their district, 36.68% know a lot, while 14.67% do not know at all (**Figure 10**). Secondly, regarding the extent of the guarantee of life during the period of lockdown, 19.38% and 28.17% of the residents thought the facilities' usage are significant and more significant respectively; 14.95% and 12.68% thought they are

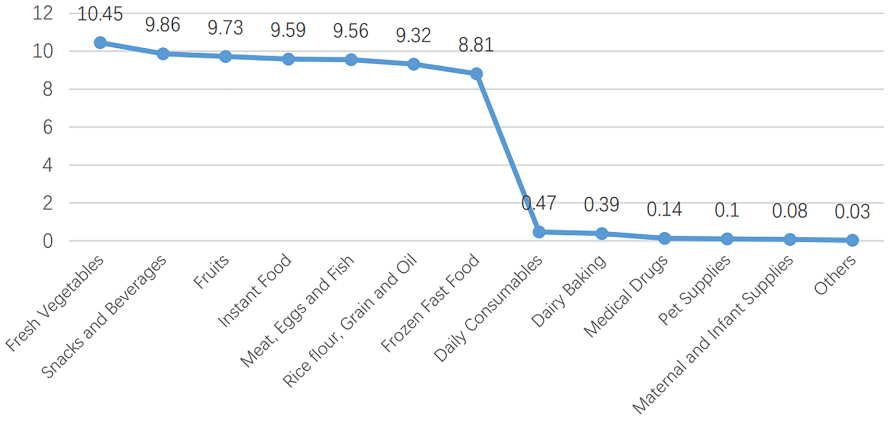

Figure 7. Composite score of demand options for the local population during the Lockdown. Source: Self-drawn by the author.

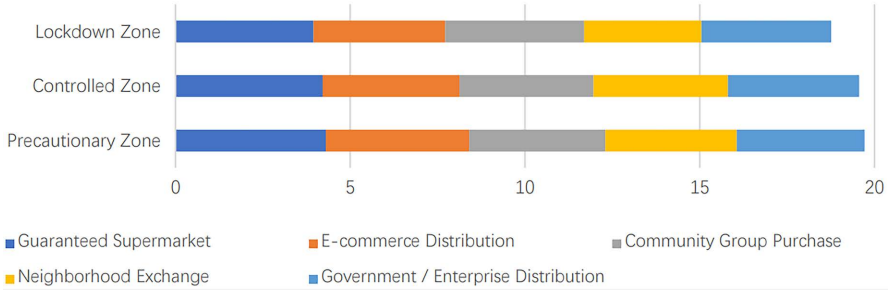

Figure 8. Goods access methods in different districts of Shanghai. Source: Self-drawn by the author.

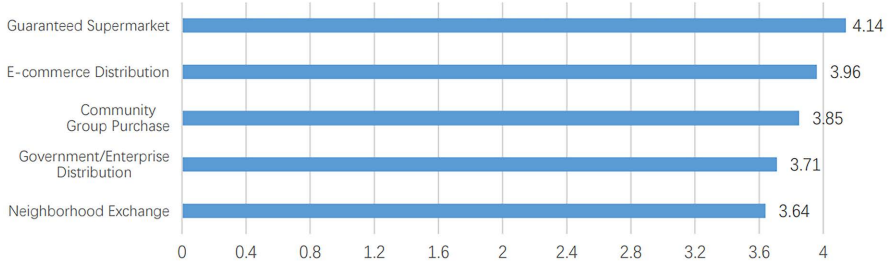

Figure 9. Overall goods access methods in Shanghai. Source: Self-drawn by the author.

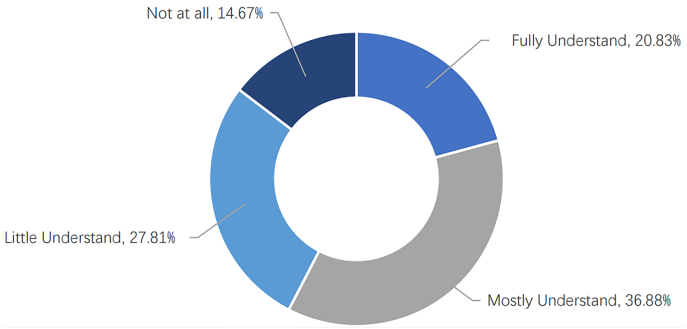

Figure 10. The degree of knowledge of the local population in Shanghai about the information of supply guarantee facility during the Lockdown. Source: Self-drawn by the author.

less significant and even almost not significant respectively; the remaining 24.82% was average (Figure 11).

4. Methodology

4.1. Calculation of the Weight of Supply Guarantee Facilities

Through "scoring scale" method, this paper calculates the degree of information mastery (1 - 4) and the degree of livelihood guarantee (1 - 5) of the local population with respect to the supply guarantee facility in the district. By quantifying the "perception of guarantee" from the subjective point of view of the local population, the weight "W" of guarantee is calculated for each district.

The calculation formula is as follows:

$$W_i = \overline{\left(\text{Information mastery} \cdot \text{Life security level}\right)_i} \tag{2}$$

The calculation results are shown in Figure 12. According to this figure, the supply guarantee weight is higher in Jiading District, Putuo District, Hongkou District, Minhang District, etc. That is to say, the supply guarantee facilities in these districts play a more significant role in the actual life of people. The lower weight of supply guarantee in Pudong New District, Baoshan District, Jinshan District, Yangpu District, Chongming District, etc. This implies the low actual utility of the supply guarantee facility. Another possibility is, the supply guarantee facility is not the main way for local residents to obtain material security in these districts.

4.2. Calculation of Regional Supply Guarantee Capacity—Based on Two Variable Factors

4.2.1. Supply Guarantee Capacity

By superimposing the population distribution during the lockdown period in Shanghai with the actual supply guarantee capacity, and calculating the "supply and demand" ratio, the per capita supply guarantee capacity coefficient "K" is obtained. Based on this, whether the supply capacity of the supply guarantee

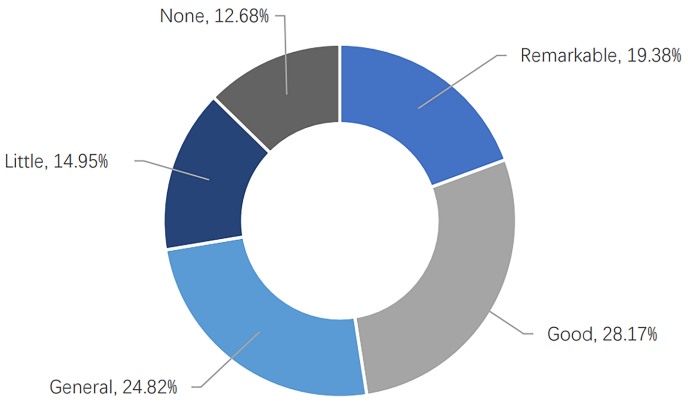

Figure 11. The degree of effects of the supply guarantee facilities in Shanghai during the Lockdown. Source: Self-drawn by the author.

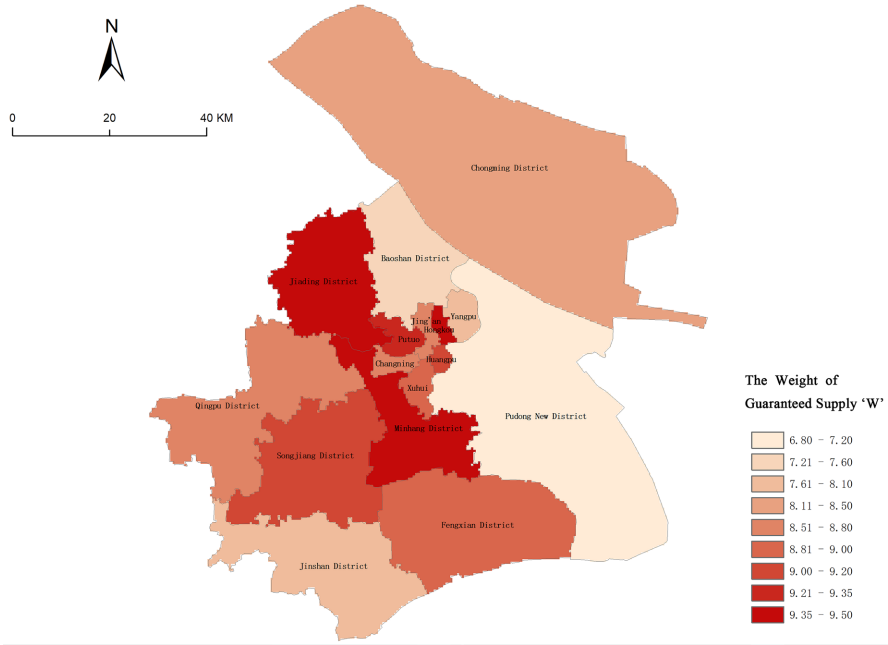

Figure 12. Supply guarantee weights of each district in Shanghai. Source: Self-drawn by the author.

facilities in each district is suitable for the demand is analyzed. The larger the value of "K", the higher the matching degree between the service capacity of the supply guarantee facilities in this district and people.

The calculation formula is as follows:

$$K_i = \frac{S_i \cdot W_i}{P_i} = \frac{S_i \cdot W_i}{C_i / d_i} \tag{3}$$

where, "S" stands for the service radiation force of the guaranteed supply facility, "W" represents the regional guaranteed supply weight, and "P" indicates the magnitude of the guaranteed supply population in the district.

The calculation results are shown in **Figure 13**. The regions with high per capita supply guarantee capacity are mostly concentrated in the central area of Shanghai. Outside the outer ring road, Songjiang District, Fengxian District, Baoshan District and other districts also have some sporadic dot shaped space, indicating a good per capita supply capacity. In contrast, the per capita supply capacity of most spatial districts in Chongming District, Pudong New District, Jinshan District and Qingpu District is weak.

4.2.2. Superimposed Strength of Supply Guarantee

Taking the service radius of 3 km around each facility as the supply coverage, it can be concluded that when the distance between two supply guarantee points is less than 6km, the supply coverage will overlap and produce superimposed effects; accordingly, the supply capacity strength will be strengthened with different weights according to the superimposed range size and distance. In other words, the closer the two supply facilities are, the greater the superimposed

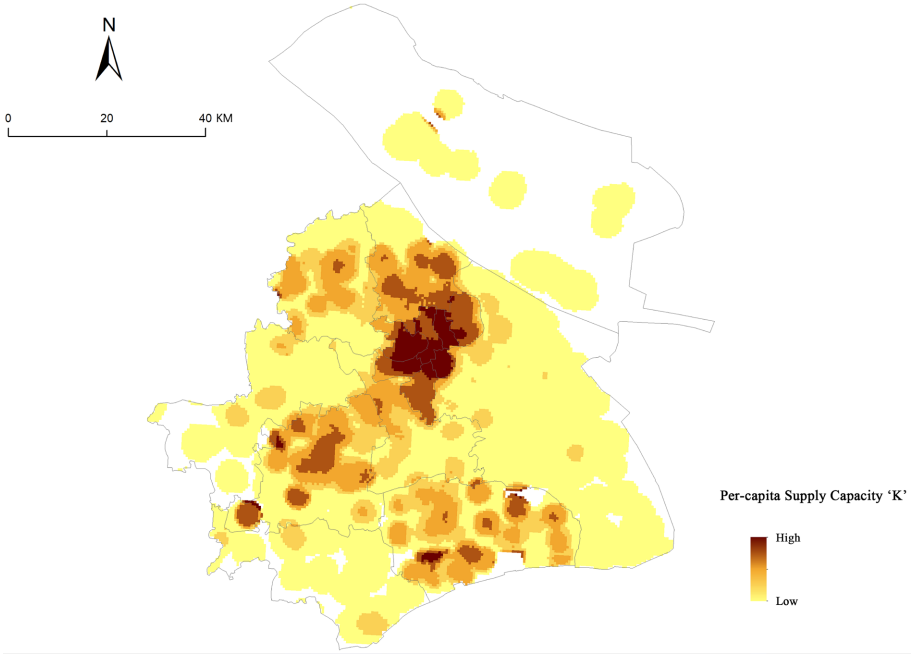

Figure 13. Per capita supply capacity coefficient K in various districts of Shanghai. Source: Self-drawn by the author.

strength will be, and *vice versa*. Therefore, the kernel density of 6 km aperture is calculated for the guaranteed supply facilities in each district of Shanghai, and the superimposed intensity "N" of the guaranteed supply in each district of Shanghai is obtained.

As shown in **Figure 14**, the distribution of the superimposed strength of the supply guarantee facilities is similar to the urban development circle structure. Specifically, the central city is the center of superimposed high intensity and the intensity decreases outward in order. Among them, Songjiang District and Fengxian District each have a superimposed sub-center in their territory.

4.2.3. Regional Supply Guarantee Resilience

By multiplying the values of the above two influencing variables, we obtain the regional range of supply guarantee resilience "R" where the facility is located, which is calculated as follows.

$$R_i = K_i \cdot N_i = \frac{S_i \cdot W_i}{P_i} \cdot N_i \tag{4}$$

The calculated results are obtained as follows:

According to **Figure 15**, the supply guarantee resilience is generally highest in the downtown. There are also more secondary high points of supply guarantee resilience in some districts such as Baoshan District, Songjiang District, FengxianDistrict, etc. The general supply guarantee resilience is lower in the urban fringe districts such as Qingpu District, Jinshan District, Pudong New District, Chongming District, etc.

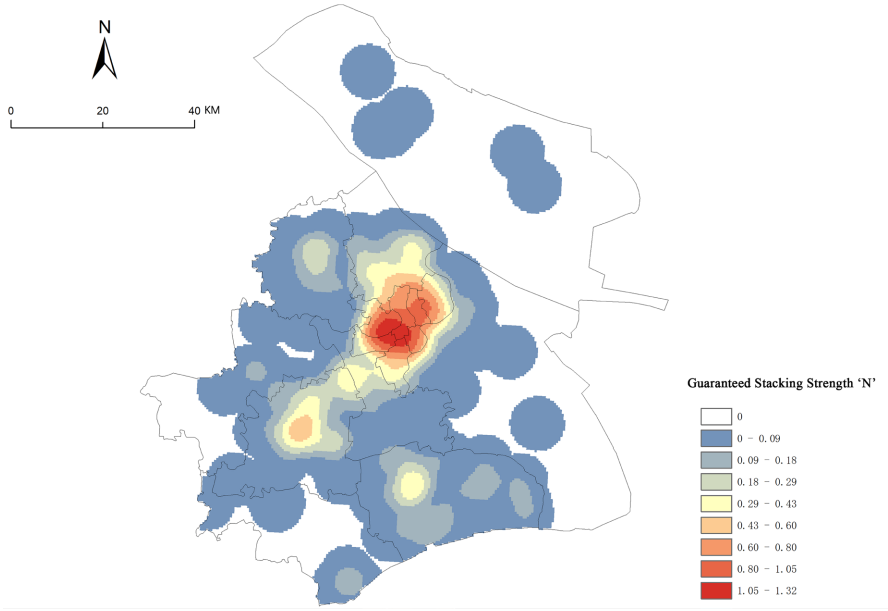

Figure 14. Superimposed intensity "N" of each guaranteed supply facility in Shanghai. Source: Self-drawn by the author.

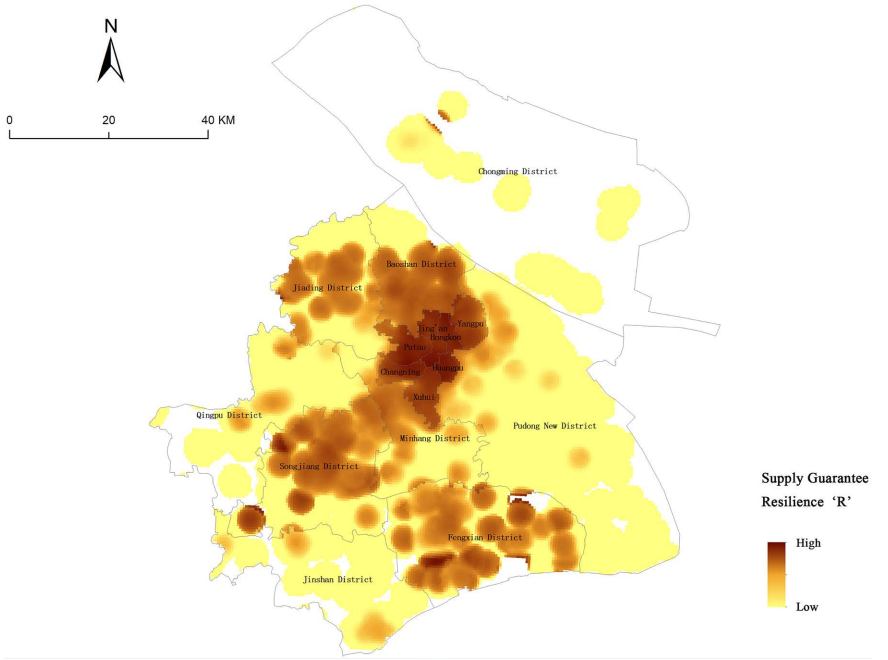

Figure 15. Supply guarantee resilience "R" in Shanghai. Source: Self-drawn by the author.

5. Analysis Results and Discussion

5.1. Analysis of the Level of Supply Guarantee Resilience

Through "quantile method", this paper classifies the urban supply guarantee resilience of Shanghai into three levels: "low-moderate-high", as shown in Figure 16.

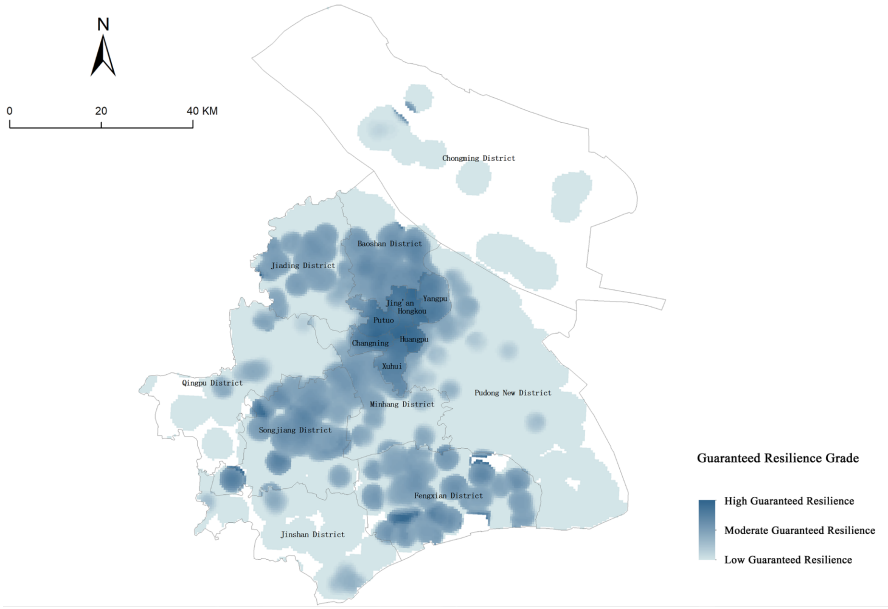

Figure 16. Distribution of the supply guarantee resilience level of Shanghai. Source: Self-drawn by the author.

According to **Figure 16**, there are much differences in the resilience of the supply guarantee in Shanghai during the lockdown. This shows the uneven and insufficient development of the urban emergency supply guarantee level and regional supply guarantee effect. The specific horizontal differences are characterized as follows:

The low level of supply guarantee resilience districts are mainly in Chongming, Jinshan, Qingpu and Pudong New District. The distribution of Supply guarantee facilities in these districts is relatively rare, which is hard to form high service radiation, especially in Chongming District, Jinshan District and Qingpu District, where the supply guarantee facilities are only 7, 11 and 7. However, it is worth noting that these districts contain a large scale of rural area. Although the coverage of supply guarantee facilities cannot be extended to rural areas, it does not mean there is no supply of basic living materials in these areas, since the rural area is more flexible than urban area.

The moderate level of supply guarantee resilience districts are mainly located in Songjiang, Fengxian, Baoshan, Jiading and Minhang districts which locate at the edge of central city. These districts have a considerable number of supply guarantee facilities but are loosely distributed, making it difficult to form a strong clustering effect. However, it is worth noting that most of these districts have high guarantee weight, *i.e.*, the guarantee effect is better evaluated. This is more obvious in Minhang District and Jiading District, where the guarantee weight ranks first and second in the city respectively.

The High level of supply guarantee resilience districts are concentrated in Huangpu District, Jing'an District, Hongkou District, Putuo District, Yangpu District, Changning District, Xuhui District and other downtown areas. The

supply guarantee facilities in these districts generally have high service radiation and supply guarantee overlay intensity. The supply guarantee resilience is high since these districts are basically compatible with the high-density demand characteristics of supply guarantee under the high-density population in the central city.

5.2. Analysis of the Spatial Characteristics of the Supply Guarantee Resilience of Shanghai

The spatial distribution of supply guarantee resilience levels has a certain correlation with the "central circle" urban development structure in Shanghai. The overall resilience level of supply guarantee in the central city is high. The situation in the suburban areas is more complicated, with some of them in the medium level and some in the low level, while the resilience level of supply guarantee in the remote suburban areas is generally low. The reasons for this spatial distribution characteristic can be analyzed at two levels of supply and demand: The supply side—the opening of the supply guarantee facilities; the demand side—the structure of the demand for supply guarantee facilities.

The remote suburban districts, such as Chongming, Jinshan, Qingpu and the coastal part of Pudong New District, are often not considered as the key districts for emergency management (*i.e.* there are few guaranteed supply facilities) because of their remote location and relatively sparse population distribution. The large number of rural areas they keep often makes their relatively low dependence on external supplies. But undoubtedly, the low scores of these suburban areas in the analysis of the supply guarantee facility in this paper indicated the little effect of guaranteed supply facilities.

The central city, as a large concentration of population, is the key area for urban emergency supply guarantee. Once the districts are lockdown, the main way for residents to obtain supplies is through the supply guarantee facilities. Therefore, the effectiveness of supply guarantee in central urban areas is very important. According to the value of "K", "N" and "R", the majority of the supply guarantee facilities in the central city have played a significant role, and can basically meet the large demands of residents with a fine supply guarantee capacity.

In contrast, the situation in near suburban areas is more complicated. First, the population thermodynamic map showed the population in the near suburban areas close to the center of city continued the concentration, represented by Jiading, Baoshan, Minhang and some areas in Pudong New District. The demand for supply guarantee facilitywas also larger. According to the calculation, there were a small number of areas that were struggling to guarantee supply. The supply guarantee capacity cannot be well matched with the dense distribution of population The other part of the suburban areas (*i.e.* the more peripheral areas), represented by the central districts of Songjiang, Jiading, Baoshan and parts of Fengxian district, had moderate population size with the scattered but relatively concentrated distribution pattern. So was the pressure of supply guarantee de-

mands. At the same time, both the number and the coverage of supply guarantee facilities hadreached a certain concentration density and breadth. Therefore, the resilience level of supply guarantee is relatively high.

5.3. Reflections and Discussion

Through further comprehensive analysis of the regional distribution characteristics of the level of resilience combined with questionnaire research, this paper concluded that:

5.3.1. The Urban Supply Guarantee Facility Is Not the Only Method for Residents to Obtain Supplies

The questionnaire found that community group purchase and neighborhood exchange, as well as government/unit distribution of supplies also accounted for a certain proportion of the access to supplies. According to the questionnaire data, nearly 30% of the city's local population was not basic guaranteed. Therefore, other methods should be encouraged instead of relying only on the urban supply guarantee facility.

5.3.2. Rural Areas Have a Positive-Supporting Effect on the City Resilience

The resilience of supply guarantee in Fengxian and Songjiang District was higher than that in the other suburban areas. These two districts are the most prominent agricultural output areas in Shanghai, constituting the important part of the supply guarantee materials during the lockdown, which are essential for the city supply guarantee chain. Agriculture does provide local residents with the conditions and possibilities to rely on their own agricultural planting to maintain their livelihood during the lockdown and form basic self-sufficiency (which was also confirmed in the questionnaire survey).

5.3.3. The Level of Resilience Does Not Have Regional Continuity and "Proximity Effect"

According to the hierarchical distribution of the whole city, the resilience level of Shanghai's supply guarantee did not show a "graded" continuous change. For example, the boundary districts between the central area and Jiading, Minhang District, etc. were the direct collision between high and low guarantee resilience levels, the guarantee resilience levels of adjacent districts were contrary to the "spatial proximity effect". In other words, the regions were in a relatively fragmented and separated state. There was no or few resource interoperabilities, which brought about a significant phenomenon of resource inequality. The supply guarantee facilites showed a regional "monopolistic" fragmented distribution. Since the regions with relatively abundant supplies did not play a supporting and moderating role for the districts with relatively scarce supplies (even if they were adjacent), the supply guarantee facilities cannot form a good circulation and deployment between districts. There was a lack of synergy between districts and a weak sense of overall cordination and deployment of resources at the city level.

Even if the flow of people was isolated and restricted during the lockdown, the logistics of supply guarantee materials cannot come to a complete standstill. The necessary inter-regional material circulation and exchange and collaboration were needed and had a positive effect on relieving the pressure of the epidemic. Therefore, it was necessary to build a benign inter-regional relationship of "synergy and mutual assistance, deployment according to needs".

6. Strategies to Improve the Resilience of Urban Supply Guarantee

6.1. The Establishment of a Scientific and Perfect Guarantee System

Firstly, the layout of the supply guarantee facilities should be settled according to the population distribution trend. In densely populated districts, the distribution of the corresponding supply guarantee facilities should be kept at an appropriate scale and density. On the contrary, in sparsely populated and relatively scattered districts, the number and layout of supply guarantee facilities can be relatively reduce and loosely distributed. On the other hand, the capacity of supply guarantee should be in line with the scale of population. The larger the population, the more attention should be paid to the improvement of the capacity of each supply guarantee facility.

Secondly, according to the data of the seventh census in Shanghai, the population aged 60 and above has accounted for 23.4% of the total. According to the questionnaire data, 29.63% of the elderly aged 60 and above during the lockdownwere in a state where their basic living cannot be guaranteed. Their access to materials mainly relied on supply guarantee facilites and neighborhood exchange mutual aid, which was narrow in terms of the selective access to materials. This suggested urban supply guarantee system should pay more attention to the aged people. In addition, there are children and patients who are also relatively disadvantaged, and these groups should be the primary focus during the lockdown.

Finally, in biological systems, the more diverse the population, the stronger the ability to recover after receiving pressure. The urban supply guarantee system should be built for more diverse in future. It could contain more different methods for supply and more flexible for variety needs of residents. In this way, the diversity of the supply guarantee system response will probably be enhanced to accommodate more diverse situations, thus obtaining greater inclusiveness, safety and stability of the system.

Therefore, we should take the initiative to break the only dependence of urban supply guarantee on government channels, and encourage diversified channels such as commerce, charity assistance, barter and so on to jointly solve the problem of residents' material demand and supply. Form a supply guarantee system under the guidance of the government, with an active social market and a "bottom line" guaranteed by the government.

6.2. The Improvement of Urban Self-Organization and Adaptation Power

The formation of regional self-organization depends largely on the activity of organizational subjects, because rich and diversified participating subjects can bring diversified forms, dimensions, perspectives, broader objects, coverage, etc. This truly highlights its "own, spontaneous and autonomous" capacity characteristics. Based on this, the way to enhance the self-organizational power of the region naturally cannot only rely on a single organizational body (e.g., the government), but should fully incorporate the synergy between the government, enterprises, institutions, NGOs, media, communities and other multiple subjects. The active participation of multiple parties at the social level should be encouraged to evoke more possible ways of supply guarantee. At the same time, this will help avoid the disadvantages of incomplete, inadequate and impractical perception of social needs by a single subject.

Moreover, an important point in self-organization is the ability to be "self-sufficient". For cities (especially central cities), self-sufficiency in terms of material demand can greatly reduce dependence on external supply chains and increase responsiveness and initiative in the event of public crises. This will prevent the city from being in a state of passivity, waiting for assistance from outside.

In recent years, the concept of "urban agriculture" has emerged and received considerable attention and discussion in the fields of urban economic production, leisure consumption, urban landscape, and green ecology. In terms of urban resilience, "urban agriculture" also has a great advantage of interest. It features better integration of the spatial characteristics of the city (concentrated and compact, vertical development) and the structural characteristics of demand (multi-level, refined). Therefore, it has given birth to a modern form of agricultural industry, which is adapted to the needs of modern urban survival and development, thus allowing "agriculture" to take root and develop in the city as well. In the event of major public emergencies, having a self-organized supply chain of self-production and self-consumption is equivalent to holding the bottom line of regional survival.

Last but not least, "independence" means that each unit in the urban area maintains a relatively independent relationship with other units without dependence. This characteristic allows the city to maintain the minimal operation of basic functions in the event of emergencies, so there is no large-scale collapse or stagnation. On the other hand, "synergy" refers to the coordination and mutual assistance among regional units, which can maintain an orderly synergy under certain rules and scope. It refers to the collaborative participation of regional stakeholders in the process of coordination.

The simultaneous balance of "independence" and "synergy" reflects the importance of a holistic and local view of urban resilience. In the face of major public emergencies, both of them enable cities to have both the self-reliance and

the overall capacity to achieve the optimal allocation of urban resources.

6.3. The Establishment of Comprehensive Risk Management and Assessment Mechanism for Supply Guarantee

First, keep "redundancy mindset" and form a "backup system mechanism" for supply guarantee with two dimensions of "normal" and "abnormal". In the first moment of an emergency, the normalized facilities can form the basis of the first resistance. Then follow up with the "abnormal" ones to enhance the overall resistance and supply guarantee ability as well as replace/assist the "normal" facilities damaged by severe impacts, ensuring the operation/recovery of emergency support functions as soon as possible.

What is important to note is, "normalization" is the basis for the construction of "non-normalization". Therefore, the government should consider urban risk assessment and simulate urban material security flow in the normal urban operation situation as much as possible, and standardize and institutionalize them. Only in this way can the government develop a good and effective "normal-abnormal" complementary system to ensure the robustness of urban supply guarantee.

Secondly, it is necessary to build a full closed-loop risk governance process from risk early warning to implementation, and then to process feedback. Form a series of measures that can independently plan supply according to risk assessment and early warning, orderly open supply channels, allocate and deliver materials, and reflect, summarize and constantly optimize a benign system in the process of work. It emphasizes that through self-learning from practice, we can improve the independent flexibility, reflective optimization and conditional adaptability of the supply guarantee system in the face of unpredictable changes, disturbances and shocks.

Finally, pay attention to the loss of trust caused by spatial heterogeneity isolation. The lockdown system cuts off the normal social exchanges of residents to varying degrees, thus deepening the cultural differences and the loss of social trust. It would greatly affect the enthusiasm and activity of residents' self-organization and self construction of material supply/acquisition channels. Therefore, spatial units of close neighbors and small-scale spatial scales should be adopted as much as possible in risk governance as the basic spatial unit of supply guarantee to increase the capacity of small-scale (e.g., community) collective action and regional autonomy.

7. Conclusions

Through the analysis in this paper, there were large regionalized differences in the level of urban supply guarantee in Shanghai during the epidemic lockdown. The central urban districts such as Huangpu, Jing'an, Hongkou, Putuo, Yangpu, Changning, and Xuhui districts were the main high supply guarantee resilience districts; Songjiang, Jiading, Baoshan, Fengxian, and Minhang districts were mostly medium supply guarantee resilience districts; Chongming, Jinshan, Qing-

pu, and Pudong New Districts were mainly low supply guarantee resilience districts.

Based on the characteristics of population distribution, economic development, industrial positioning and other development levels, we further considered the discussion from two levels of supply and demand. The characteristics and opportunities of Shanghai in this supply guarantee include: the urban supply guarantee facility is not the only method for residents to obtain materials. Rural areas can play a positive-supporting role in the regional supply guarantee resilience level. Guarantee resilience level in urban areas does not vary in a spatially continuous manner.

According to the problems and opportunities obtained from the above analysis, this paper proposed three main strategies for improving the resilience level of supply guarantee. Firstly, we establish a scientific and complete supply guarantee system in terms of distribution, target focus, and supply channels; Secondly, we enhance the urban self-organization-adaptability through multiple subjects, urban agriculture, and the balance of independence and synergy; Thirdly, we build a comprehensive supply guarantee risk management and evaluation mechanism based on robustness, reflexivity, and credibility.

The research of the global impact and influence of the COVID-19 pandemic on human social life since its outbreak in 2020 foresaw that these epidemics would remain persistent and episodic. Therefore, the post-epidemic normalization outlook reminds us: urban supply guarantee facilities and operational systems need to be urgently brought up to the "always ready" normalization. In the face of major public emergencies like this, the "supply guarantee resilience" of cities may also become and should be incorporated into the normalization of the post-epidemic era. At the same time, it should also become one of the key indicators for urban resilience planning and evaluation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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