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Calculate the resilience value amongst 4 cities in Yangtze River Delta region in China to discover the changes in urban resilience under the impact of COVID-19

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Abstract:

The global spread of the COVID-19 has had a significant impact on lots of cities. However, this crisis also provides a crucial opportunity to determine the drawbacks in the city's construction and propose solutions for improvement. In detail, the fluctuations in a city's urban resilience values between 2020 and 2022 can present its ability of withstand the disaster or recover quickly. This constitutes the central idea of the study. This study will discuss the concept of urban resilience, introduce the four target research cities located in the Yangtze River Delta of China, explain the rationale for selecting the entropy method and the specific calculation process, present the design ideas of the indicator system and justify the selection of certain specific indicators, analyse the calculated values, and finally offer recommendations for future construction in each city. In the Explanation section, a substantial amount of research on the targeted city is cited to provide a reasonable explanation for some strange calculation results. The division of urban resilience into five aspects (economic, infrastructure, ecological, social and community) allows for the identification of specific weaknesses, which in turn informs the targeted suggestions made for each city in the subsequent section. Furthermore, the successful experience of analogous urban construction in the past is also referenced, thus rendering these suggestions highly feasible.

Keywords: Yangtze River Delta, Urban resilience, COVID-19, Entropy method.

1. Introduction

The most significant event in recent years is undoubtedly the global pandemic of COVID-19. The outbreak of this novel, highly contagious virus in Wuhan

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city in 2018 had a profound impact on China, affecting various aspects of life. In the period between January and June 2020, 83,534 cases of confirmed infection with the COVID-19 were reported in China, with a total of 90 million individuals undergoing testing for the disease [1]. The social impact has been particularly severe. In comparison to the same period in 2019, the number of new urban jobs decreased by 1.73 million [2]. In the aftermath of this significant health crisis, it is imperative that the government assess the disaster resilience of different cities to inform future policy and preparedness strategies. The concept of urban resilience can be a valuable framework for this assessment.

In recent years, the popularity of “resilience” has exploded in both academic and policy discourse, with numerous explanations for this dramatic rise [3]. The conventional definition is as the „The capacity of any urban system, in conjunction with its inhabitants, to maintain continuity in the face of external shocks and stresses, while simultaneously undergoing positive adaptation and transformation towards sustainability“. Therefore, a resilient city is one that assesses, plans and acts to prepare for and respond to hazards, irrespective of whether they are natural or human-made, sudden or slow-onset, expected or unexpected. Cities that are resilient are better placed to protect and enhance the lives of their inhabitants, to secure the benefits of development and to drive positive change [4].

This thesis will therefore develop a framework for calculating and assessing the urban resilience of four Chinese cities located in the Yangtze River Delta (YRD) region during the three years of the epidemic. An urban resilience evaluation system will be utilised to facilitate a comparison including five aspects: ecology, economy, society, infrastructure and community. This approach enables a direct identification of the cities’ weaknesses, so as to provide more targeted suggestions to the cities.

2. Literature review

2.1 The definition of urban resilience and the existing calculation methods

Resilience was originally transformed from the Latin word “resilio” and came from applied science, meaning to recover the original state [5]. As cities continue to grow and grapple with uncertainties and challenges like climate change, urban resilience has become an increasingly favored concept [6].

Nevertheless, a unified definition, calculation standard, or method for urban resilience remains elusive within the academic community. Meerow et al. synthesized 25 existing definitions of urban resilience in 2016, in order to propose a new definition of urban resilience, one that explicitly includes these six conceptual tensions, yet remains flexible enough to be adopted by a range of disciplines and stakeholders. This definition is: Urban resilience refers to the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity [3].

However, despite the existence of a relatively comprehensive definition that encapsulates the disparate perspectives of numerous scholars, there persists a divergence in the methodologies employed by different scholars to quantify urban resilience. Many current studies on urban resilience use a variety of different approaches. For example, Yi, Hu & Huang’s study on the urban agglomeration in the middle reaches of the Yangtze River pointed that the concept of urban resilience can be distilled into five key domains: economic resilience, social resilience, ecological resilience, infrastructure resilience, and organisational management resilience [7]. Then, the resilience assessment value of each city is determined by calculating the weights (Using information entropy, the weight of each indicator is calculated to provide a basis for comprehensive evaluation of multiple indicators). Other studies employ a similar methodology, namely the construction of an indicator system and the subsequent calculation of weights. However, the indicator layers utilized in these studies are usually different. You et al‘s study rearranged the indicators to include community resilience and removed organizational management resilience, and employed the entropy method with a time variable on the dimensions and indicators of empowerment to guarantee objectivity and precision. Their research also utilise the Theil index, which assesses the extent of regional resilience disparities [8]. Some other scholars choose less indicator layers, for example, Zhu et al.’s indicator system was composed of economy, society and polity [9].

Additionally, there is another method to discover the relationship between factors and urban resilience. Chen et al. assumed that the inflow risk pressure of COVID-19, the city‘s economic activity, population density, and gross domestic product per capita would correlate in a logarithmic form with the time required to contain the epidemic‘s spread. The remaining variables would correlate in a linear form. Based on these assumptions, an econometric model is constructed: $Time = \alpha 1 + \beta 1 lninflow + \beta 2 lngarbage + \beta 3 lndensity + \beta 4 lnGDPp + \beta 5 med + \beta 5 SARS + \varepsilon i$. Then the correlation was represented by scatter diagram [10].

2.2 Previous findings on urban resilience

You, Sun & Liu discussed the value of urban resilience and its influencing factors of Jiangsu. This study examined the resilience of cities in Jiangsu Province from 2009 to 2018, and identified a declining trend in the spatial configuration of resilience across southern, central, and northern Jiangsu, with an observed increase in resilience towards the end of 2018. Spatial correlation analysis indicates a positive correlation between overall and partial urban resilience in Jiangsu, suggesting an interaction between areas with comparable economic levels and geographical proximity. The spatial evolution map of urban resilience demonstrates that the resilience of cities in Jiangsu is not a random process [8].

Wang and Wang employed a comprehensive weighting method to evaluate urban resilience in the YRD. The findings demonstrated an average annual growth rate of 4.23% from 2010 to 2020, with notable enhancements observed in each subsystem. The urban resilience core density curve demonstrated a rightward shift, accompanied by a reduction in convergence between cities. The city of Shanghai was the most economically, socially, and ecologically resilient, while the province of Anhui has demonstrated the most significant improvement in engineering resilience. The Hurst index value was 0.607, indicating that future resilience development would be consistent with existing trends, while enhancements in openness, ecological prevention, digitalisation and industrial structure can bolster local urban resilience [11].

Moreover, Wang, Wang & Shi's study examined the urban resilience of the central plains urban agglomeration in China from 2006 to 2019. The findings demonstrated an overall increase in urban resilience, with notable variations across regions. The spatial distribution of urban resilience was characterised by a prevalence of negative correlation types of low-low cold spot agglomeration areas, exhibiting a notable degree of spatial homogeneity. The spatial evolution of urban resilience in the northwest of the agglomeration and surrounding areas of Zhengzhou City is more dynamic, with areas exhibiting low resilience demonstrating greater stability. The urban agglomeration represents a significant constraint on the development of urban resilience, and the city‘s resilience is driven by a range of factors, including economic development, government finance, technological innovation, public services and the ecological environment [12].

2.3 The background of the four chosen cities

The Yangtze River Delta urban agglomeration (YRD) is a highly developed economic region in the eastern coastal area of China, which is composed of the following important cities:

Shanghai was selected by the Globalization and World Cities Study Group, ranking fifth in the world [13]. In 2021, Shanghai‘s GDP reached 4.32 trillion yuan, ranking fourth in the world [14].

Nanjing is the capital of Jiangsu Province in China, with a total area of 6,582.31 square kilometres. In 2017, the total economic output of Nanjing reached 1,171.5 billion yuan, ranking 11th among Chinese cities [15]. Hefei is the capital of Anhui Province. The total administrative area of the city is 11,445 square kilometres. In 2023, the GDP of Hefei reached 1,267.38 billion yuan [16].

Hangzhou is the capital of Zhejiang, and a megacity. It is situated in the eastern part of China, with a total area of 16,850 square kilometres. In 2023, the GDP of Hangzhou is projected to reach 2,005.9 billion yuan [17].

2.4 Summary, gap and critical review

There are many studies on urban resilience, but with regard to the selected target research cities, the majority of studies focus on all cities within a province or region. In selecting the cities to be included in the study, insufficient attention was paid to the differences in status and level between the cities in question. This has resulted in a lack of clarity regarding the similarities and differences in urban resilience between the research objects themselves. This study will focus on four representative cities in the three years of the epidemic, thus enabling a comparison of urban resilience values and the severity of the epidemic. This kind of comparative study between different cities in the same region is a novel approach.

With regard to the calculation methods and indicator layer design, the majority of the aforementioned studies did not introduce novel approaches to the existing indicator system. Instead, they merely eliminated a few factors based on the availability of data. While there are some discrepancies in the initial indicator layer, the total number of factors included is comparable.

Furthermore, the dynamic nature of this type of research can be overlooked, whereby a dedicated indicator system is developed for events that occurred in the target research year. Consequently, the disparate studies exhibit considerable homogeneity, rendering it challenging to offer the academic community a tangible and beneficial contribution.

3. Methodology

3.1 Aim

The objective of this article is to analyse the impact of Covid-19 on four cities in the YRD of China from 2020

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to 2022. This will be achieved by calculating the city resilience value, which will enable the derivation of the trend of change and the vulnerability of each city to be determined. The entropy method will be used because it assigns weights completely objectively based on data only. See below for details.

3.2 The construction of indicator system

The indicator system this research used is shown below in Figure 1, which is designed by combining 10+ different indicator systems previous researches used and some other literatures.

Firstly, the majority of studies employ indicator levels that encompass urban economic resilience, urban environmental resilience, urban infrastructure resilience, and urban social resilience, so this will exist in this study [7, 8, 9, 11, 12].

Table 1 Resilience Indicator System

Level 1 Indicator	Level 2 Indicator
urban ecological resilience	Park greenery area
	Green coverage rate in urban constructed areas
	Volume of industrial wastewater discharged
	Percentage of sewage disposed
	Harmless disposal rate of household garbage
urban economic resilience	GDP per capita
	Proportion of tertiary industry in GDP
	Actual utilization of foreign capital
	Urban disposable income per capita
	Revenue in the general public budgets
urban social resilience	Number of college students on campus
	Number of beds in health facilities
	Gross foor area per capita
	Natural growth rate
urban infrastructure resilience	Annual electricity consumption
	Freight trafc of highways
	Internet broadband access users
urban community resilience	Number of residents' committees
	Number of people covered by unemployment insurance
	Expenditure on urban and rural community affairs

The only added Level 1 indicator is community resilience. The community serves as a regional social living community with multiple functions. It serves as a pivotal space for grassroots governance and a crucial position for epidemic prevention and control. In the event of a public crisis, the community can leverage its inherent multi-functionality and flexibility to undertake a range of emergency response measures to address the crisis [18].

Volume of industrial wastewater discharged, percentage of sewage disposed and harmless disposal rate of household garbage is added in the ecological resilience which most of the previous researches didn't include. That is because Zhu & Sun thought that the precipitous reduction in urban public green space, deficiencies in sewage and waste disposal systems and saturation of ecosystems will heighten the probability of urban vulnerability, while most researches only focus on the urban green area [19].

Number of residents' committees was selected, since in the context of the epidemic, the neighbourhood committee bore responsibility for antigen testing of residents, the distribution of supplies, and the assurance of basic living. The number of neighbourhood committees can be used as an indirect indicator of the government's capacity to control and protect the population in the event of a crisis.

Additionally, unemployment insurance coverage has been specifically incorporated in light of the ongoing epidemic. In recent years, the Chinese government has publicly declared its intention to cease calculating the urban unemployment rate, which is why this general indicator is absent from this study [20]. Consequently, unemployment insurance can indirectly inform conclusions regarding people's living standards and overall employment conditions, and also compensate for the absence of employment indicators.

Another indicator that was deleted is the urban green coverage rate. This was due to the fact that it was considered to be somewhat redundant with the urban park green area indicator. Furthermore, the statistical bases of the coverage rates for various cities are not consistent. Some are for built-up areas, while others are for the entire city. As a result, it is challenging to obtain an accurate result through this indicator.

3.3 Data collection

The four research cities selected for this study are all provincial capitals or municipalities situated within the YRD region, which means data is more available. The four cities share several common characteristics, including their relatively close geographical proximity, their status as economic centres within their respective regions, and their substantial populations. The choice of four cities allows for the simultaneous examination of the characteristics of a single region and the comparison of differences between different cities.

The time period selected is 2020-2022. The outbreak of COVID-19 in China was at the end of 2019. In light of the potential for the impact of the epidemic on urban resilience to manifest with a temporal lag, the data from 2019 has been excluded from the research scope. The epidemic has essentially subsided in 2023, and there is a considerable dearth of statistical data for that year, which has consequently been excluded from the research scope. The years 2020 and 2022 represent the two most severe instances of the epidemic, marking the initial emergence of COVID-19 and the apex of the Omicron variant. In comparison, 2021 appears to be the most stable year in terms of the epidemic, and therefore the data from these three years may fluctuate and be comparable.

The fundamental indicators have been primarily sourced from the China City Statistical Yearbook, Statistical Yearbook of Shanghai, Hangzhou, Hefei and Suzhou, the National Economic and Social Development Statistical annual report of the four cities, and the official website of the Chinese government. The Statistical Yearbook is published annually by the statistical departments of local governments in China and has the highest timeliness and reliability. It should be noted that the data presented for each city in this study represents the entire city, rather than a specific district or region. In the absence of sufficient data, only a limited number of indicators have been replaced by the city district caliber, while indicators with significant data gaps have been substituted with indicators of comparable representativeness.

3.4 Calculation method

In order to avoid interference and calculation error of subjective factors, this study adopts the entropy method on the dimensions and indicators of empowerment to ensure objectivity and accuracy [21].

In order to eliminate dimensional differences, the level difference method is adopted to standardize the original data, and the obtained value is X.

1. If X is a positive indicator, then the standardization equation is given as follows:

$$X = \frac{x - x_{Min}}{x_{Max} - x_{Min}}$$

2. If X is a negative index, then the standardization equation is given as follows:

$$X = \frac{x_{Max} - x}{x_{Max} - x_{Min}}$$

3. Calculate the proportion of the i-th sample under the j-th indicator and regard it as the probability used in the information entropy calculation.

$$y_{ij} = \frac{\bar{x}_{ij}}{\sum_{i=1}^{m} \bar{x}_{ij}}$$

4. According to the definition of information entropy in information theory, the information entropy of a set of data is:

$$e_j = -K \sum_{i=1}^{m} y_{ij} ln y_{ij}$$

$$K = 1 / lnm$$

Where $e_j \geq 0$. If $y_{ij}=0$, define $e_j=0$, and m is the number of influencing factors considered.

5. Determine the weight of each indicator.

$$W_j = \frac{1 - e_j}{m - \sum_{j=1}^{m} e_j}$$

$$(j = 1, 2, 3, \ldots, m)$$

6. Calculate overall score.

$$S_i = \sum_{j=1}^{n} y_{ij} w_j$$

7. The scores of the cities were then recorded in an Excel and compared.

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3.5 Supplement: Calculated weight value

Table 2 Summary of Weight Calculation Results Using Entropy Method

indicator	Information entropy (e)	Information utility value (d)	Weight coefficient (w)
Volume of industrial wastewater discharged	0.8973	0.1027	3.19%
Green coverage rate in urban constructed areas	0.8804	0.1196	3.72%
Percentage of sewage disposed	0.8917	0.1083	3.37%
Harmless disposal rate of household garbage	0.967	0.033	1.03%
Park Greenery Area	0.8219	0.1781	5.54%
GDP per capita	0.929	0.071	2.21%
Proportion of tertiary industry in GDP	0.8859	0.1141	3.55%
Actual utilization of foreign capital	0.8243	0.1757	5.46%
Urban disposable income per capita	0.9339	0.0661	2.06%
Revenue in the general public budgets	0.7773	0.2227	6.92%
Number of college students on campus	0.8115	0.1885	5.86%
Number of beds in health facilities	0.7944	0.2056	6.39%
Gross floor area per capita	0.8985	0.1015	3.15%
Natural Growth Rate	0.9203	0.0797	2.48%
Annual electricity consumption	0.8525	0.1475	4.58%
Freight traffic of highways	0.8842	0.1158	3.60%
Internet broadband access users	0.8349	0.1651	5.13%
Number of residents' committees	0.7395	0.2605	8.10%
Number of people covered by unemployment insurance	0.5701	0.4299	13.36%
Expenditure on urban and rural community affairs	0.668	0.332	10.32%

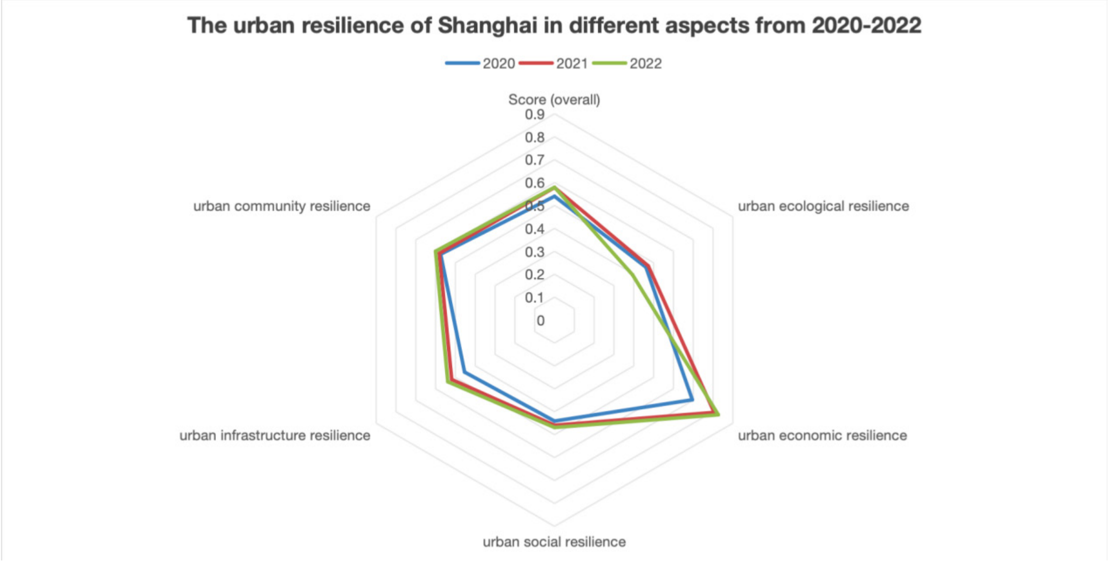
4. Results

4.1 Shanghai

Table 3 Shanghai's Urban Resilience Values in Different Aspects and Overall Value

City	Year	Score (overall)	urban ecological resilience	urban economic resilience	urban social resilience	urban infrastructure resilience	urban community resilience
Shanghai	2020	0.539976046	0.461323324	0.695653906	0.440598212	0.453860572	0.574730413
	2021	0.578260601	0.472867297	0.805738283	0.458887981	0.518719814	0.58167805
	2022	0.579477042	0.394130893	0.826395299	0.468583614	0.538402883	0.600392628

Table 4 The Urban Resilience of Shanghai in Different Aspects from 2020-2022



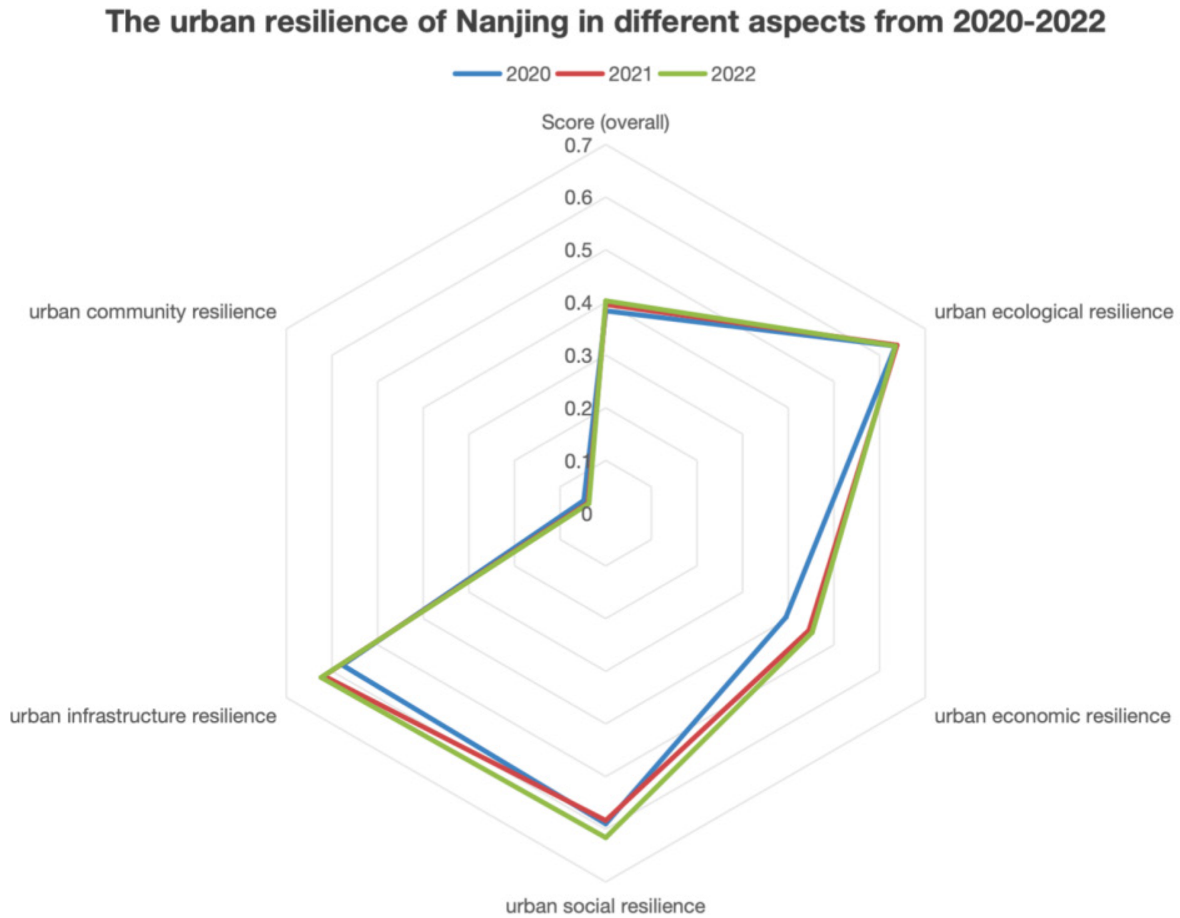
Shanghai displays a notable degree of economic resilience, whereas its ecological resilience is the lowest among the cities under consideration. Furthermore, it is the sole city to exhibit a decline in its ecological resilience over the three-year period.

4.2 Nanjing

Table 5 Nanjing's Urban Resilience Values in Different Aspects and Overall Values

City	Year	Score (overall)	urban ecological resilience	urban economic resilience	urban social resilience	urban infrastructure resilience	urban community resilience
Nanjing	2020	0.384127549	0.634645071	0.394848062	0.589826092	0.576934636	0.048086223
	2021	0.396241228	0.638221127	0.445100836	0.583483963	0.617936414	0.038769715
	2022	0.403166547	0.634924947	0.452481871	0.615937731	0.623758864	0.036921443

Table 6 The Urban Resilience of Nanjing in Different Aspects from 2020-2022



The community resilience of Nanjing is notably low, approaching zero, while its infrastructure and ecological resilience are both exceptionally high. The sole area in which resilience declined is that of social resilience.

4.3 Hefei

Table 7 Hefei's Urban Resilience Values in Different Aspects and Overall Values

City	Year	Score (overall)	urban ecological resilience	urban economic resilience	urban social resilience	urban infrastructure resilience	urban community resilience
Hefei	2020	0.385968921	0.72981687	0.138838549	0.32512097	0.279547585	0.43963796
	2021	0.407736848	0.790256695	0.198255937	0.345300586	0.307866194	0.41514724
	2022	0.398340462	0.867504957	0.177643977	0.366459413	0.261879231	0.365117265

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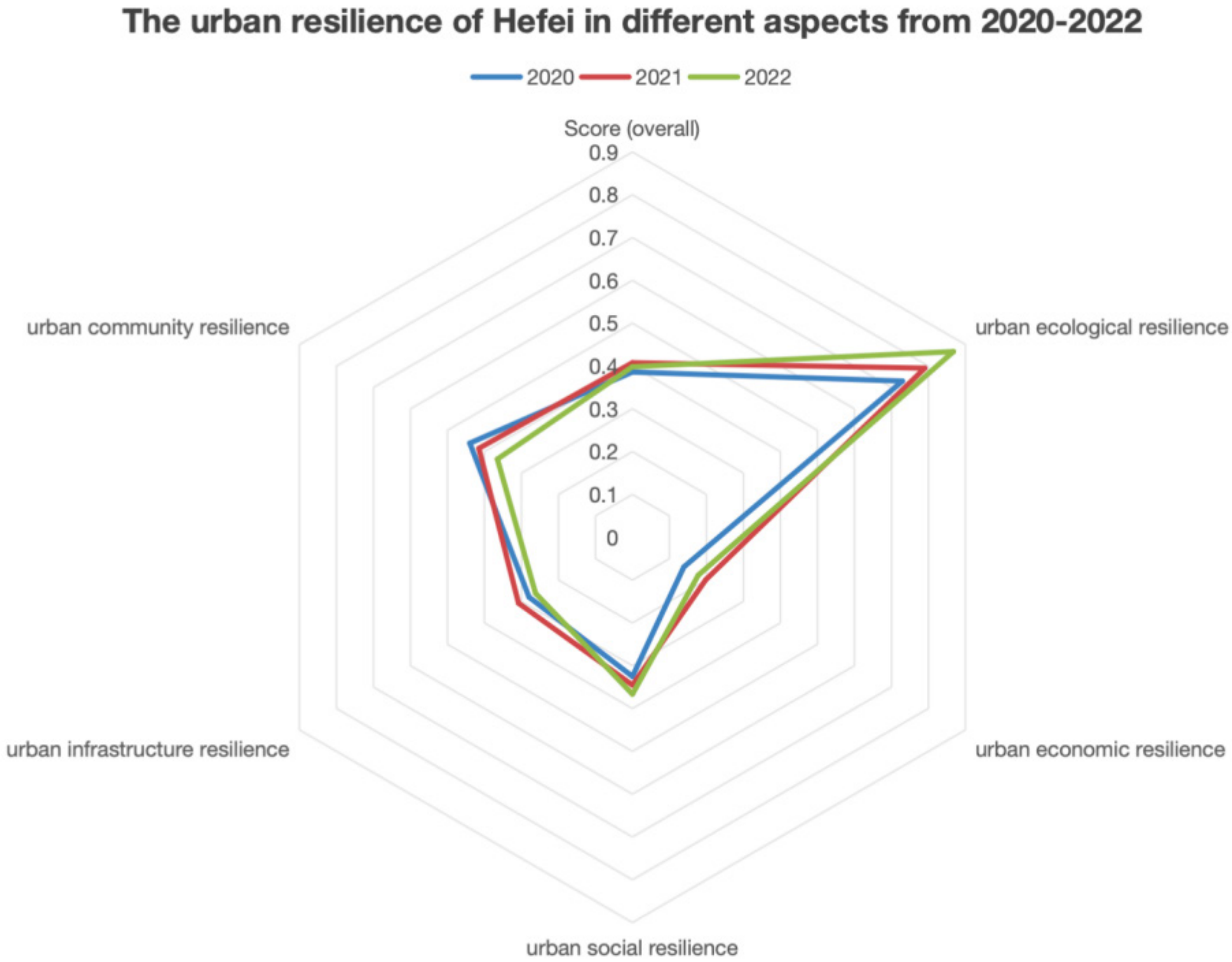
Table 8 The Urban Resilience of Hefei in Different Aspects from 2020-2022



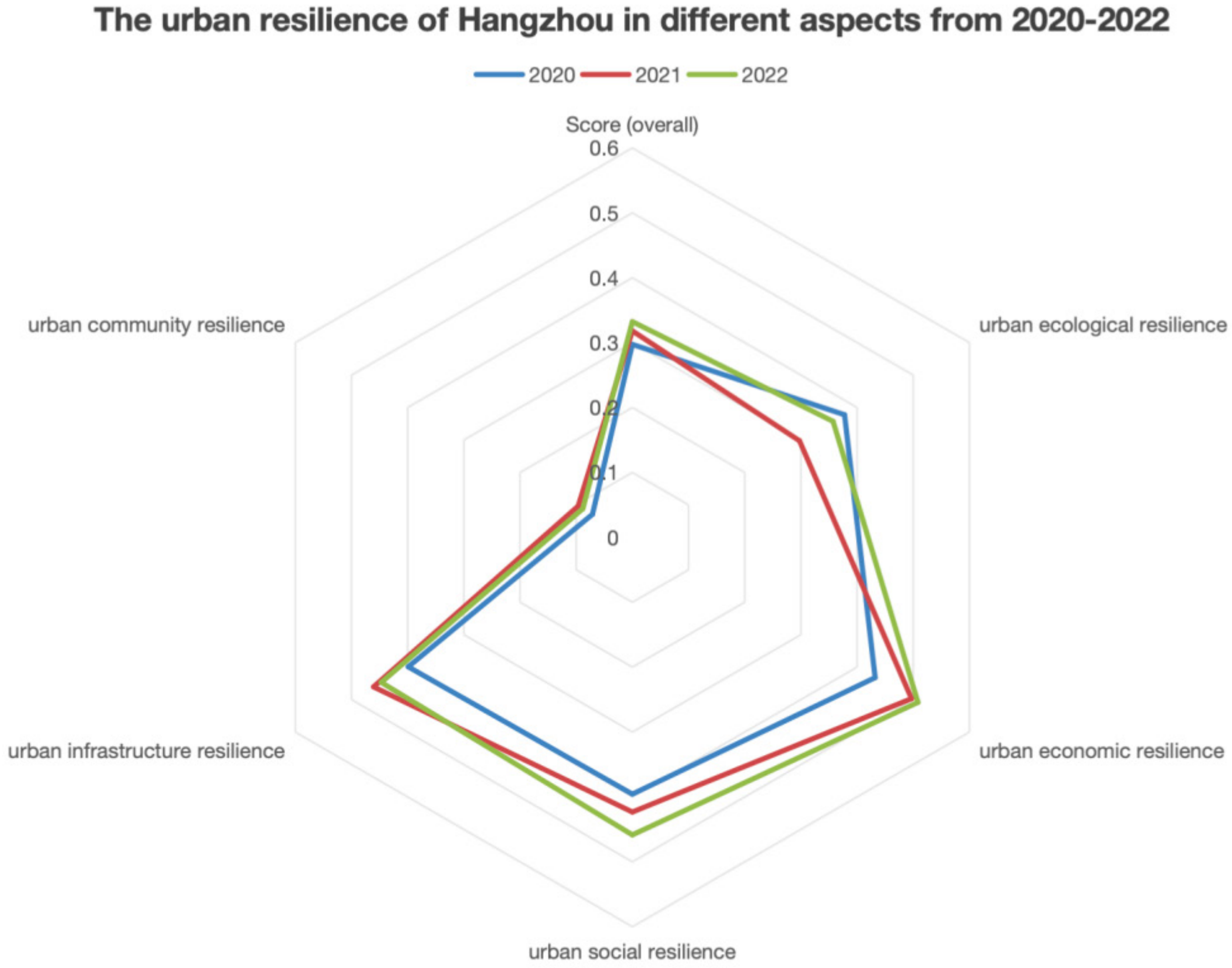
Hefei exhibits the highest ecological resilience among the five indicators, while its economic resilience is the lowest. Furthermore, it is notable that community resilience and infrastructure resilience are the only two indicators that have demonstrated a decline.

4.4 Hangzhou

Table 9 Hangzhou's Urban Resilience Values in Different Aspects and Overall Values

City	Year	Score (overall)	urban ecological resilience	urban economic resilience	urban social resilience	urban infrastructure resilience	urban community resilience
Hangzhou	2020	0.297288794	0.377697321	0.432194142	0.395658256	0.398958093	0.071039422
	2021	0.318108953	0.29750391	0.496976443	0.423241246	0.46075739	0.09646817
	2022	0.332326505	0.357312288	0.508394903	0.458435652	0.447000367	0.088232461

Table 10 The Urban Resilience of Hangzhou in Different Aspects from 2020-2022



The city of Hangzhou exhibits the highest indicator of economic resilience, while community resilience is the lowest. In general, the only indicator that shows a decline during this period is ecological resilience.

4.5 Contrast of resilience among the four cities

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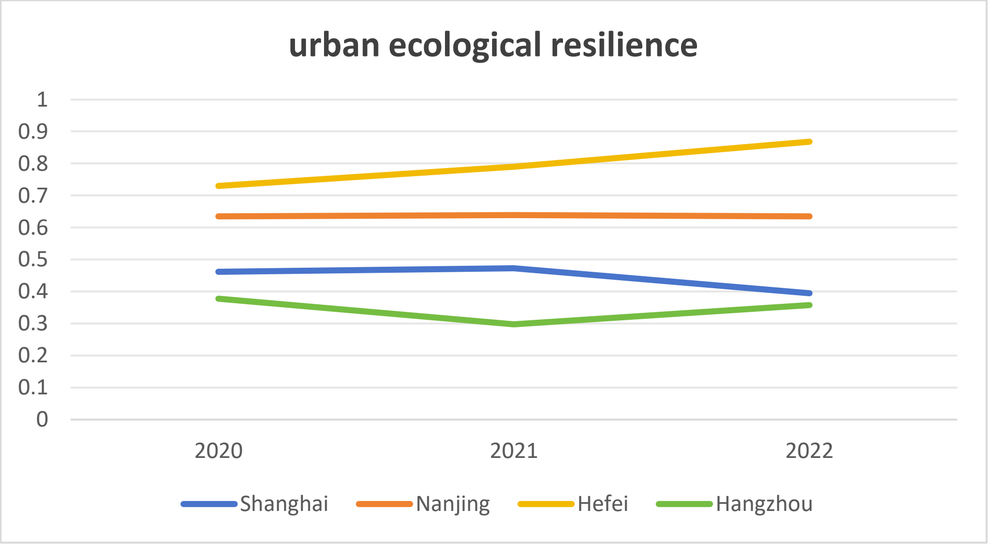
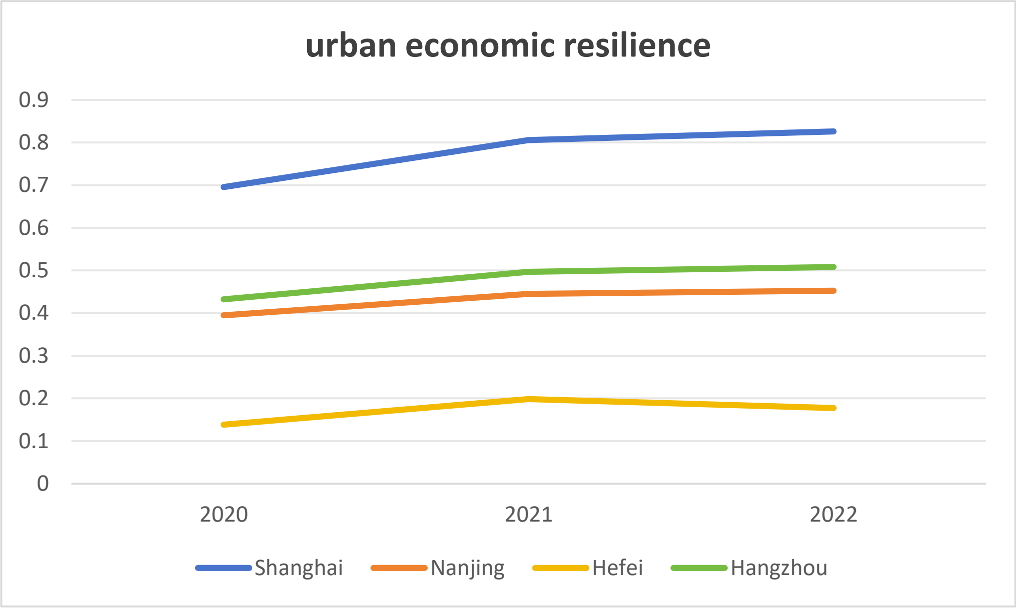
Table 11 The Urban Ecological Resilience Among 4 Cities From 2020-2022



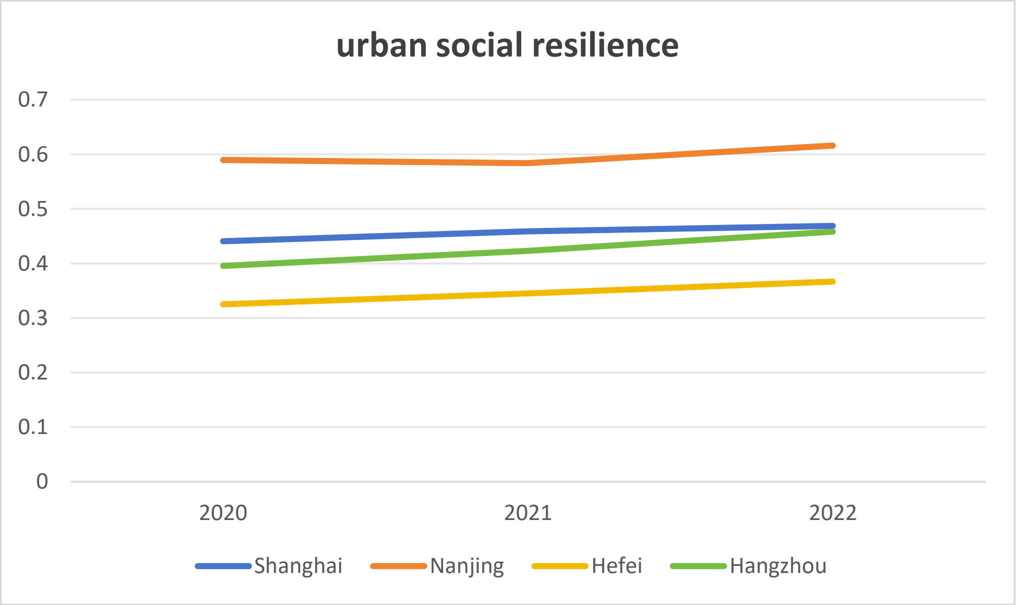
Among all the three years, Hefei's urban ecological resilience was always the highest, while Hangzhou's was always the lowest. The other notable point is that all of the resilience value of these cities was growing all the time except for Shanghai.

Table 12 The Urban Economic Resilience Among 4 Cities From 2020-2022



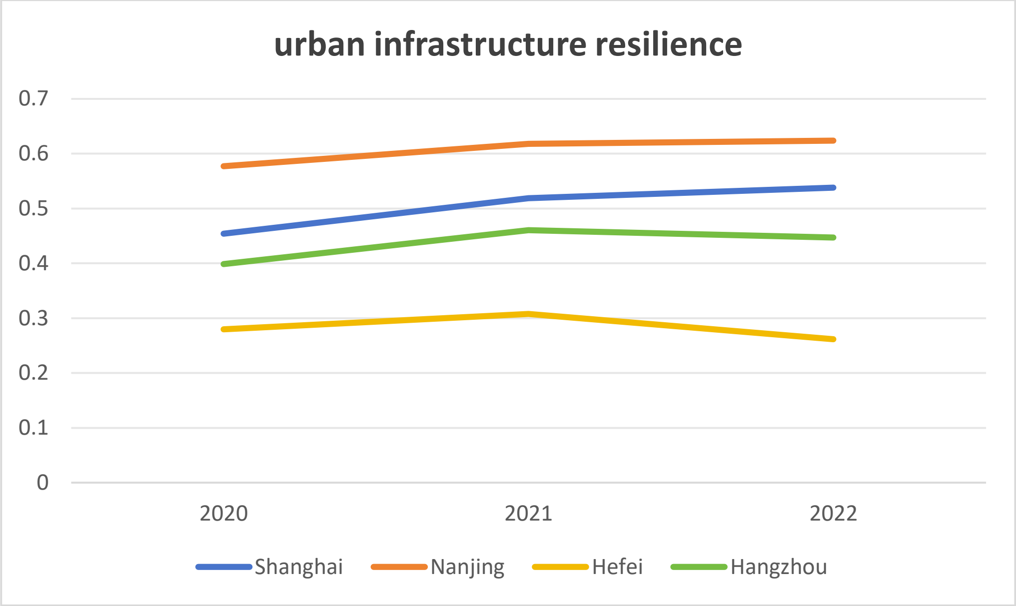
In the period spanning 2020 to 2022, Shanghai's urban economic resilience value was always the highest, with Hefei's be the lowest. Additionally, Nanjing's and Hangzhou's urban economic resilience value were very close all the time.

Table 13 The Urban Social Resilience Among 4 Cities From 2020-2022



From 2020 to 2022, the city of highest urban social resilience value was Nanjing, with Hefei be the city of lowest score. The gap between Hangzhou's and Shanghai's social resilience value was decreasing year by year, finally nearly the same in 2022. All the cities' value was increasing during the period.

Table 14 The Urban Infrastructure Resilience Among 4 Cities From 2020-2022



From 2020 to 2022, the city of highest urban infrastructure resilience value was Nanjing, and the city of lowest value was Hefei. Furthermore, only Hefei's infrastructure value showed an downward trend overall, with Hangzhou's value still keep a higher position compare with the value in 2020 after a reduction in 2022.

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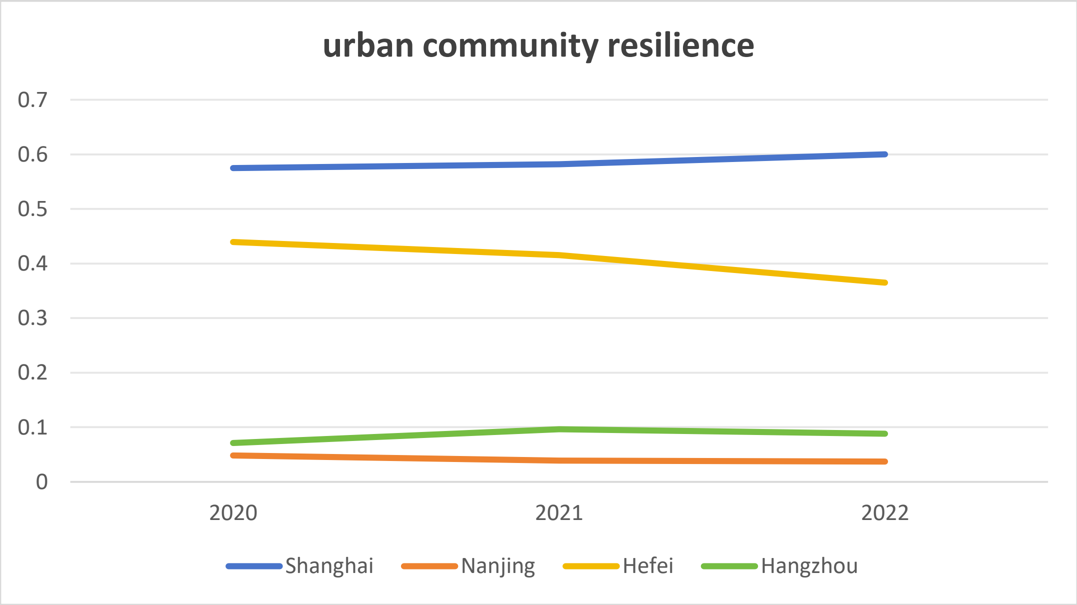
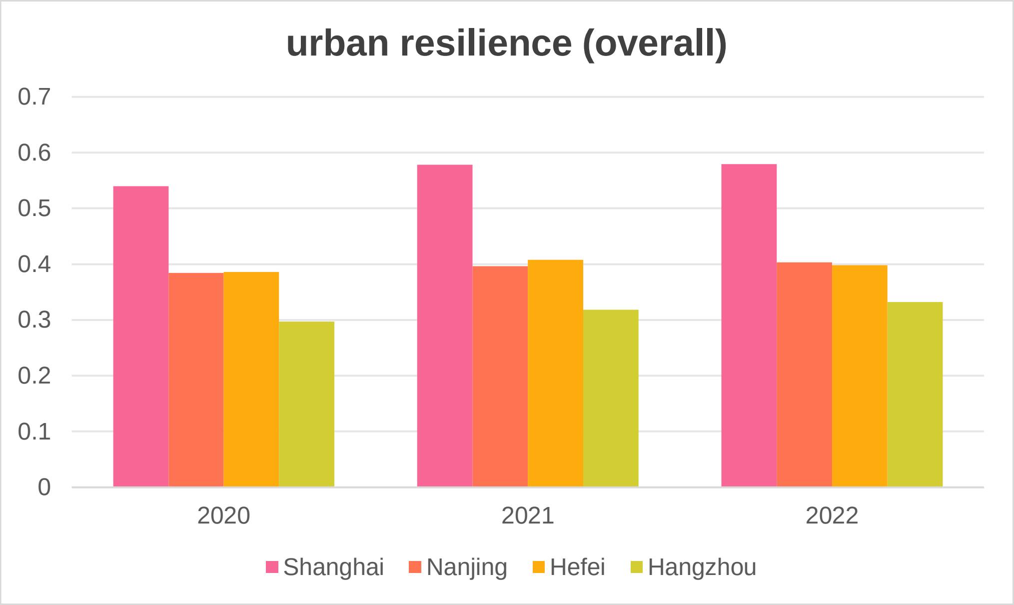
Table 15 The Urban Community Resilience Among 4 Cities From 2020-2022



From 2020-2022, the city of highest value of urban community resilience value was Shanghai. Additionally, Nanjing and Hangzhou's values were extremely low compare to the other two, with Nanjing's be the lowest.

4.6 Overall score

Table 16 The Overall Value of Urban Resilience in 4 Cities from 2020-2022



In terms of overall urban resilience value, Shanghai has consistently ranked as the highest-performing city for the past three years, while Hangzhou has consistently ranked as the lowest-performing city. The urban resilience values of Nanjing and Hefei have exhibited a high degree of proximity over the course of the three-year period under consideration. In both 2020 and 2021, Hefei exhibited a higher urban resilience value than Nanjing. However, in 2022, Nanjing surpassed it with a small gap.

5. Discussion

This study aims to calculate urban resilience values of four major cities in China's YRD region between 2020 and 2022. It identifies weaknesses in each city and suggests future development pathways. Shanghai has the highest overall resilience, while Hangzhou has the lowest. Resilience values are generally increasing in all cities, but Hefei has a decrease in 2021-2022. Hefei and Hangzhou have very low economic resilience, and the social resilience of all cities were increasing.

Firstly, Shanghai has the highest overall urban resilience value, which is attributed to its robust construction standards and expertise in enhancing urban resilience. The city has established and improved emergency response systems for epidemic prevention and control, including during the global pandemic. Shanghai has constructed sponge cities, enhanced urban risk warning and prevention systems, and implemented a comprehensive urban drainage system transformation strategy to alleviate urban waterlogging pressure. It also improved the emergency management system and enhanced new urban emergency management capabilities [22]. The Kearney Global Cities Index report indicates that the digital economy and advanced technologies have experienced accelerated development due to the pandemic [23]. Shanghai is the leading position in China in terms of data infrastructure, digital integration applications, and digital economy demand, underscoring its competitive edge [24].

However, Hangzhou's urban resilience value is relatively low due to a lack of public awareness, low levels of participation, and lack of legislation and regulations for resilient city construction. The implementation of policies is hindered by unclear implementation processes, inefficiencies in management, and inadequate urban infrastructure [25]. Hangzhou's urban infrastructure resilience declined significantly in 2022 according the above data, indicating that its infrastructure is inadequately constructed and unable to withstand the impact of the Omicron variant of the COVID-19. Additionally, Hangzhou's community resilience was extremely low, which can be the major factor for its low overall resilience score. The reason for this discrepancy is that Hangzhou's expenditure on urban and rural affairs is the lowest among the four cities, amounting to RMB 31.43 billion in 2022. In comparison, Shanghai, which has the highest expenditure, spent RMB 142.524 billion during the same period [26].

The second result is the overall urban resilience value was increased in all cities despite the downward trend in Hefei from 2021-2022. The urban resilience in YRD has seen a significant increase from 2010 to 2020, with an average annual growth rate of 4.23% [11]. Similarly, the results of the current research indicates that the growth rate for the four cities was 5.72% for 2020-2021 and 1.03% for 2021-2022, which aligns with past trends, but with a deceleration in growth rate. Zhang and Wang explained that the dual impact of the epidemic and stringent management strategy may have contributed to this result [27]. In 2019, China implemented the most stringent dynamic zero-clearance policy. In 2021, Shanghai implemented a relaxed approach to epidemic prevention, only imply strict regulation and closed-loop management for incoming personnel [28]. In 2022, a further outbreak of the epidemic led to more stringent measures, including full-area static management and nucleic acid screening for all residents [29]. The timing of policy adjustments in the current study is consistent across cities, which aligns with Zhang and Wang's study [27]. Hefei's urban resilience decline between 2021 and 2022 can be attributed to the city's late relaxation of control measures, which remained unrestored by the end of 2022. As a result, Hefei's actual use of foreign capital was US$1.21 billion in 2022, a 66% decrease from US$3.6 billion in 2020. Another indicator that has dropped significantly is road freight, which fell to 72.6% of last year's level in 2022 [30].

Thirdly, Hefei and Hangzhou have very low economic resilience all the time. Previous studies have indicated that the economic scale gap within the YRD region is narrowing; however, Anhui has not yet been fully integrated into the regional economic system. Anhui exhibits the poorest traffic accessibility, with the majority of its indicators lagging behind those of other provincial capitals. Concurrently, Anhui exhibits a lower degree of trade dependence than Shanghai and Zhejiang, and its market is relatively closed. As the capital of Anhui Province, Hefei has worse conditions and foundations for economic development in comparison to other cities [31]. Moreover, the negative impact of the epidemic on Hangzhou's economic resilience may be attributed primarily to the significant decline in the tourism industry. Tourism is a significant contributor to the economy of Hangzhou. In 2019, the tourism industry accounted for 36.71% of the province's total tourism revenue and 26.05% of the city's GDP [32]. Consequently, the revenue generated by the tourism industry in Hangzhou in 2020 was 333.54 billion and 138.92 billion in 2022, representing a final decrease of 41.65% [26].

Lastly, the data above demonstrate that social resilience increased in all cities. Social resilience examined in this study includes the number of college students on campus, the number of beds in health facilities, the gross floor area per capita, and the natural growth rate. Specifically, the outbreak did not result in a significant decline in student numbers in China, even a growth of 54600 in Nanjing, with the vast majority of schools opting for either online or offline teaching methods under controlled conditions [20]. Concurrently, the admission standards for Chinese universities have become less stringent, resulting in a sustained increase in the number of college students. The

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number of beds in health facilities has also risen in all four cities, for example, the 7.46% growth rate in Shanghai from 2020-2022, reflecting a significant investment in medical resources to address the COVID-19 [14]. The floor area per capitain all four cities has exhibited fluctuations but has not undergone significant change, indicating that the epidemic has had a negligible impact on this aspect. Despite a decline in the natural population growth rate, the impact on urban social resilience has not been as pronounced as the growth of other indicators.

Overall, urban social resilience has demonstrated an upward trajectory in response to the pandemic.

6. Recommendation

The above findings reveal that each city has demonstrated deficiencies in its capacity to withstand external disasters in the wake of the epidemic's impact. However, the extent and nature of this impact vary considerably across cities. In light of the aforementioned conclusions, recommendations for future construction in these cities can be formulated.

It is recommended that Shanghai should endeavour to maintain the current trajectory of development, whilst simultaneously ensuring environmental protection. In Singapore, environmental education is a component of the school curriculum. Schools provide students with an "ecological protection garden" wherein they may plant and observe the growth of plants of their own choosing. In addition, Singapore conducts an annual "Clean and Green Week," which is open to the general public. Furthermore, the government has established environmental education bases, including landfill sites and new water treatment facilities, and has mandated that schoolteachers, students, and the general public visit these locations to enhance environmental awareness [33]. As a city with a similar economic status to Singapore, Shanghai could emulate its environmental protection measures.

The future development of Nanjing should prioritise community-level construction. For instance, urban and rural affairs expenditures augmented, and the potential for policy implementation and the guarantee of basic living standards to be compromised in crises in the future mitigated. Furthermore, the number of neighbourhood committees could be increased. During COVID-19, neighborhood committees positively correlated with residents' perceived social cohesion and negatively with psychological stress. They serve as a bridge between residents and the municipal government, implementing social welfare policies [34]. In comparison, in 2022, the number of neighborhood committees in Nanjing was 909, while that in Shanghai was 4,849 [14, 20].

It is imperative that Hangzhou recovers expeditiously from the impact of the epidemic and enhances its urban resilience in a comprehensive manner. Among the most crucial aspects is the advancement of economic development. For details, we can refer to the construction of Silicon Valley in the United States. Silicon Valley has become a global centre for technology and entrepreneurship, with a strong technological innovation ecosystem, venture capital and support from university research centres. In fact, Hangzhou has already begun to attract overseas students, including living allowances of 10,000 yuan for undergraduates and 30,000 yuan for masters [35]. But these measures are not enough, and the appeal is not as great as other cities, such as Shanghai, which also offers more property purchase rights and reduces vehicle purchase taxes [36].

It is recommended that Hefei prioritizes economic development and community-level improvement. In addition to the solutions mentioned above that can be applied to Hefei, it can also try to build a smart community, including strengthening the public's scientific cognition, formulating systems, formulating smart platform standards, and improving governance performance [37]. Conversely, Hefei's decline in overall resilience during 2021-2022 indicates a need to enhance emergency preparedness and the efficacy and velocity of post-disaster recovery strategies. Hefei's government departments can review and analyze after the epidemic is over to identify wrong decisions and exposed weaknesses.

7. Evaluation

This study offers a number of significant advantages. Firstly, the concept of urban resilience is relatively novel, and this paper contributes to the existing body of knowledge in this field. Additionally, this study incorporates both spatial and temporal variables, spanning four cities across a three-year period, thereby enhancing the research's depth and breadth. The four cities are relatively developed urban centres situated within the YRD region of China. The period of investigation coincides with the peak of the global pandemic caused by the COVID-19 , allowing for a direct comparison of the findings and their potential for informing future policy. Furthermore, the indicator system employed in this study has been reorganised and designed with the objective of reflecting the various aspects of a city in the most comprehensive manner possible. In the course of data analysis, the data were interpreted from a variety of perspectives, and numerous comparisons and trends were identified, therefore, the suggestions given to each city is capable to solve their most pressing issues at this time.

It should be acknowledged that this study is not without shortcomings. The research scope of this study does not extend to 2023, which may limit the richness of the research results presented in this article. However, the data from the National Bureau of Statistics of China for 2023 have yet to be released, and subsequent research may seek to address this gap. Additionally, the time span of this research does not cover 2019 as a base year for comparison. That is because of the inconsistency of units in this year's statistical data, and the calculation will be inaccurate. Furthermore, due to the inconsistency in the definition and calculation methods of urban resilience, it is not possible to make a direct comparison between the resilience values calculated in this article and those calculated in other literature. This limits the extent to which previous research can be used when analysing the results.

8. Conclusion

This paper employs an indicator system to analyse the response of four Chinese cities during the period of COVID-19 with urban resilience value calculated for each city. The results indicates that Shanghai has the highest comprehensive resilience value, while Hangzhou has the lowest. Resilience values are generally increasing in all cities, while Hefei has a decrease in 2021-2022. Hefei and Hangzhou have very low economic resilience, and the social resilience of all cities were increasing. Furthermore, recommendations are put forth for future development. The concept of urban resilience is not yet fully developed, and therefore future research on this concept should be extended to encompass a larger geographical area and a longer time span, or to include other disasters. Ultimately, these cities will have greater resilience in the face of disasters, reduce economic losses and casualties, and promote social development.

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