Risk Management and Healthcare Policy

Dovepress
Taylor & Francis Group

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ORIGINAL RESEARCH

Equity and Efficiency of Medical Resource Allocation in National Central Cities, China

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Objective: To analyze the equity and efficiency of medical resource allocation in national central cities in China in order to promote the development of medical resources in national central cities.

Methods: Data on medical resources in 9 national central cities were extracted from 2018 to 2022, descriptive analysis, health resource density index (HRDI), and health resource agglomeration degree (HRAD) were used to evaluate equity, and data envelopment analysis (DEA) was used to evaluate efficiency.

Results: The HRDI of medical resources in national central cities is higher than the Chinese average from 2018 to 2022. The HRAD for the number of beds in Shanghai, Guangzhou, and Zhengzhou is greater than 14.40, and the HRAD for registered nurses, licensed (assistant) physicians, and health technicians in Shanghai, Guangzhou, and Beijing is greater than 15.80, indicating that the medical resources in these regions are highly concentrated by geographical allocation. The HRAD/PAD for licensed (assistant) physicians, registered nurses, and health technicians in Chongqing is less than 1, indicating that there is a shortage of medical resources in these regions relative to the agglomeration population. The technical efficiency, scale efficiency and overall efficiency in Shanghai, Guangzhou, and Chongqing are all 1, and the DEA is relatively effective. In Beijing in 2018–2020, Zhengzhou in 2020, and Chengdu in 2019–2021, the overall efficiency, scale efficiency, and technical efficiency are not 1, and the DEA is relatively ineffective.

Conclusion: The level of medical resource allocation in national central cities is higher than the Chinese average. The medical resources allocated in the national central cities are highly concentrated by geography. Licensed (assistant) physicians, registered nurses, and health technicians in Chongqing is insufficient relative to the agglomeration population. Except for Shanghai, Guangzhou and Chongqing, the other of the cities have a relatively inefficient allocation of medical resources.

Keywords: medical resources, equity, efficiency, national central cities, China

Introduction

The level of medical resource allocation reflects a city's economic strength and health development level, but more medical resource allocation is not always better. If medical resources are moderately concentrated in cities, it is conducive to guide medical resources to form a radiation effect (to enable medical resources to cover a wider area), and give play to the role of demonstration and leadership in the development of medical resources. If medical resources are over-concentrated in the cities, it will lead to an uneven distribution of medical resources, which is not conducive to the equity of medical resources and the use of services.[1] Equity and efficiency are the two basic principles that should be followed in the allocation of health resources, where equity requires that people enjoy equal access to health services and health rights and interests, and efficiency requires that limited health resources be able to maximize output, so that the principles of equity and efficiency should be taken into account in the allocation of health resources. The outline of the "Healthy China 2030" plan requires that the integration and promotion of regional medical resource sharing at the provincial level and above, basically realize the equalization of high-quality medical resource allocation, and at the same time plays the role of driving the regional development and the overall level of medical services.[2] National central cities are the highest level of urban system planning in China, and are the core cities of the urban system in China, which must play the role of power sources and growth poles in the development of medical services. National central cities should

Received: 13 December 2024
Accepted: 5 June 2025
Published: 11 June 2025

not only form a medical resource highland and lead the development of regional health care, but also promote the equity and efficiency of medical resources and meet the people's demand for medical services.[3] In order to identify the problems and the direction of the next development in the national central cities, this study analyzes the equity and efficiency of medical resource allocation in the national central cities, and puts forward targeted recommendations to improve medical resource allocation, so as to promote the role of national central cities as model leaders in medical resource development.

At present, studies on medical resource allocation in China are mainly divided into two aspects: equity and efficiency. In terms of the equity, it includes traditional Chinese medicine medical resources,[4] public medical and health resources, and other related studies,[5] covering the national level, provincial administrative level,[6] and some municipal levels. In terms of the efficiency, it includes the efficiency of medical services in county-level hospitals,[7] the efficiency of medical and health resource allocation in the three-tier healthcare system,[8] and other related studies, as well as some studies that combine the equity and efficiency of medical resource allocation together. In addition, medical resource allocation also includes studies on the structure, prediction, and influencing factors of resource allocation. Specifically on the studies of medical resource allocation in cities in China, it mainly includes the following three aspects. First, studies related to the urban-rural differences in the utilization of medical services, including studies on urban-rural differences in health care utilization among cancer patients,[9] urban-rural differences in public health service utilization among diabetic patients,[10] and urban-rural differences in healthy aging trajectories in China.[11] Second, studies related to the efficiency of urban medical and health services, including the efficiency of medical services in 13 cities in Jiangsu Province,[12] medical service utilization of lung cancer in urban China.[13] Third, studies related to the medical resource allocation in individual cities, including the evaluation of medical resources in Beijing,[14] the evaluation of the spatial accessibility and equity evaluation of medical facilities in Xi'an.[15] The existing relevant studies have better insights into the evaluation of equity and efficiency of medical resource allocation, but focusing on the national central cities, the existing studies of individual city data is relatively outdated, the overall analysis of the national central city is limited focus, and there is a need to further analyze the equity and efficiency of medical resource allocation, in order to identify the direction of the development in the national central cities, and to better play the role of demonstrating and leading the development of medical resources.

As the urban population continues to grow, people's awareness of health care is gradually increasing, and their demand for medical resources is growing. With the aging of the population, the disease spectrum is gradually changing to one dominated by chronic non-communicable diseases, which places new demands on urban medical services. Therefore, in order to identify the problems of medical resource allocation in national central cities and to promote the national central cities to better play the leading role of medical resources, this study extracted the medical resource data of 9 national central cities, and conducted descriptive analysis, health resource density index (HRDI) and health resource agglomeration degree (HRAD) were used to evaluate the equity, and data envelopment analysis (DEA) was used to evaluate the efficiency, so as to promote the development of medical resources in national central cities.

Methods

Data Sources and Statistical Analysis

Data on medical resources in the 9 national central cities were taken from the China Health Statistics Yearbook from 2018 to 2022, and some of the data were supplemented by the city statistical yearbooks published by the statistical bureau of each city. In case of inconsistency of data in the statistical yearbooks of different years, the data published in the most recent year shall prevail.

Region Division

National central cities are the highest level of urban system planning in China, and play an important role in economic, political, cultural and social fields. In February 2010, the Ministry of Housing and Urban-Rural Development issued the National Township System Planning (2010–2020), which clearly proposed the construction of 5 national central cities in Beijing, Tianjin, Shanghai, Guangzhou, and Chongqing. From May 2016 to February 2018, the National Development

and Reform Commission and the Ministry of Housing and Urban-Rural Development successively supported the construction of Chengdu, Wuhan, Zhengzhou, Xi'an to build national central cities.

Indicators

Healthcare institutions, health technicians, the number of beds, licensed (assistant) physicians and registered nurses were selected as the equity evaluation indicators in this study. The number of beds, registered nurses and health technicians were selected as efficiency input indicators, and hospital admissions and the number of consultations were selected as efficiency output indicators.[16]

Research methods

Descriptive analysis, HRDI and HRAD were used to evaluate the equity, and DEA was used to evaluate the efficiency of medical resource allocation in national central cities.

Health Resources Density Index (HRDI)

The HRDI is the geometric mean of the product of health resources per 1,000 population and health resources per square kilometer.[17] The HRDI reflects the combined level of health resource distribution by population and geography, with larger values indicating better health resource allocation.[18] The formula is:

$$\mathrm{HRDI} = \sqrt{\frac{\text{Medical resources}}{\text{Per1,000population}} \times \frac{\text{Medical resources}}{\text{Per square kilometer}}}$$

Health Resource Agglomeration Degree (HRAD)

The HRAD is a reflection of the extent to which health resources are concentrated in an area relative to the wider region, and is usually used in combination with the population agglomeration degree (PAD) to objectively reflect the balance in the geographic and population distribution of the health resource allocation.[19] A HRAD less than 1 indicates that health resources are under-allocated by geography; a HRAD/PAD greater than 1 indicates an over-allocation of health resources relative to the agglomerated population.[20] The formula is:

$$\mathrm{HRAD_i} = \frac{\left(\frac{\mathrm{HR_i}}{\mathrm{HR_n}}\right) \times 100\%}{\left(\frac{\mathrm{A_i}}{\mathrm{A_n}}\right) \times 100\%}$$

Where HRi is the medical resources of region i, HRn is the medical resources of the whole region, Ai is the land area of region i, and An is the land area of the whole region. PAD is calculated by replacing medical resources with population.

Data Envelopment Analysis (DEA)

The DEA is a non-parametric approach to efficiency assessment, DEA does not require specific modeling, is independent of parameter choices, is superior in dealing with multi-input and multi-output problems, and is widely used in the field of resource allocation.[21] The DEA-BCC model assumes variable returns to scale and decomposes the overall efficiency into the product of technical efficiency and scale efficiency, with an overall efficiency value of 1 being relatively efficient for DEA.[22] Technical efficiency is a technically induced change in efficiency, with an efficiency value of 1 indicating that output is maximized with the available inputs. Scale efficiency is the change in efficiency due to changes in scale, with an efficiency value of 1 indicating that the same proportion of inputs produces the same proportion of outputs. In order to promote the efficiency of medical resource allocation to a relatively efficient state, for regions where DEA is ineffective, the input redundancy analysis and output deficiency analysis can be used to calculate the slack variables that need to reduce inputs or increase outputs. Input redundancy analysis is mainly used to analyze how much inputs need to be reduced for each variable to achieve the target efficiency, and output deficiency analysis is mainly used to analyze how much outputs need to be increased for each variable to achieve the target efficiency. The formula is:

$$\begin{cases} \min\theta \\ \sum_{j=1}^{n} X_{fj}\lambda_j + S^- = \theta X_{fj} \\ \sum_{j=1}^{n} X_{gj}\lambda_j + S^+ = \theta X_{gj} \\ \sum_{j=1}^{n} \lambda_j = 1 \\ \lambda_j \geq 0 \\ S^- \geq 0, S^+ \geq 0 \end{cases}$$

Where θ is the DMU efficiency value, $\theta \in (0, 1)$; λ_j is the weight of DMU_j; and S^+ and S^- are the input and output slack variables, respectively.

Results

Basic Situation of Medical Resources in National Central Cities

Healthcare institutions, health technicians, licensed (assistant) physicians, registered nurses, and beds per 1,000 population in central cities increased from 0.45, 8.82, 3.24, 4.00, and 6.43 in 2018 to 0.50, 10.19, 3.81, 4.66, and 6.97 in 2022, respectively. Health technicians, beds, licensed (assistant) physicians, and registered nurses per 1,000 population, excluding healthcare institutions, are higher than the Chinese average during 2018–2022. Healthcare institutions, licensed (assistant) physicians, registered nurses, beds, and health technicians per square kilometer in central cities in China increased from 0.45, 3.24, 4.00, 6.42, and 8.81 in 2018 to 0.52, 3.97, 4.85, 7.26, and 10.61 in 2022, respectively. The medical resources per square kilometer in central cities are higher than the Chinese average during 2018–2022 (Table 1).

Medical Resources per 1,000 Population in 9 National Central Cities in 2022

In 2022, the best allocation of the number of beds per 1,000 population is Zhengzhou (8.86), and the best allocation of licensed (assistant) physicians, health technicians, and registered nurses per 1,000 population is Beijing, with 5.72, 14.75, and 6.53 respectively. The worst allocation of the number of beds and registered nurses per 1,000 population is Tianjin, with 5.03 and 3.54 respectively, and the worst allocation of licensed (assistant) physicians and health technicians per 1,000 population is Chongqing, with 2.94 and 7.88 respectively (Figure 1).

Medical Resources per Square Kilometer in 9 National Central Cities in 2022

In 2022, the best allocation of healthcare institutions, licensed (assistant) physicians, registered nurses, the number of beds and health technicians per square kilometer is Shanghai, with 1.01, 13.57, 16.78, 27.38, and 37.21, respectively. The worst allocation of the number of beds, health technicians, healthcare institutions, licensed (assistant) physicians, and registered nurses per square kilometer is Chongqing, with 3.04, 3.07, 0.27, 1.15, and 1.42, respectively (Figure 2).

Table 1 Basic Situation of Medical Resources in National Central Cities

Year	Regions	Per 1,000 Population					Per Square kilometer				
		Healthcare Institutions	The Number of Beds	Health Technicians	Licensed (assistant) Physicians	Registered Nurses	Healthcare Institutions	The Number of Beds	Health Technicians	Licensed (assistant) physicians	Registered nurses
2018	National central cities	0.45	6.43	8.82	3.24	4.00	0.45	6.42	8.81	3.24	4.00
	The average in China	0.71	5.98	6.78	2.57	2.92	0.10	0.88	1.00	0.38	0.43
2019	National central cities	0.49	6.74	9.47	3.52	4.33	0.48	6.66	9.36	3.48	4.28
	The average in China	0.71	6.25	7.20	2.74	3.15	0.11	0.93	1.07	0.41	0.47
2020	National central cities	0.48	6.58	9.51	3.56	4.35	0.49	6.79	9.82	3.67	4.49
	The average in China	0.72	6.44	7.56	2.89	3.33	0.11	0.96	1.12	0.43	0.50
2021	National central cities	0.49	6.76	9.99	3.74	4.58	0.51	7.04	10.40	3.90	4.77
	The average in China	0.73	6.69	7.96	3.04	3.55	0.11	0.99	1.18	0.45	0.53
2022	National central cities	0.50	6.97	10.19	3.81	4.66	0.52	7.26	10.61	3.97	4.85
	The average in China	0.73	6.91	8.26	3.14	3.70	0.11	1.03	1.23	0.47	0.55

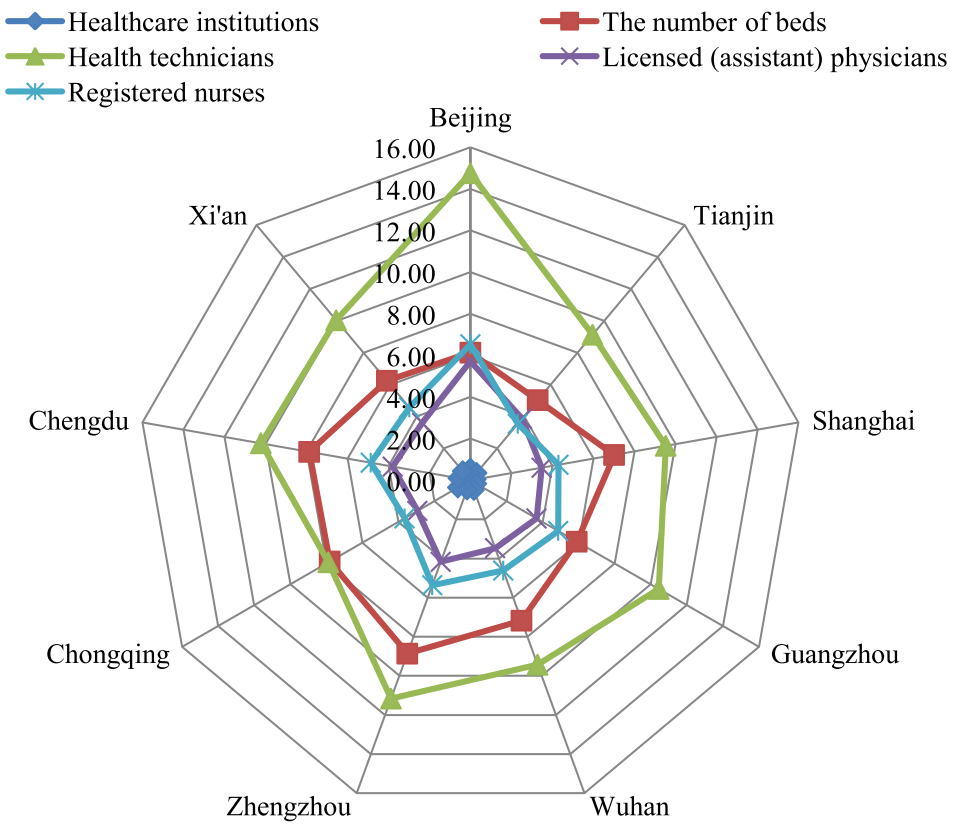

Figure 1 Medical resources per 1,000 population in 9 national central cities in 2022.

HRDI of Medical Resources in National Central Cities

The HRDI of medical resources in the 9 national central cities is larger than the average in China during 2018–2022. The HRDI of Shanghai, Beijing and Guangzhou is relatively large, and the HRDI of Chongqing and Xi'an is relatively small, indicating that medical resources are relatively well allocated in regions such as Shanghai, Beijing, and Guangzhou, and relatively poorly allocated in regions such as Chongqing and Xi'an (Table 2).

HRAD of Medical Resources in National Central Cities

The HRAD of healthcare institutions in Shanghai and Chengdu is greater than 7.10, the HRAD of the number of beds in Shanghai, Guangzhou and Zhengzhou is greater than 14.40, and the HRAD of health technicians, registered nurses and licensed (assistant) physicians in Shanghai, Guangzhou and Beijing is greater than 15.80, indicating that medical resources are highly concentrated by geographic allocation in these regions. The HRAD of Chongqing is less than 3.10, indicating that medical resources in Chongqing are less concentrated by geographical allocation compared with other national central cities.

The HRAD/PAD of healthcare institutions in 9 national central cities is less than 1, the HRAD/PAD of the number of beds in Beijing, Tianjin, Guangzhou and Xi'an is less than 1, the HRAD/PAD of licensed (assistant) physicians, registered nurses and health technicians in Chongqing is less than 1, indicating that there is a shortage of medical resources relative to the agglomeration population in these regions (Table 3).

Efficiency Values of Medical Resource Allocation in National Central Cities

The scale efficiency, technical efficiency, and overall efficiency of Shanghai, Guangzhou and Chongqing in 2018–2022 are all 1, and the DEA is relatively efficient. The overall efficiency, technical efficiency, and scale efficiency of Beijing

https://doi.org/10.2147/RMHP.S510508

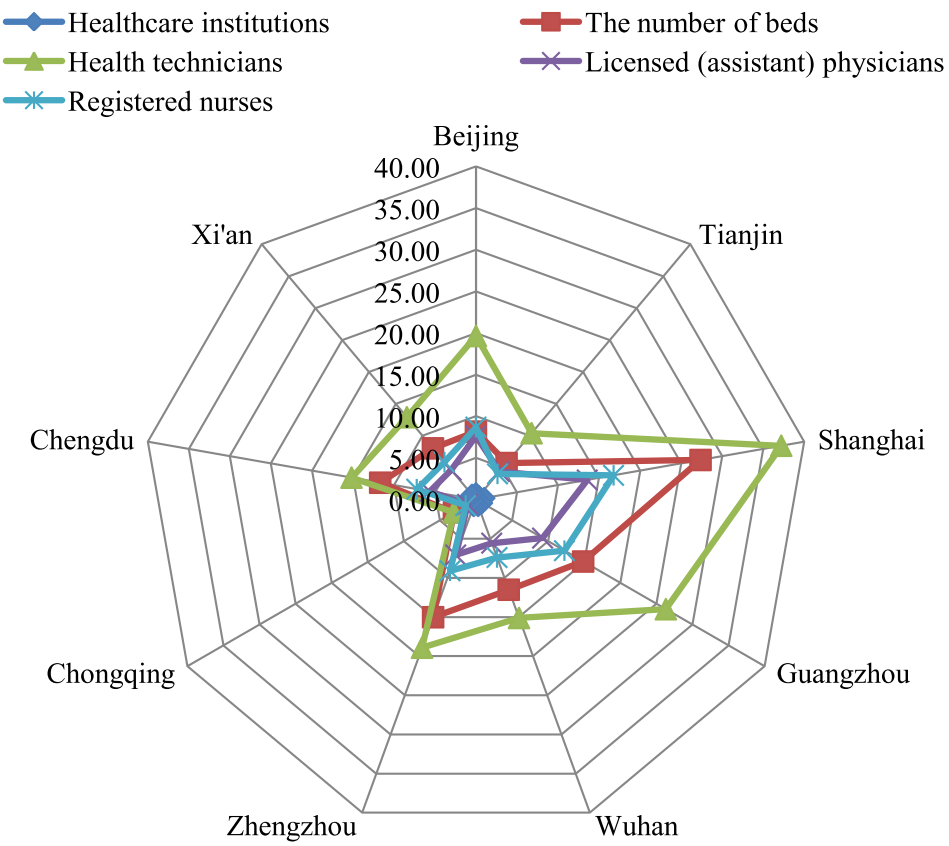

Figure 2 Medical resources per square kilometer in 9 national central cities in 2022.

and Chengdu are not 1 in some years, and the DEA is relatively inefficient, indicating the coexistence of input redundancy. The scale efficiency and the overall efficiency of Tianjin, Wuhan, and Zhengzhou are not 1 in some years, and the DEA is relatively inefficient, indicating that there are problems of poorly scaled allocation of health resources and underutilization of services (Table 4).

Table 2 HRDI of Medical Resources in National Central Cities

Year	Medical resources	Beijing	Tianjin	Shanghai	Guangzhou	Wuhan	Zhengzhou	Chongqing	Chengdu	Xi'an	China
2018	Healthcare institutions	0.59	0.44	0.42	0.40	0.48	0.50	0.40	0.64	0.60	0.27
	The number of beds	6.51	5.31	11.75	8.23	9.78	10.29	4.31	8.50	6.29	2.30
	Health technicians	14.85	8.12	16.48	13.54	11.25	12.25	4.10	10.01	9.25	2.61
	Licensed (assistant) physicians	5.77	3.34	5.98	4.68	4.06	4.40	1.50	3.65	3.08	0.99
	Registered nurses	6.52	3.06	7.46	6.20	5.59	5.99	1.86	4.65	4.23	1.12
2019	Healthcare institutions	0.60	0.46	0.45	0.44	0.66	0.52	0.41	0.79	0.63	0.28
	The number of beds	6.70	5.30	12.33	8.58	9.83	10.39	4.52	9.66	6.49	2.41
	Health technicians	15.68	8.53	17.01	14.40	11.65	12.53	4.38	12.00	10.05	2.77
	Licensed (assistant) physicians	6.11	3.61	6.20	5.03	4.22	4.61	1.63	4.45	3.44	1.06
	Registered nurses	6.93	3.22	7.74	6.67	5.80	6.13	2.01	5.70	4.64	1.21
2020	Healthcare institutions	0.59	0.45	0.47	0.47	0.62	0.64	0.41	0.69	0.62	0.28
	The number of beds	6.71	5.31	12.86	8.61	9.09	10.73	4.58	8.87	6.55	2.48
	Health technicians	16.02	8.85	18.02	15.07	11.16	13.66	4.62	11.27	10.28	2.91
	Licensed (assistant) physicians	6.25	3.82	6.55	5.28	4.06	5.18	1.73	4.18	3.56	1.12
	Registered nurses	7.10	3.32	8.20	6.99	5.55	6.62	2.13	5.37	4.75	1.29

(*Continued*)

Table 2 (Continued).

Year	Medical resources	Beijing	Tianjin	Shanghai	Guangzhou	Wuhan	Zhengzhou	Chongqing	Chengdu	Xi'an	China
2021	Healthcare institutions	0.62	0.47	0.50	0.49	0.61	0.64	0.42	0.72	0.62	0.28
	The number of beds	6.87	5.36	13.41	9.01	9.03	11.17	4.68	9.23	6.96	2.58
	Health technicians	16.76	9.50	19.07	15.87	11.79	14.31	4.79	12.19	10.81	3.07
	Licensed (assistant) physicians	6.52	4.04	6.93	5.60	4.35	5.38	1.79	4.59	3.79	1.17
	Registered nurses	7.48	3.65	8.65	7.44	5.80	6.86	2.22	5.78	5.00	1.37
2022	Healthcare institutions	0.64	0.49	0.51	0.52	0.63	0.62	0.43	0.71	0.65	0.28
	The number of beds	7.07	5.37	13.86	9.36	9.09	11.54	4.87	9.58	7.08	2.66
	Health technicians	17.02	9.74	18.83	16.58	11.94	14.53	4.92	12.45	11.38	3.18
	Licensed (assistant) physicians	6.60	4.11	6.87	5.82	4.39	5.43	1.84	4.62	4.08	1.21
	Registered nurses	7.54	3.78	8.49	7.73	5.84	6.98	2.28	5.92	5.18	1.43

Table 3 HRAD of Medical Resources in National Central Cities

Year	Regions	HRAD					HRAD/PAD				
		Healthcare Institutions	The Number of Beds	Health Technicians	Licensed (assistant) Physicians	Registered Nurses	Healthcare Institutions	The Number of Beds	Health Technicians	Licensed (assistant) physicians	Registered nurses
2018	Beijing	6.45	8.51	17.12	17.57	17.47	0.71	0.94	1.90	1.94	1.93
	Tianjin	4.53	6.45	8.71	9.48	7.63	0.58	0.83	1.11	1.21	0.98
	Shanghai	7.96	26.27	32.49	31.15	34.20	0.30	0.99	1.23	1.18	1.29
	Guangzhou	5.89	14.48	21.00	19.19	22.38	0.36	0.88	1.28	1.17	1.37
	Wuhan	5.16	12.58	12.76	12.17	14.73	0.59	1.44	1.46	1.39	1.68
	Zhengzhou	6.01	14.69	15.43	14.65	17.52	0.56	1.36	1.43	1.36	1.63
	Chongqing	2.37	3.02	2.53	2.44	2.68	0.91	1.16	0.98	0.94	1.03
	Chengdu	7.15	11.30	11.74	11.32	12.69	0.76	1.21	1.26	1.21	1.36
	Xi'an	6.26	7.72	10.02	8.81	10.66	0.79	0.97	1.26	1.10	1.34
2019	Beijing	6.52	8.36	16.96	17.34	17.11	0.72	0.93	1.88	1.93	1.90
	Tianjin	4.70	6.16	8.59	9.54	7.40	0.60	0.79	1.10	1.22	0.95
	Shanghai	8.35	26.33	31.50	30.14	32.74	0.32	1.00	1.19	1.14	1.24
	Guangzhou	6.46	14.53	21.16	19.40	22.39	0.39	0.88	1.27	1.17	1.35
	Wuhan	7.15	12.14	12.48	11.86	14.18	0.81	1.38	1.41	1.34	1.61
	Zhengzhou	6.23	14.34	14.99	14.49	16.75	0.57	1.30	1.36	1.32	1.52
	Chongqing	2.41	3.04	2.55	2.49	2.68	0.92	1.16	0.98	0.95	1.03
	Chengdu	7.98	11.22	12.08	11.75	13.10	1.02	1.44	1.55	1.51	1.68
	Xi'an	6.54	7.75	10.40	9.36	10.98	0.79	0.94	1.26	1.14	1.33
2020	Beijing	6.35	8.09	16.48	16.81	16.57	0.71	0.90	1.83	1.87	1.84
	Tianjin	4.53	5.97	8.48	9.57	7.21	0.58	0.77	1.09	1.23	0.92
	Shanghai	8.66	26.61	31.79	30.20	32.81	0.33	1.01	1.20	1.14	1.24
	Guangzhou	6.94	14.28	21.30	19.51	22.40	0.41	0.84	1.25	1.15	1.32
	Wuhan	6.99	11.44	11.97	11.37	13.50	0.71	1.17	1.22	1.16	1.38
	Zhengzhou	7.68	14.48	15.71	15.58	17.25	0.68	1.29	1.40	1.39	1.54
	Chongqing	2.36	2.99	2.57	2.51	2.68	0.90	1.14	0.98	0.96	1.02
	Chengdu	7.75	11.20	12.13	11.75	13.09	0.79	1.14	1.23	1.19	1.33
	Xi'an	6.55	7.75	10.36	9.37	10.85	0.76	0.90	1.20	1.09	1.26
2021	Beijing	6.59	7.99	16.37	16.69	16.35	0.73	0.89	1.82	1.86	1.82
	Tianjin	4.68	5.77	8.60	9.59	7.41	0.61	0.75	1.11	1.24	0.96
	Shanghai	9.19	26.73	31.95	30.43	32.46	0.35	1.01	1.21	1.15	1.23
	Guangzhou	7.21	14.41	21.35	19.75	22.42	0.42	0.85	1.25	1.16	1.32
	Wuhan	7.09	11.47	12.58	12.17	13.87	0.66	1.07	1.17	1.14	1.29
	Zhengzhou	7.64	14.58	15.70	15.47	16.86	0.67	1.29	1.39	1.36	1.49
	Chongqing	2.39	2.94	2.53	2.48	2.62	0.91	1.12	0.96	0.94	1.00
	Chengdu	8.04	11.29	12.53	12.37	13.31	0.81	1.13	1.26	1.24	1.34
	Xi'an	6.50	7.90	10.31	9.50	10.68	0.76	0.92	1.20	1.11	1.25

(*Continued*)

https://doi.org/10.2147/RMHP.S510508

Table 3 (Continued).

Year	Regions	HRAD					HRAD/PAD				
		Healthcare Institutions	The Number of Beds	Health Technicians	Licensed (assistant) Physicians	Registered Nurses	Healthcare Institutions	The Number of Beds	Health Technicians	Licensed (assistant) physicians	Registered nurses
2022	Beijing	6.85	7.96	16.01	16.32	15.83	0.76	0.89	1.79	1.82	1.77
	Tianjin	4.83	5.58	8.48	9.41	7.34	0.63	0.73	1.11	1.23	0.96
	Shanghai	9.32	26.70	30.35	29.09	30.53	0.35	1.02	1.15	1.11	1.16
	Guangzhou	7.62	14.49	21.47	19.81	22.32	0.45	0.85	1.26	1.17	1.32
	Wuhan	7.32	11.22	12.33	11.92	13.46	0.68	1.04	1.14	1.10	1.25
	Zhengzhou	7.38	14.65	15.43	15.16	16.55	0.65	1.28	1.35	1.33	1.45
	Chongqing	2.49	2.97	2.51	2.46	2.59	0.95	1.13	0.95	0.94	0.99
	Chengdu	7.97	11.38	12.37	12.05	13.13	0.80	1.14	1.24	1.21	1.31
	Xi'an	6.75	7.83	10.52	9.91	10.69	0.78	0.90	1.22	1.15	1.23

Table 4 Efficiency Values of Medical Resource Allocation in National Central Cities

Year	Efficiency	Beijing	Tianjin	Shanghai	Guangzhou	Wuhan	Zhengzhou	Chongqing	Chengdu	Xi'an
2018	Overall efficiency	0.85	1.00	1.00	1.00	0.93	1.00	1.00	0.95	0.97
	Technical efficiency	0.87	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.00
	Scale efficiency	0.98	1.00	1.00	1.00	0.93	1.00	1.00	1.00	0.97
2019	Overall efficiency	0.87	1.00	1.00	1.00	0.96	1.00	1.00	0.94	0.95
	Technical efficiency	0.90	1.00	1.00	1.00	1.00	1.00	1.00	0.97	1.00
	Scale efficiency	0.97	1.00	1.00	1.00	0.96	1.00	1.00	0.97	0.95
2020	Overall efficiency	0.74	0.99	1.00	1.00	0.75	0.72	1.00	0.97	0.97
	Technical efficiency	0.75	1.00	1.00	1.00	1.00	0.90	1.00	0.98	1.00
	Scale efficiency	0.98	0.99	1.00	1.00	0.75	0.80	1.00	0.99	0.97
2021	Overall efficiency	1.00	0.97	1.00	1.00	0.91	1.00	1.00	0.93	0.90
	Technical efficiency	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.00
	Scale efficiency	1.00	0.97	1.00	1.00	0.91	1.00	1.00	0.98	0.90
2022	Overall efficiency	1.00	1.00	1.00	1.00	0.96	0.98	1.00	1.00	1.00
	Technical efficiency	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Scale efficiency	1.00	1.00	1.00	1.00	0.96	0.98	1.00	1.00	1.00

Non-DEA Effective Input-Output Optimization of Medical Resources in the National Central Cities

A decision unit projection analysis of input redundancies and output deficiencies for non-DEA effective national central cities was conducted to find out the amount of adjustments needed in inputs and outputs. To promote the efficiency of medical resource allocation to reach a relatively strong effective state, taking Tianjin in 2020 as an example, the number of beds needs to be reduced by 1,411.94, and the number of health technicians needs to be reduced by 19,932.92, while the number of admissions can be increased by 245,700 (Table 5).

Table 5 Non-DEA Effective Input-Output Optimization of Medical Resources in the National Central Cities

Year	Regions	Amount of Inputs that can be Reduced			Amount of Output that can be Added	
		Number of Beds (beds)	Health Technicians (persons)	Registered Nurses (persons)	Number of Consultations (10,000)	Number of Hospital Admissions (10,000)
2018	Beijing	0.00	70,469.44	27,300.00	0.00	0.00
	Chengdu	0.00	1720.50	0.00	0.00	0.00
	Wuhan	0.00	0.00	1429.34	0.00	0.00
	Xi'an	0.00	16,420.53	5244.60	0.00	0.00

(*Continued*)

Table 5 (Continued).

Year	Regions	Amount of Inputs that can be Reduced			Amount of Output that can be Added	
		Number of Beds (beds)	Health Technicians (persons)	Registered Nurses (persons)	Number of Consultations (10,000)	Number of Hospital Admissions (10,000)
2019	Beijing	0.00	78,710.73	30,559.08	0.00	0.00
	Chengdu	0.00	363.15	0.00	0.00	0.00
	Wuhan	0.00	0.00	1855.36	0.00	0.00
	Xi'an	0.00	18,250.26	6551.82	0.00	0.00
2020	Beijing	0.00	62,856.04	24,672.47	0.00	0.00
	Tianjin	1411.94	19,932.92	0.00	0.00	24.57
	Chengdu	0.00	0.00	2858.58	0.00	0.00
	Wuhan	0.00	0.00	3133.64	0.00	0.00
	Zhengzhou	0.00	1733.15	2947.97	0.00	0.00
	Xi'an	0.00	36,830.06	17,086.30	0.00	0.00
2021	Tianjin	0.00	17766.50	0.00	0.00	15.51
	Chengdu	0.00	0.00	937.54	0.00	0.00
	Wuhan	0.00	0.00	2356.73	0.00	0.00
	Xi'an	0.00	16,581.02	6165.04	0.00	0.00
2022	Wuhan	0.00	0.00	1834.22	1284.35	0.00
	Zhengzhou	0.00	0.00	862.93	2637.51	0.00

Discussion

Except for the healthcare institutions, the medical resources per 1,000 population and per square kilometer and the HRDI of medical resources in the national central cities are higher than the Chinese average, indicating that the medical resources in the national central cities are relatively well allocated. National central cities are the core cities of urban systems in China, which concentrate the main advantages of Chinese cities in terms of space, population, resources and policies. The construction policy of national central cities further improves the level of medical resource allocation in the national central cities, and gradually forms a pattern of driving the development of the surrounding areas. On the one hand, the national central cities have large populations, more developed socio-economic systems, more medical colleges, more large medical institutions, and active medical markets, with better medical resource allocation.[23] On the other hand, the national central cities are important strategic cities built with national efforts, which have a strong "siphon effect" on the surrounding areas, and concentrate more medical resources.[24] The continued growth of the HRDI in the national central cities indicates that COVID-19, which started in December 2019, has had a relatively small impact on health resource allocation, and that the cities' focus on attracting medical personnel for centralized treatment has not significantly changed the level of medical resource allocation. Therefore, national central cities should further optimize the quality and structure of medical resource allocation and improve the efficiency of medical services. They should also play a the leading role of medical resources, expand the coverage of medical resources and make them more beneficial to the people.

In terms of the medical resource allocation per 1,000 population and per square kilometer and the HRDI, the medical resource allocation is better in regions such as Beijing and Shanghai, and worse in regions such as Chongqing and Xi'an. We believe there are three reasons for this. First, regions such as Beijing and Shanghai are located in the eastern coastal region, which has a better economic basis for medical resource allocation. While regions such as Chongqing and Xi'an are located in the western region, the level of economic development level is relatively low compared to that of Beijing and Shanghai, and the development of medical resources is relatively slow.[25] Second, regions such as Beijing and Shanghai have concentrated a large number of medical colleges and large medical institutions, with a better level of medical resource allocation. While regions such as Chongqing and Xi'an have fewer medical colleges and medical institutions compared to Beijing and Shanghai, the concentration of medical talents is relatively insufficient, and the medical resource allocation is slightly worse.[26] Third, regions such as Beijing and Shanghai have higher income levels,

and people's willingness and ability to pay for medical care are stronger, which promotes the development of the medical market. While regions such as Chongqing and Xi'an have lower income levels compared to Beijing and Shanghai, their ability to pay varies, and the medical market is relatively less active.[27] Therefore, regions such as Beijing and Shanghai should continue to improve the quality of medical resources, raise the level of basic scientific research and clinical diagnosis and treatment, and fully play to their leading role in the country.[28] Regions such as Chongqing and Xi'an should continue to promote socio-economic development, cultivate and expand the medical market, make use of local specialties in medical resources and improve the service capacity. Beijing, Shanghai and other regions can promote the redistribution of medical resources and the improvement of medical capacity in areas with weak medical resources through targeted financial support and cross-regional cooperation, such as the national regional medical center construction project, which will use areas with rich in medical resources as output areas and weak areas as input areas, and gradually realize the homogenization of medical services among regions.

Chongqing, which has the lowest HRAD among the national central cities, is above 2.36, which indicates that medical resources in the national central cities are highly concentrated by geography. On the one hand, medical resources in national central cities are more concentrated compared with other areas, and the overall medical resource allocation is better.[29] On the other hand, the geographical area of national central cities is relatively small, with an average geographical area of 18,348 square kilometers, and the largest geographical area, Chongqing, is only 80,403 square kilometers, which leads to a greater concentration of the already richer medical resources in terms of geographical area. The high concentration of medical resources by geographical allocation is conducive to shortening the distance between the people's visits to the doctor and better providing medical services to the people.[30] With the accelerated aging of the population, the demand for medical services from the elderly population has increased, and there is a strong demand for a closer medical service radius, which poses new requirements for the allocation and spatial arrangement of medical resources in the city. Therefore, the national central cities should focus on the distance of medical resources to serve the local people,[31] with large-scale medical institutions to solve the problems of difficult and complicated diseases, as well as improve the primary medical institutions to solve the problems of common and frequent diseases,[32] so as to promote the medical resources to serve the people more equitably.

Beijing, Tianjin, Guangzhou and Xi'an have a shortage of beds relative to the agglomerated population. The number of beds in these regions has continued to increase, but it still cannot meet the needs of the urban population as people's demand for medical care increases massively. The overall high level of medical care in these regions has attracted people from neighboring areas to seek medical care across regions, further exacerbating the shortage of beds.[33] Therefore, regions such as Beijing and Tianjin should further strengthen bed allocation, and promote bed resources to meet the medical needs. The shortage of licensed (assistant) physicians, health technicians and registered nurses in Chongqing relative to the agglomeration population indicates that Chongqing needs to further strengthen the allocation of health human resources. Chongqing is located in the western region, has a large population and a large geographical area, and insufficient investment in health has led to inadequate construction of health human resources.[34] Health human resources in Chongqing are highly concentrated in the central urban areas, resulting in insufficient health human resources in remote and grassroots areas, which affects the equity of health human resources.[35] Therefore, Chongqing should increase the investment in health, further improve the career development, salary and benefits of health personnel, and carry out the construction of medical service systems in remote and grassroots areas.[36]

In 2020, there are six cities with relatively ineffective DEA, significantly more than the four cities with relatively ineffective DEA in 2019, indicating that COVID-19, which started in December 2019, has a greater impact on medical resource allocation efficiency, exposing the imbalance of urban medical resource allocation, uneven spatial distribution, etc. In 2021, medical resource allocation efficiency gradually improves, and the number of cities with relatively ineffective DEAs is reduced to four. The DEAs in Shanghai, Guangzhou and Chongqing are relatively efficient, indicating that the optimal state of efficiency is achieved without changing the inputs and outputs. Except for Shanghai, Guangzhou, and Chongqing, other cities have a relatively inefficient state, indicating that there is room for further improvement in efficiency. In particular, regions such as Beijing and Chengdu have redundant inputs. On the one hand, regions such as Beijing and Chengdu have a high concentration of medical resources in the central urban areas, with numerous medical colleges and large medical institutions. The relatively poor allocation of medical resources in

grassroots areas has led to an irrational structure of medical resource allocation, resulting in the redundancy of inputs.[37] On the other hand, regions such as Beijing and Chengdu have a large number of large medical institutions, which crowd out the space for the development of primary hospitals and private hospitals,[38] resulting in the understaffing of primary and private hospitals, and thus the phenomenon of inefficiency of insufficient output and input.[39] Therefore, regions such as Beijing and Chengdu should further improve the construction of grassroots health care systems, promote the coverage of health care inputs to grassroots areas, and further improve the allocation structure of medical resources.[40] It is also necessary to strengthen the support of regions with surplus medical resources to the weaker regions,[41] and guide the grassroots regions in providing medical services through telemedicine and joint wards, so as to promote the full utilization of medical resources in the grassroots areas.[42]

The DEA is relatively ineffective in regions such as Tianjin, Wuhan and Zhengzhou, indicating the existence of both input redundancy and output deficiency. There is an imbalance in the distribution of medical resources in these regions, with a high concentration of medical resources in the central urban areas and a serious under-allocation of medical resources in non-central and grassroots areas,[43] and the poor scale of medical resource allocation has led to inefficiency, with further input optimization needed. The convenience of transportation and the implementation of the policy of medical insurance reimbursement in different places have further facilitated the flow of patients to the central urban areas where the level of medical care is higher,[44] thus exacerbating the imbalance in the structure of medical resource allocation. The irrational structure of medical resource allocation has led to poor scale efficiency, insufficient patient throughput, and inefficient output of medical resources, thus affecting the overall efficiency of medical resources. In the actual provision of medical services, there may also be problems such as insufficient investment in health care and insufficient medical personnel at the grassroots level, making it difficult to improve the efficiency of medical resource allocation in the short term. Therefore, these regions should further promote the sinking of medical resources to non-central urban areas and grass-roots areas, improve measures such as two-way referral and family doctor contracting services, upgrade the level of medical technology and medical service capacity in grass-roots areas, and strengthen the publicity and guidance for patients to seek medical treatment, so as to improve the utilization efficiency of medical resource allocation.[45]

Limitations

This study still has some limitations. First, the medical resource allocation should consider the actual needs of the resident population, which is not covered in this study. Second, there are many factors affecting the medical resource allocation, including population, economic and social factors, and this paper does not analyze the influencing factors. Third, the differences between urban areas and rural areas in the medical resource allocation of the national central cities, which is not covered in this paper.

Conclusions

In order to promote national central cities to play a leading role in medical resource demonstration, descriptive analysis, HRDI, HRAD, and DEA were used to evaluate the equity and efficiency of medical resource allocation in national central cities. The study found that the level of medical resource allocation in national central cities is higher than the Chinese average. The lowest HRAD is over 2.36 in Chongqing. The number of beds in Beijing, Tianjin, Guangzhou and Xi'an, and licensed (assistant) physicians, registered nurses and health technicians in Chongqing are insufficient relative to the agglomeration population. The technical efficiency, scale efficiency and overall efficiency in Shanghai, Guangzhou and Chongqing are all 1, and the DEA is relatively effective. Except for Shanghai, Guangzhou and Chongqing, the other cities have relatively inefficient allocation of medical resources. There is input redundancy in cities such as Beijing and Chengdu, and structural irrationality in the health resource allocation and underutilization of services in cities such as Tianjin, Wuhan and Zhengzhou. We suggest that national central cities should focus on improving the quality of medical resource allocation and expanding the coverage of medical resources. They should also further optimize the structure of medical resources and strengthen the support and assistance from regions with surplus medical resources to the weaker regions. National central cities should further promote the balanced layout of medical resources and play the role of power source and growth pole.

Data Sharing Statement

The data for this study are available at China Health Statistics Yearbook (http://www.nhc.gov.cn/mohwsbwstjxxzx/tjtjnj/tjsj_list.shtml).

Funding

This work was supported by Health Commission of Sichuan Province Medical Science and Technology Program (24WSXT019) and the primary health development research center of Sichuan Province program (SWFZ24-Y-36).

Disclosure

The author declares no competing interests in this work.

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