Efficiency and Equity of Rural Healthcare Resource Allocation in China: A DEA-GIS Approach (Postprint)

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Abstract

Background Strengthening primary-level healthcare constitutes a key priority of China's healthcare reform. Investigating the efficiency and equity of rural medical and health resource allocation in China holds significant importance for promoting the orderly development of primary-level medical and health services. However, few existing studies have simultaneously examined both equity and efficiency using the DEA-GIS methodology.

Objective To analyze the efficiency and equity of rural medical and health resource allocation across 29 provinces in China in 2020, thereby providing evidence for optimizing rural medical and health resource allocation and improving the rural medical and health service system.

Methods Data were sourced from the "Statistical Table of Administrative Divisions of the People's Republic of China" and the "2021 China Health Statistics Yearbook". Based on a comprehensive review of existing literature, data availability, and expert consultation, township health centers and village clinics in 29 Chinese provinces (excluding Beijing, Shanghai, Hong Kong, Macao, and Taiwan) were selected as research subjects. Input indicators included: the number of township health centers and village clinics (hereinafter referred to as health institutions), the number of beds in township health centers (hereinafter referred to as beds), and the number of health technicians in township health centers and village clinics (hereinafter referred to as health technicians). Output indicators comprised: the number of visits to township health centers and village clinics (hereinafter referred to as visits) and the number of admissions to township health centers (hereinafter referred to as admissions). Data Envelopment Analysis (DEA) was employed to evaluate the efficiency of rural medical and health resource allocation, while agglomeration degree and Geographic In-

formation System (GIS) technology were utilized for spatial mapping to analyze equity.

Results In 2020, among China's rural medical and health resources, 4 provinces achieved DEA efficiency, 7 provinces were DEA weakly efficient, and 18 provinces were inefficient. All DEA-inefficient regions exhibited varying degrees of input surplus, with only Shandong Province and the Tibet Autonomous Region experiencing output insufficiency. Regional analysis revealed that rural medical and health resources were predominantly concentrated in the eastern region, followed by the central region, while the western region demonstrated the lowest agglomeration degree.

Conclusion The government should prioritize enhancing the technical efficiency of rural medical and health resource allocation by optimizing input-output structures and reducing resource redundancy. Rational coordination of resource allocation across eastern, central, and western regions, coupled with region-specific targeted policies, is essential to promote both equity and efficiency.

Full Text

Research on the Efficiency and Equity of Rural Medical and Health Resources Allocation in China Based on DEA-GIS Methodology

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Abstract

Background: "Strengthening primary health care" is one of the focal points of China's medical reform. Studying the efficiency and equity of rural medical and health resource allocation in China is of great significance for promoting the orderly development of primary health care services. However, there is currently scarce literature that employs DEA-GIS methodology to examine both equity and efficiency simultaneously.

Objective: To analyze the efficiency and equity of rural medical and health resource allocation across 29 provinces in China in 2020, providing a reference for optimizing rural medical and health resource allocation and improving the rural medical and health service system.

Methods: Data for this study were collected from the *Statistical Tables of Administrative Divisions of the People's Republic of China* and the *2021 China Health Statistical Yearbook*. After synthesizing existing literature, assessing data availability, and consulting experts, township hospitals and village clinics in 29 provinces (excluding Beijing, Shanghai, Hong Kong, Macao, and Taiwan) were selected as study objects. Input indicators included the number of township hospitals and village clinics (hereinafter referred to as health institutions), the number of beds in township hospitals (hereinafter referred to as beds), and the number of health technicians in township hospitals and village clinics (hereinafter referred to as health technicians). Output indicators included the number of consultations in township hospitals and village clinics (hereinafter referred to as consultations) and the number of hospital admissions to township hospitals (hereinafter referred to as admissions). The Data Envelopment Analysis (DEA) model was used to evaluate the efficiency of rural medical and health resource allocation, while agglomeration degree and Geographic Information System (GIS) technology were employed for spatial mapping to analyze equity.

Results: In 2020, among China's rural medical and health resources, 4 provinces achieved DEA effectiveness, 7 provinces were DEA weakly effective, and 18 provinces were DEA ineffective. All DEA-ineffective regions exhibited varying degrees of input redundancy, with only Shandong Province and the Tibet Autonomous Region showing output insufficiency. Regional analysis revealed that rural medical and health resources were concentrated in the eastern region, followed by the central region, with the lowest agglomeration in the western region.

Conclusion: The government needs to focus on improving the technical efficiency of rural medical and health resource allocation, optimizing input-output structures, reducing resource redundancy, and rationally coordinating resource allocation across eastern, central, and western regions. Precise, targeted policies should be implemented to promote both equity and efficiency.

Keywords: Health resources; Rural health services; Medical and health resource; Health inequities; Resource allocation; Data envelopment analysis; Geographic information system

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Introduction

"Strengthening primary health care" represents a central focus of China's medical reform. The *Opinions on Further Deepening Reform to Promote the Healthy Development of the Rural Medical and Health System* emphasizes optimizing the layout of rural medical and health institutions and rationally allocating resources at both township and village levels according to local conditions. However, medical and health services in China's vast rural areas still face severe challenges, including insufficient total health resources, irrational structural distribution, and low service efficiency. Therefore, studying the efficiency and equity of rural

medical and health resource allocation is crucial for promoting orderly development of primary health care services.

Previous studies have several limitations: they are often outdated, rarely consider both efficiency and equity indicators simultaneously, and are typically confined to township hospitals or village clinics within a single province. This constrains comprehensive, real-time understanding and precise judgment of national rural medical and health service resource allocation issues. To address these gaps, this study employs Data Envelopment Analysis (DEA), Health Resource Agglomeration Degree (HRAD), and Geographic Information System (GIS) methods to analyze the equity and efficiency of rural medical and health resource allocation in China in 2020, providing references for optimizing regional medical and health resource planning and improving the rural medical and health service system.

Methods

1.1 Data Sources This study utilized data from the *Statistical Tables of Administrative Divisions of the People's Republic of China* and the *2021 China Health Statistical Yearbook*. After reviewing existing literature, assessing data availability, and consulting experts, township hospitals and village clinics in 29 provinces (excluding Beijing, Shanghai, Hong Kong, Macao, and Taiwan) were selected as study objects. Input indicators comprised the number of township hospitals and village clinics (health institutions), the number of beds in township hospitals (beds), and the number of health technicians in township hospitals and village clinics (health technicians). Output indicators included the number of consultations in township hospitals and village clinics (consultations) and the number of hospital admissions to township hospitals (admissions).

1.2 Analytical Methods **1.2.1 DEA:** DEA is an evaluation method for assessing the effectiveness of similar decision-making units and calculating relative efficiency among them. It is widely used to analyze multi-input and multi-output efficiency problems and has been extensively applied in health resource allocation efficiency studies. This study used DEAP 2.1 software with the BCC variable returns-to-scale model in an input-oriented configuration. Under variable returns-to-scale conditions, comprehensive technical efficiency can be decomposed into pure technical efficiency and scale efficiency, with values ranging from 0 to 1. When comprehensive technical efficiency, pure technical efficiency, and scale efficiency all equal 1, DEA relative effectiveness is achieved, indicating optimal resource allocation efficiency with full resource utilization at the production frontier. When comprehensive technical efficiency and scale efficiency are less than 1 while pure technical efficiency equals 1, DEA weak effectiveness occurs, indicating technical efficiency but scale inefficiency with irrational resource structure allocation. When all three efficiency measures are less than 1,

DEA ineffectiveness is indicated, showing low resource allocation efficiency with underutilized resources.

1.2.2 HRAD: HRAD refers to the proportion of health resources agglomerated on 1% of the land area of a higher-level region, which can be used to evaluate the equity of health resource allocation. The formula is: HRADi = (HRi/HRn) × 100% / (Ai/An) × 100%, where HRADi represents the health resource agglomeration degree of the region, HRi represents the health resource quantity of the region, HRn represents the health resource quantity of the higher-level region, Ai represents the land area of the region, and An represents the land area of the higher-level region. When HRAD = 1, absolute equity in health resource allocation by geographic area is achieved. When HRAD > 1, higher equity is indicated, while HRAD < 1 indicates lower equity.

1.2.3 GIS: GIS is a method based on geographic spatial data that combines relevant resources for spatial analysis. It can integrate health resource data with geographic space to present spatial distribution characteristics of health resources and is widely used in health resource allocation research. This study employed GIS technology to explore geographic spatial distribution differences in the equity of rural medical and health resource allocation.

1.3 Statistical Processing Data were entered using Excel 2021 software to calculate the agglomeration degree of rural medical and health input resources. DEAP 2.1 was used to calculate health resource allocation efficiency, and ArcMap software was utilized for geographic mapping of agglomeration degree data.

Results

2.1 Current Status of Rural Medical and Health Resource Inputs and Outputs in China, 2020 The current status of rural medical and health resource inputs and outputs in China in 2020 is detailed in Table 1 . Large differences exist between maximum and minimum values across all indicators. Among maximum values, Henan Province had relatively large numbers of health technicians and consultations, Sichuan Province had large numbers of beds and admissions, and Hebei Province had a large number of institutions. Among minimum values, Tianjin had small numbers of institutions and health technicians, while Ningxia Hui Autonomous Region, Qinghai Province, and Tibet Autonomous Region had sequentially smaller numbers of beds, consultations, and admissions.

2.2 DEA Analysis Results 2.2.1 Efficiency Analysis: DEAP 2.1 was used to analyze the efficiency of rural medical and health resource allocation across China. The results are presented in Table 2 and Figure 1 [Figure 1: see original paper]. Among 29 provinces, only Jiangsu, Zhejiang, Guangxi

Zhuang Autonomous Region, and Chongqing achieved comprehensive technical efficiency effectiveness, representing optimal resource allocation efficiency with rational allocation of rural medical and health resource elements. Seven provinces—Tianjin, Henan, Hunan, Guangdong, Sichuan, Qinghai, and Ningxia Hui Autonomous Region—were DEA weakly effective, indicating pure technical efficiency but scale inefficiency with irrational resource structure allocation. The remaining 18 provinces had all efficiency indicators below 1, failing to achieve DEA effectiveness and indicating low resource allocation efficiency.

From the perspective of scale efficiency, 15 provinces including Tianjin, Shanxi, and Inner Mongolia Autonomous Region exhibited increasing returns to scale (51.72%), suggesting these provinces could expand scale to increase benefits. Ten provinces including Hebei, Anhui, and Jiangxi exhibited decreasing returns to scale (34.48%), indicating diminishing returns where scale reduction could decrease waste. The remaining four provinces had constant scale effects (13.79%), representing optimal status.

2.2.2 Improvement Directions for Non-DEA Effective Provinces: S^+ and S^- represent slack variables for outputs and inputs, respectively. The magnitude of S^+ indicates the degree of output insufficiency, requiring corresponding output increases, while S^- indicates input redundancy, requiring corresponding input reductions. When both equal 0, neither output nor input waste exists, achieving optimal status and DEA effectiveness.

All 18 non-DEA effective provinces exhibited input redundancy while maintaining constant output. Only Shandong Province showed insufficient admissions output, while Tibet Autonomous Region showed insufficient consultations and admissions, indicating underutilization of rural medical and health resources at current input scales. This suggests Shandong and Tibet need to strengthen rural medical and health construction, continuously improve service capacity, and expand output effects.

The comparison between actual and target values for input and output in non-DEA effective provinces is shown in Table 4 . All 18 non-DEA effective provinces could reduce rural medical and health resource inputs according to improvement ratios while maintaining constant output. Table 5 presents improvement reasons and reference sets for non-DEA effective provinces. Only Shandong Province and Tibet Autonomous Region simultaneously exhibited input redundancy and output insufficiency, while the remaining 16 provinces showed only input redundancy. In the improvement reference sets, Zhejiang Province and Chongqing Municipality tied for first place as reference provinces, each appearing 15 times.

2.3 Equity Analysis of Rural Medical and Health Resources The agglomeration degrees of rural medical and health institutions, beds, and health technicians were calculated to reflect geographic equity of rural medical and health resources in China in 2020, with results shown in Table 6 . At the provincial level, Henan Province had the highest overall agglomeration degree

for all types of rural medical and health resources (4.97–5.21), while Tibet Autonomous Region had the lowest (0.02–0.07). No province achieved optimal equity in resource allocation. Among non-DEA effective provinces, border provinces including Inner Mongolia Autonomous Region, Jilin, Heilongjiang, Yunnan, Tibet, Gansu, and Xinjiang Uygur Autonomous Region all had agglomeration degrees below 1, indicating unfair geographic allocation and poor geographic accessibility. The remaining 11 non-DEA provinces had excessively high agglomeration degrees, indicating resource allocation redundancy.

Regarding input indicators, the agglomeration degrees of rural medical and health institutions (0.07–5.21) and beds (0.13–5.32) were generally lower than those of health technicians (0.15–5.80), suggesting that physical resource allocation equity is generally better than human resource equity. Additionally, rural medical and health resources showed an overall increasing trend from west to east, with the highest agglomeration in Hebei, Henan, Shandong, Jiangsu, and Anhui provinces. These results reflect insufficient equity in geographic area-based allocation of rural medical and health resources, with significant inter-regional disparities.

Discussion

3.1 Overall Low Efficiency in Rural Medical and Health Resource Allocation Requires Attention to Technical Efficiency Improvement In 2020, the mean comprehensive technical efficiency of rural medical and health resource allocation across 29 provinces was 0.68, with only 15 provinces above the mean at the production frontier. A total of 62.07% of provinces were non-DEA effective, indicating widespread resource redundancy. Among non-DEA effective provinces, 72.22% had pure technical efficiency lower than scale efficiency, demonstrating that low pure technical efficiency is the primary constraint on improving comprehensive technical efficiency. This indirectly reflects past emphasis on scale efficiency improvement while insufficient attention was paid to pure technical efficiency, which will become the key focus for enhancing comprehensive technical efficiency. For the 13 provinces with low pure technical efficiency—including Hebei, Shanxi, and Inner Mongolia—efforts should integrate provincial rural medical and health resources, transition from scale expansion to high-quality development, and continuously promote county medical community construction to facilitate high-quality resource 下沉 to rural systems. Advanced management models and new technologies should be introduced, with enhanced "Internet Plus" applications to improve pure technical efficiency through multiple measures.

Shandong Province showed insufficient admissions output, while Tibet Autonomous Region showed insufficient consultations and admissions, indicating underutilization of rural medical and health resources at current input scales. This suggests both provinces need to strengthen rural medical and health

construction, continuously improve service capacity, and expand output effects.

3.2 Optimize Input-Output Structure and Reduce Redundancy Waste All non-DEA effective provinces exhibited input redundancy, while output insufficiency only occurred in Shandong's admissions and Tibet's consultations and admissions. This indicates input redundancy is common across provinces, suggesting the need to appropriately control resource increments or focus on adjusting existing stock and optimizing structural layout to improve utilization rates. Additionally, residents' health awareness should be enhanced to promote active and reasonable healthcare-seeking behavior. Shandong should increase admission rates, while Tibet needs to improve both admission and consultation rates to align resource allocation with scale.

Non-DEA effective provinces can select reference provinces as improvement templates based on their actual conditions. Zhejiang Province appears most frequently in reference sets and offers valuable experience in narrowing urban-rural development gaps, achieving high-quality public service sharing, and promoting balanced distribution of high-quality medical resources as a high-quality common prosperity demonstration zone. Provinces can learn from Zhejiang to optimize input-output ratios and improve allocation efficiency, advancing high-quality health development based on common prosperity.

3.3 Rationally Coordinate Regional Resource Allocation to Promote Balanced Development Rural medical and health institutions, beds, and health technicians all show polarization tendencies, with resource allocation levels in eastern regions significantly higher than in central and western regions. This indicates that geographic distribution equity of rural medical and health resources needs improvement. Research shows that economic development level differences are primary factors affecting health resource supply and demand, creating gaps in fiscal investment across regions. In high-agglomeration areas—particularly Hebei, Henan, Shandong, Jiangsu, and Anhui—resource allocation is associated not only with economic development but also with urbanization rates, population density, education levels, and aging demographics.

Therefore, governments must coordinate allocation across eastern, central, and western regions to compensate for regional disparities. Industrial transfer and paired assistance should be intensified to develop central and western economies, optimize medical resource input structures, control scale in areas with resource redundancy, and 倾斜 toward underserved areas to avoid clustered distribution and promote health service equalization to meet rural residents' needs.

3.4 Tailor Policies to Local Conditions Based on Regional Development Status Eastern provinces demonstrate better equity but still have room for efficiency improvement. These regions should appropriately reduce incremental resource input, optimize input-output structures, reduce allocation redundancy, focus on improving pure technical efficiency, implement refined manage-

ment, and further enhance utilization efficiency. Central regions show moderate equity and efficiency, requiring strengthened health resource planning to address equity issues while optimizing inputs to elevate both equity and efficiency above standards. Western provinces exhibit poor equity and efficiency, necessitating economic development based on local rural characteristics and complementary advantages with eastern regions. Economic growth should drive expanded rural medical and health resource investment, prioritizing equity improvement to promote service equalization while optimizing allocation structures and ensuring steady development.

3.5 Study Limitations Domestic literature using DEA-GIS methods to evaluate rural medical and health resources is limited. This study primarily referenced research on health resource allocation and geographic information systems. Regarding indicator selection, due to data availability, county hospitals and county-level city hospitals were not included in the analysis, which may affect results.

Conclusion

China's rural medical and health resource allocation demonstrates overall low efficiency with widespread redundancy. Low pure technical efficiency is the primary constraint on improving comprehensive technical efficiency. All non-DEA effective provinces exhibit input redundancy, with eastern regions showing significantly higher allocation levels than central and western regions. Both equity and efficiency are higher in eastern regions, while western regions show the poorest performance in both dimensions. Recommendations include focusing on pure technical efficiency improvement, optimizing input-output structures to reduce redundancy, rationally coordinating regional resource allocation to promote balanced development, and implementing tailored policies based on local conditions. This study provides references for applying DEA-GIS methodology in resource allocation, optimizing regional medical and health resource planning, and improving rural medical and health systems.

Author Contributions: GAO Dian conceptualized and designed the study, collected and organized data, performed statistical analysis, interpreted results, and drafted the manuscript. SHI Lushaobo and LIN Jinhui revised the manuscript and provided supervision. WANG Xingmin organized literature, materials, and figures. WANG Dong oversaw study implementation and feasibility, and controlled manuscript quality.

Conflict of Interest: The authors declare no conflict of interest.

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Note: Figure translations are in progress. See original paper for figures.