Spatial equity and influencing factors of coupling coordination degree of healthcare resources allocation and service utilization in China

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Abstract

Background: The COVID-19 epidemic in early 2020 has made the contradiction between allocation and utilization of healthcare resources in China more prominent. However, there is still no conclusion about the coordination degree of healthcare resources and service utilization in China, especially in the context of hierarchical diagnosis and treatment. Based on the hierarchical analysis framework for healthcare institutions, this paper mainly analyzes the coordination level of healthcare resources of primary healthcare institutions and hospital in China’s provincial scale from 2010 to 2018.

Method: In this paper, the entropy-weighted TOPSIS evaluation method is used to calculate the healthcare resources allocation and service utilization index, the coupled coordination model is used to evaluate the coordination relationship between healthcare resource allocation and service utilization, and the exploratory spatial data analysis method is used to evaluate the spatial distribution characteristics of the coordination level and detect its impact on the surrounding spatial units and the geographic detector is used to analyze the driving factors that affect the spatial inequity of the coordination level.

Results: The coupling coordination degree of primary healthcare institutions and hospitals increased from 0.448 and 0.418 in 2010 to 0.519 and 0.534 in 2018, respectively, while the relative development degree increased from 0.469 and 0.466 in 2010 to 0.767 and 0.578 in 2018, respectively. The coupling coordination type has shifted from slight imbalance to general coordination. The lagging situation of healthcare resources allocation has gradually improved. The coupling coordination degree basically shows the spatial distribution characteristics of higher in the eastern area, central in the central area, and lower in the border areas in the northwest, northeast, and southwest. At the same time, the spatial inequity is more obvious. The coupling coordination degree between China’s healthcare resources allocation and service utilization has spatial autocorrelation, and formed hotspot and coldspot areas centered on the middle and lower reaches of the Yangtze River and the Tibetan Plateau respectively. The lag of healthcare resources allocation is the main reason for lowering the degree of coupling coordination between healthcare resources and service utilization in China. The spatial differentiation of coupling coordination degree is influenced by population distribution and structure, economic development level and topographical condition factors, and has obvious spatial and temporal heterogeneity. These results have similarities and differences at the level of hospitals and primary medical institutions.

Conclusions: From 2010 to 2018, China’s healthcare resources allocation and service utilization coupling coordination system changed from slight imbalance to general coordination. This kind of transformation is more obvious in hospitals than primary healthcare institutions. Whether it is hospitals or primary healthcare institutions, the coordination level has obvious spatial distribution characteristics and spatial inequity. The lag of healthcare resources allocation is the main reason for lowering the level of coupling coordination. This spatial inequity is affected by the distribution and structure of economic population, the level of economic development, and topographical conditions. These conclusions have similarities and differences at the level of hospitals and primary healthcare institutions.

Keywords: healthcare resources; healthcare utilization; coupling coordination degree; spatial equity; hierarchical
Background

At the beginning of the new year of 2020, the rapidly spreading COVID-19 epidemic outbreak in China has brought a major test to the field of public healthcare system. Existing studies have shown the potential link between the mortality rate of COVID-19 epidemic and the availability of healthcare resources. The huge regional differences in the availability and accessibility of China's healthcare resources are the root cause of regional differences in epidemic mortality\(^1\). In the early stage of the epidemic, the existing “inverted triangle” pattern of healthcare resources allocation in Wuhan made it more difficult to implement a graded diagnosis and treatment system based on community-square cabin hospitals-intensive care hospitals. Primary healthcare institutions can't form an effective first line of defense. The hierarchical diagnosis and treatment order will not be realized until the nationwide assistance and the continuous release of the number of beds in various institutions. The COVID-19 epidemic like a magnifying glass, which makes the distribution of healthcare resources in the public health service system inequity, the function of the level of healthcare institutions unreasonable, and the contradiction between the allocation and utilization of healthcare resources become more apparent. In February 2020, President Xi Jinping emphasized that it is necessary to “establish and improve mechanisms for the treatment of major epidemics such as grading, stratification, and diversion of infectious diseases”, and “continuously strengthen the system construction of general practitioner training and grading diagnosis and treatment”. Hierarchical diagnosis and treatment is a mechanism to realize the rational allocation and utilization of healthcare resources. Healthcare institutions of different levels provide medical services according to their respective functions. Analyze the relationship between the allocation and utilization of healthcare resources in China based on the background of hierarchical diagnosis and treatment can provide decision-making basis for optimizing the allocation and utilization of healthcare resources. At the same time, it can also provide experience for other developing countries to solve similar problems.

So far, the healthcare service systems of the United Kingdom, the United States, Canada, Australia, Japan and other countries have established a comprehensive graded diagnosis and treatment pattern. In the pattern, the positioning and responsibilities of healthcare institutions are clear, and the division of labor and cooperation has improved the efficiency of healthcare resources allocation and service utilization. Research on the space allocation and utilization of healthcare resources at various levels based on the background of graded diagnosis and treatment has gradually become an international hot spot. The content of the research on the spatial allocation of healthcare resources mainly involves the spatial distribution of primary healthcare institutions and general practitioners\(^2\)[3], the optimization of the spatial allocation of multi-level healthcare resources aimed at two-way referrals\(^4\)[5], the spatial equity of different levels of healthcare institutions\(^6\). Healthcare service utilization research focuses on the referral utilization of specific diseases\(^7\)[8], the effectiveness of patient referral service utilization\(^9\)[10], and the impact of graded diagnosis and treatment service utilization system\(^11\). The existing literature also pays attention to the hierarchical issues of China's healthcare resources allocation and service utilization. For example, the fairness of healthcare resources allocation in specific regions\(^12\), the accessibility of healthcare service space\(^13\)[14][15], and the comparison of the spatial equity of healthcare resources in prefecture-level and county-level cities \(^16\). Existing researches in China also involve the correlation research of the spatial allocation and utilization of healthcare resources, such as exploring the fairness and utilization efficiency of healthcare resources allocation\(^17\)[18] or research on the allocation and service utilization of a grade of healthcare resources from the perspective of spatial geography\(^19\). The medical service utilization research mainly discusses the bed utilization rate of different levels of health institutions\(^20\), urban and rural residents' medical service utilization preference\(^21\) and inequality issues\(^22\). In terms of factors influencing the equity of healthcare resources allocation, local economic level\(^23\), demographic characteristics\(^24\), decision-making mechanism\(^25\), terrain
conditions\textsuperscript{[16]}, information asymmetry and adverse selection\textsuperscript{[26]} are considered to be the main factors. In terms of factors influencing the equity of utilization of healthcare services, demographic characteristics\textsuperscript{[27]}, urban-rural differences\textsuperscript{[28]}, institutional equity, income levels\textsuperscript{[29]}, and medical insurance\textsuperscript{[30]} are considered to be the main factors. However, there is still a lack of quantitative analysis of the relationship between healthcare resources allocation and service utilization. So what is the relationship between the allocation and utilization of healthcare resources in China; how is this relationship evolving; whether there is a spatial inequity or not; how is this relationship affected by the influencing factors of healthcare resources allocation and service utilization, there is still no reasonable answer.

Based on the above analysis, this paper builds a hierarchical analysis framework for healthcare institutions, and uses the entropy-weighted TOPSIS evaluation method, coupled coordination model, exploratory spatial analysis, geographic detectors methods to analyze the level of coupling coordination between healthcare resources allocation and service utilization in provincial-scale hospitals and primary healthcare institutions from 2010 to 2018 in China, explore the spatial equity of this relationship and its influencing factors, and then propose strategies to optimize healthcare resources allocation and service utilization.

**Materials and Methods**

**Index system and data sources**

In the design of healthcare resources allocation indicators, the number of healthcare institutions, beds and healthcare technicians are the basic indicators for measuring the ability of medical services. They have the characteristics of completeness, availability, and comparability of statistical data. The existing literature shows that healthcare resources allocation based on population and space alone can't accurately reflect the actual situation of healthcare resources allocation in a region. Therefore, this paper introduces the “Healthcare resources Density Index”\textsuperscript{[18]} (Health Resources Density Index, HRDI) to measure the comprehensive level of the population and geographical distribution of healthcare resources in a region, and construct the corresponding resources density index for institutions, healthcare beds, and healthcare technicians. The third level hospital is a key hospital for the allocation and utilization of regional healthcare resources. Therefore, it is necessary for the hospital resources allocation index system to add a three-level hospital density index. In the design of healthcare service utilization indicators, considering utilization includes outpatient (including emergency) and inpatient services, six indicators were selected. Considering the different function of hospitals and primary healthcare institutions, the index of hospital medical service utilization also includes the number of inpatient operations per capita and the number of health checks. Therefore, following the principles of scientificity, comparability, and availability of index acquisition, this paper establishes an evaluation index system of healthcare resources allocation and service utilization in China (Table 1). The index weights in the table are calculated by the entropy method.

This paper uses 31 provinces, municipalities, and autonomous regions as the basic spatial unit of research (data missing in Hong Kong, Macau, and Taiwan) to analyze the situation of China's healthcare resources allocation and service utilization coupling coordination. The data in this paper is mainly from the “China Health Statistics Yearbook”, “China Statistical Yearbook” and “China Population and Employment Statistics Yearbook” from 2010 to 2018.

| System layer | Target layer | Hospital | Primary healthcare institutions |
|--------------|--------------|----------|---------------------------------|
| Resources    | Institutions | Hospital density index | 0.345 | + | Institutional density index | 0.311 | + |
|              |              | Third level hospital density index | 0.254 | + |                               |      |   |
|              |              | Bed density index | 0.185 | + | Bed density index | 0.189 | + |
Technicians

|                        | Health Technician Density Index | Number of consultations per person (times) | Physicians are responsible for daily visits (times) | Health checkup rate (%) | Bed utilization rate (%) | Average hospital stay (days) | Hospitalization rate (%) | Physicians are responsible for hospital bed days (days) | Number of hospital operations per capita |
|-----------------------|---------------------------------|-------------------------------------------|----------------------------------------------------|--------------------------|--------------------------|---------------------------|--------------------------|-----------------------------------------------------|----------------------------------------|
|                       | 0.217                           | +                                         | 0.163                                               | 0.095                    | +                        |                           | 0.069                                                  | 0.088                                               | 0.098                                                |

Utilization

|                        | Number of consultations per person (times) | Physicians are responsible for daily visits (times) | Health checkup rate (%) | Bed utilization rate (%) | Average hospital stay (days) | Hospitalization rate (%) | Physicians are responsible for hospital bed days (days) | Number of hospital operations per capita |
|-----------------------|-------------------------------------------|----------------------------------------------------|--------------------------|--------------------------|---------------------------|--------------------------|-----------------------------------------------------|----------------------------------------|
|                       | 0.249                                      | +                                                  | 0.153                    | -                        | -                         | -                        | 0.069                                                | 0.088                                                | 0.098                                                |

|                        | Number of consultations per person (times) | Physicians are responsible for daily visits (times) | Health checkup rate (%) | Bed utilization rate (%) | Average hospital stay (days) | Hospitalization rate (%) | Physicians are responsible for hospital bed days (days) | Number of hospital operations per capita |
|-----------------------|-------------------------------------------|----------------------------------------------------|--------------------------|--------------------------|---------------------------|--------------------------|-----------------------------------------------------|----------------------------------------|
|                       | 0.095                                      | +                                                  | -                        | -                        | -                         | -                        | -                                                    | -                                                     |

|                        | Number of consultations per person (times) | Physicians are responsible for daily visits (times) | Health checkup rate (%) | Bed utilization rate (%) | Average hospital stay (days) | Hospitalization rate (%) | Physicians are responsible for hospital bed days (days) | Number of hospital operations per capita |
|-----------------------|-------------------------------------------|----------------------------------------------------|--------------------------|--------------------------|---------------------------|--------------------------|-----------------------------------------------------|----------------------------------------|
|                       | 0.095                                      | +                                                  | -                        | -                        | -                         | -                        | -                                                    | -                                                     |

Note: this table was compiled by the authors. The healthcare institutions in this study don’t include professional public health institutions with relatively small resource allocation and utilization. According to China’s “Hospital Classification Management Standards”, there are three levels of hospitals. The third level hospital is the highest level.

Research Methods

Entropy Weight and TOPSIS Method

The entropy method determines the index weights based on the degree of differentiation of each index. At the same time, it can largely avoid the subjective factors of evaluation index weight calculation, making the evaluation more objective and scientific. This paper refers to the existing research to improve the entropy method, adding time variables to make the analysis results more reasonable. TOPSIS (Technique for Order Preference By Similararity to Ideal Solution) is a analysis method proposed by Hwang and Yoon in 1981, which is suitable for comparing and selecting multiple schemes based on multiple indicators. This paper apply the entropy-weight TOPSIS method to calculate the healthcare resources allocation and utilization index. The related calculation formula as follows:

Index selection: With r years, n provinces, and m indexes, then y_{ij} is the j index value of province i in year θ.

Standardization of indicators: Since different indicators have different dimensions and units, they need to be standardized. In this paper, the 0-1 standard transformation is used to co-trend the decision matrix:

Positive indicator: 

\[ d_{ij}^{+} = \frac{y_{ij} - y_{\min}^j}{y_{\max}^j - y_{\min}^j}, \]

Negative indicator: 

\[ d_{ij}^{-} = \frac{y_{\max}^j - y_{ij}}{y_{\max}^j - y_{\min}^j}, \]

Normalize \( d_{ij} \):
\[ d_{ij} = \frac{d_{ij}}{\sum d_{ij}} (1) \]

Calculate the entropy of the jth indicator:
\[ e_j = -k \sum d_{ij} \ln (d_{ij}), k > 0, k = \ln (m) \] (2)

Calculate the information utility value of the jth indicator:
\[ g_j = 1 - e_j \] (3)

Calculate the weight of each indicator:
\[ w_j = g_j / \sum g_j \] (4)

Using the method of vector normalization to find the standard decision matrix:
\[ z_{ij} = y_{ij} / \sqrt{\sum_{i=1}^{n} y_{ij}^2} \] (5)

Weighted canonical matrix:
\[ X = (x_{ij})_{m \times n} = [w_j * z_{ij}]_{m \times n} \] (6)

Determine positive ideal solution \( x^+ \) and negative ideal solution \( x^- \):
\[ x^+_j = \max (x_{1j}, x_{2j}, \ldots, x_{nj}) \quad j = 1, \ldots, n \] (7)
\[ x^-_j = \min (x_{1j}, x_{2j}, \ldots, x_{nj}) \quad j = 1, \ldots, n \] (8)

Calculate the distance between each evaluation scheme and the positive ideal solution and negative ideal solution:
\[ R^+_i = \sqrt{\sum_{j=1}^{m} (x_{ij} - x^+_j)^2}, i = 1, \ldots, n \] (9)
\[ R^-_i = \sqrt{\sum_{j=1}^{m} (x_{ij} - x^-_j)^2}, i = 1, \ldots, n \] (10)

Calculate the comprehensive evaluation index of each program, and rank the pros and cons of the programs according to the index:
\[ V^+_i = R^-_i / (R^-_i + R^+_i), i = 1, \ldots, n \] (11)

Coupled coordination model

There is a close relationship between healthcare resources allocation and service utilization system, which is similar to the coupling concept in physics. The closeness and harmony between the two systems can be measured by coupling and coordination. The coupling coordination degree emphasizes the comprehensive development among subsystems under the coordination constraint which is applicable to the research theme of this paper[36]. The model formula is as follows:
\[ C = \left\{ (P_1 \times P_2) \right\} / \left\{ (P_1 + P_2) \times (P_1 + P_2) \right\}^2 \] (12)

In the above formula, \( P_1 \) and \( P_2 \) are the healthcare resources allocation and utilization index, \( C \) is the coupling degree of the two, and the value range of \( C \) is \([0,1]\), the larger \( C \) is, the better the coupling. The model has the problem that when both system evaluation indexes are low, the degree of coupling can be very high. Therefore, it is necessary to continue to introduce the coordination model[37]. The model expression is as follows:
\[ T = \alpha P_1 + \beta P_2 \] (13)
\[ D = \sqrt{C \times T} \] (14)

In the above formula, \( \alpha \), \( \beta \) are the contribution coefficient, assuming that the level of healthcare resources allocation and utilization are equally important, \( \alpha = \beta = 0.5 \). \( D \) is the degree of coordination of healthcare resources allocation and utilization. \( T \) is the comprehensive evaluation index of healthcare resources allocation and service utilization. Considering that the coupled coordination model can't reflect the relative development of the two systems, this paper introduces a relative development model to reveal the relative development of the two systems.
\[ \omega = P_1 / P_2 \] (15)

In the above formula, \( \omega \) is the relative development degree. Based on the existing research results[38], the coupling coordination stages and types of this study are classified as follows (Table 2):

\[ \text{development among} \left\{ \begin{align*}
\alpha e^{\text{development among}} & = \text{development among} \\
\end{align*} \right. \]
Table 2 Types of coupling coordination between healthcare resources allocation and service utilization system

| Stage              | D     | Type            | Subtype          |
|--------------------|-------|-----------------|------------------|
| Low level coupling | 0<D≤0.3 | Serious imbalance | Lagging resource allocation |
| Lower level coupling | 0.3<D≤0.4 | Moderate imbalance | Synchronous development |
|                     | 0.4<D≤0.5 | Sligh imbalance | Advance resource allocation |
| Run-in coupling     | 0.5<D≤0.6 | General coordination |              |
|                     | 0.6<D≤0.7 | Better coordination |              |
|                     | 0.7<D≤0.8 | Good coordination |              |
| High level coupling | 0.8<D≤1 | Best coordination |                  |

Note: this table was compiled by the authors.

Exploratory spatial data analysis

Spatial autocorrelation can effectively detect the spatial characteristics of the coupling coordination degree, including global and local spatial autocorrelation.[39] The global spatial autocorrelation is usually expressed by the Global Moran’s I index and the Getis-Ord General G index. The former is used to test the similarity of spatially adjacent or adjacent research units, and the latter is used to further verify whether there are spatially high and low value clusters. The local spatial autocorrelation is mainly measured by the Getis-OrdGi* index, which can describe the spatial differentiation characteristics of the research units in the region in more detail.[40]

\[
\text{Moran’s } I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} (x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}} / \left( \frac{\sum_{i=1}^{n} x_i^2}{n} - \overline{x}^2 \right)
\]

\[
G(d) = \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} x_i x_j / \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}
\]

\[
G_i(d) = \sum_{j=1}^{n} W_{ij} x_j / \sum_{j=1}^{n} W_{ij}
\]

In the above formula: \(\overline{x}\) and \(s^2\) represent the mean and standard deviation of the variable \(x\), \(n\) is the number of research units; \(x_i\) and \(x_j\) are the attribute values of the spatial units \(i\) and \(j\). \(W_{ij}\) is the spatial weight matrix.

Geographic detector

The geographic detector method is a set of statistical methods to detect spatial differentiation and reveal the driving force behind it. Because it can scientifically determine the formation mechanism of a certain element’s spatial distribution without premise assumptions, and has low sample size requirements, it is immune to collinear immunity, so it has been widely used in the social and economic field.[41][42]. The factor detector of this method is suitable for exploring the influence of external factors on the coupling coordination relationship between healthcare resources allocation and service utilization. The model formula is as follows:

\[
q = 1 - \frac{1}{N\sigma^2} \sum_{h=1}^{L} N_h \sigma_h^2
\]

In the above formula, \(q\) is the interpretive degree value of factor \(X\); \(h=1, ..., L\) is the layering of factor \(X\), \(N\) and \(N_h\) are the number of samples in the entire area and the detection area; \(\sigma^2\) and \(\sigma_h^2\) represent the total area and the detection area \(Y\) value variance. The value range of \(q\) is \([0, 1]\). The larger the value of \(q\), the stronger the interpretive degree of the detection factor to the spatial difference of the dependent variable[43].

Results

Overview of the development of coupling coordination

According to relevant formulas, this paper calculated healthcare resources allocation, service utilization index, coupling coordination degree and relative development degree (Fig.1). From 2010 to 2018, China’s healthcare resources allocation index showed an upward trend, and the coefficient of variation of primary healthcare institutions
and hospital indexes dropped from 0.723 and 1.023 to 0.713 and 0.813, respectively (Fig. 2). The healthcare service utilization index of primary healthcare institutions showed a trend of rising first and then decreasing, while hospitals showed an upward trend. The former coefficient of variation of primary healthcare institutions and hospital indexes increased from 0.344 to 0.385, and the latter decreased from 0.442 to 0.342. The coupling coordination degree of primary healthcare institutions and hospitals increased from 0.448 and 0.418 in 2010 to 0.519 and 0.534 in 2018, respectively, while the relative development degree increased from 0.469 and 0.466 in 2010 to 0.767 and 0.578 in 2018, respectively. Therefore, the basic preliminary conclusions can be drawn as follows: On the one hand, the level of healthcare resources allocation and service utilization in China has been improved. The degree of improvement in the former is not much different between the two types of institutions, and the latter is more obvious in the hospital. This shows that although the service capacity of primary healthcare institutions has improved rapidly in recent years, the utilization level of healthcare services has not been synchronously improved. The possible reasons for this are as follows: Firstly, the starting point for the allocation of healthcare resources in primary healthcare institutions is low, and it is difficult to make major improvements in a short time. Secondly, the increase in income per capita has led to a decrease in the price elasticity of demand for healthcare services. Thirdly, the improvement of traffic conditions has improved the hospital's accessibility. Finally, the residents pay more and more attention to the quality and effect of healthcare services. On the other hand, the spatial inequity of healthcare resources allocation is still relatively serious.

The shrinking speed of hospitals is significantly faster than that of primary healthcare institutions. This spatial inequity still needs to be resolved urgently. Besides, the spatial equity in the utilization of healthcare services is relatively small, and the difference between the two types of institutions is not obvious. This inequity in hospitals has decreased significantly, which may be related to the decline in the spatial inequity in the allocation of hospital healthcare resources. Furthermore, the coordinated development of the healthcare resources allocation and service utilization of the two types of institutions has changed from the lower level stage to the run-in stage. The coupling coordination types has shifted from slight imbalance to general coordination, and the relative development situation also shows the feature of lagging healthcare resources allocation, but it has been improved. Specifically, the improvement of the coupling coordination degree of the hospital is more obvious, and the improvement of the relative development degree of the primary healthcare institutions is more obvious. All in all, China's healthcare resources allocation and service utilization coupling coordination system has a good development trend, the lagging situation of healthcare resources allocation has gradually improved, and the coupling performance has tended to be optimized.
Spatial pattern distribution and type evolution of coupling coordination degree

In order to study the spatial distribution characteristics and type evolution of the coupling coordination degree of healthcare resources allocation and service utilization in China, this paper draws the evolutionary spatial distribution map of coupling and coordination types in 2010, 2014 and 2018 (Fig.3). The study found that the coupling coordination degree basically shows the spatial distribution characteristics of higher in the eastern area, central in the central area, and lower in the border areas in the northwest, northeast, and southwest. At the same time, the spatial inequity is more obvious. The average condition of the spatial pattern of the coupling coordination relationship of the
primary healthcare institutions is better than that of the hospitals. However, the spatial pattern of the coupling coordination relationship of the hospital has improved significantly.

In order to more comprehensively show the development of China's healthcare resources allocation and service utilization coupling coordination degree, a 2010-2018 coupling coordination type evolution table was produced. It can be seen from Table 3 that the average condition of the spatial pattern of the coupling coordination relationship of the primary healthcare institutions is better than that of the hospitals. However, the spatial pattern of the coupling coordination relationship of the hospital has improved significantly. This result is actually directly related to the unsatisfactory implementation of the policy of grading diagnosis and treatment reform in recent years.  

Table 3 The evolution of coupling coordination type of healthcare resource allocation and utilization in 2010, 2014 and 2018

| Area       | Primary healthcare institutions | Hospital  |
|------------|---------------------------------|-----------|
|            | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  |
| China      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Shanghai   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Beijing    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Jiangsu    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Guangdong  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Zhejiang   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Shandong   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Chongqing  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Hubei      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Henan      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Tianjin    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Hunan      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Sichuan    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Hebei      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Guangxi    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Fujian     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Jiangxi    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Hainan     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Anhui      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Shaanxi    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Guizhou    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Liaoning   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Shanxi     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Jilin      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Gansu      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Ningxia    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Heilongjiang |    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
The evolution of the coupling coordination patterns: The level of primary healthcare institutions has changed from the "3-6-13-8-0-0-1" (the numbers indicate the number of 7 types of coupling coordination from severe imbalance to best coordination in the current year) pattern in 2010 to the "2-3-8-10-6-1-1" pattern in 2018. The hospital level changed from the "4-10-11-3-1-1-1" pattern in 2010 to the "2-3-8-10-6-1-1" pattern in 2018. After the number of serious imbalance, moderate imbalance, and slight imbalance types of coupling coordination between the two types of institutions decreased, they were mainly distributed in the border areas of the northwest, northeast, southwest, and parts of the middle and upper reaches of the Yellow River. After the number of general coordination types increased, they were mainly distributed in the central region and individual regions in the east and west. After the number of general, better and Best coordination types increases, it is mainly distributed in the economically developed areas of the east.

The evolution of the coupling coordination types: In the past 9 years, there have been more primary healthcare institutions than hospitals in the areas where coupling and coordination types have not changed. Beijing, Tianjin at the level of primary healthcare institutions and Gansu, Sichuan, Ningxia, Guizhou, Shandong, and Zhejiang at the hospital level has been upgraded by two levels. Beijing and Zhejiang changed from general coordination type to good coordination type. Tianjin and Shandong changed from slight imbalance type to general coordinated type. Gansu changed from serious imbalance type to slight imbalance type. Sichuan, Ningxia and Guizhou changed from moderately uncoordinated type to general coordination type. This shows that the coupling coordination in these areas has developed rapidly in recent years. In addition, the remaining areas have only been upgraded by one level. The specific types of changes in various regions are not detailed here.

The evolution of the coupling coordination subtypes: The lagging feature of China's healthcare resources allocation is obvious, but it has improved over the past 9 years (Fig.4). The primary healthcare institutions have shifted from a severely lagging resource allocation pattern of "29-2-0" (the numbers indicate the number of three types of relative development from lagging resources to advanced resources in the current year) in 2010 to a relatively lagging pattern of resource allocation of "15-13-3" in 2018. In 2010 ("27-4-0") and 2018 ("26-3-2"), the hospital resources allocation was seriously lagging behind. It can be seen that the improvement of primary healthcare institutions is more obvious than that of hospitals. The study also found that after 9 years of development, the relative development of the eastern region is better than that of the central and western regions. Specifically, After 9 years of development, at the level of primary healthcare institutions, the eastern regions except Guangdong are all non-resource lagging types, while the central and western regions are only Henan, Jilin, Guizhou and Shaanxi. After nine years of development, only Beijing, Shanghai, Tianjin, Zhejiang, Shandong, and Henan are lagging in non-resources allocation at the hospital level, while
the remaining 26 provinces are all lagging in resource allocation. The remaining 26 provinces, cities, and autonomous regions are all lagging resource allocation types. The types of advanced resources allocation in primary healthcare institutions and hospitals have emerged from 2012 and 2015, respectively. The changes in the relative development types of various regions are not detailed here.

**Spatial clustering characteristics and evolution of coupling coordination degree**

Global spatial autocorrelation

In this paper, the *Global Moran's I* index and Getis-Ord General G index (Table 4) in 2010, 2014 and 2018 are calculated to further analyze the evolution of the spatial agglomeration characteristics of the coupling coordination degree. The study found that: ① The *Global Moran's I* values for all three years are positive \( Z(I) > 1.96, P(I) < 0.05 \), indicating that the coupling coordination degree between China's healthcare resources allocation and service utilization has spatial autocorrelation. The value of the *Global Moran's I* value of primary healthcare institutions during 2010-2014 has continued to weaken the spatial autocorrelation of the coordination degree, and it has increased during 2014-2018, while the situation in hospitals is just the opposite. However, the spatial autocorrelation years of the coupling coordination degree of the two types of institutions in 2018 have weakened compared with 2010. ② The \( G(d) \) and \( E(d) \) values of the three years are relatively close, and all have passed the significance test. The coupling coordination degree of healthcare resources allocation and service utilization has significant high-value aggregation and low-value aggregation in space, indicating that there are hot spots in the development of coupled coordination. The difference between the \( G(d) \) value and the \( E(d) \) value shows that the spatial agglomeration of the coupling coordination of the primary healthcare institutions shows a trend of weakening and then increasing, while the hospital shows a trend of weakening. The value of \( G(d) \) and the range of its change indicate that the hot spot of the coupling coordination degree has evolved and migrated slightly based on the original distribution pattern.

| Institutions | \( M(I) \) | \( Z(I) \) | \( P(I) \) | \( G(d) \) | \( Z(d) \) | \( P(d) \) | \( E(d) \) | \( G(d)-E(d) \) |
|--------------|---------|---------|---------|---------|---------|---------|---------|---------|
| Primary 2010 | 0.223   | 4.785   | 0.000   | 0.414   | 3.498   | 0.000   | 0.359   | 0.055   |
| Primary 2014 | 0.186   | 4.060   | 0.000   | 0.409   | 3.291   | 0.001   | 0.359   | 0.050   |
| Primary 2018 | 0.192   | 4.144   | 0.000   | 0.415   | 3.503   | 0.000   | 0.359   | 0.055   |
| Hospital 2010 | 0.122  | 2.914   | 0.004   | 0.410   | 2.689   | 0.007   | 0.359   | 0.051   |
| Hospital 2014 | 0.136  | 3.140   | 0.002   | 0.405   | 2.838   | 0.005   | 0.359   | 0.045   |
| Hospital 2018 | 0.116  | 2.777   | 0.005   | 0.400   | 2.804   | 0.005   | 0.359   | 0.041   |

Note: this table was compiled by the authors.

Local spatial autocorrelation
In this paper, by calculating the Getis-OrdG* \( i \) value of the coupling coordination degree of China's healthcare resources allocation and service utilization in 2010, 2014, and 2018, the local hotspot area evolution status is identified and the contribution of different spatial units to the global autocorrelation is analyzed. Based on the Manual classification in ArcGIS, the Getis-OrdG* \( i \) value is divided into 7 types (Fig.5). The study found that there is a change in the overall pattern of the coupling coordination hotspot area. This change mainly occurred between 2010 and 2014, and also formed hotspot and coldspot areas centered on the middle and lower reaches of the Yangtze River and the Tibetan Plateau respectively. Compared with the primary healthcare institutions, the hospital has more radiation areas in hot spots than Hebei and Tianjin. In terms of the significance of local hotspots, the hotspot significance of primary healthcare institutions in the middle and lower reaches of the Yangtze River is higher than that of hospitals, that is, the local spatial aggregation effect of primary healthcare institutions is stronger than that of hospitals, which also verifies the above Getis-Ord General G index size. In terms of changes in cold and hot spots, the radiation range of the hospital's medium and low significance hot spots has expanded, while the number of high significance cold spots in primary healthcare institutions has decreased. This shows that the spatial agglomeration effect of hospital coupling coordination in the middle and lower reaches of the Yangtze River is obviously strengthened, while the spatial agglomeration effect of primary healthcare institutions in the Qinghai-Tibet region is significantly weakened. This may be closely related to such comprehensive factors as economic development, population structure and distribution, utilization of healthcare resources and services in these areas.

![Fig.5 Hot spot evolution of coupling coordination degree of healthcare resources allocation and service utilization in 2010, 2014 and 2018](image)

**Detection of spatial differentiation factors of coupling coordination**

On the basis of the above analysis, a bivariate correlation analysis of the relative development degree and coupling coordination degree of China's healthcare resources allocation and service utilization from 2010 to 2018 was conducted, and the average Person correlation coefficients of primary healthcare institutions and hospitals were calculated to be 0.681 and 0.784, which is a strong positive correlation, and the \( P \) value is 0.000. Therefore, combined with the above research, it is found that, within the healthcare service system, the lag of healthcare resources allocation is the main reason for lowering the degree of coupling coordination between healthcare resources and service utilization in China. The lag of healthcare resources allocation is actually relative to the utilization of healthcare services. At the same time, the above literature research also found that healthcare resources allocation and service utilization have the same influencing factors. Therefore, this paper selects the common influencing factors that affect the allocation of healthcare resources and service utilization to detect the spatial differentiation factors of the coupling coordination relationship. Combined with the previous research results and the availability of indicators, the population distribution and structure (population density, population urbanization, population aging), economic development level
(GDP per capita, non-agricultural industry ratio) and topographic conditions were finally selected as detection factors (Table 5). Empirical research is carried out using factor detection analysis methods of geographic detector. In ArcGIS 10.4 software, the relevant factors are classified into natural crack points, and the interpretive degree of each factor is calculated. The influence of each factor on the spatial differentiation of the coupling coordination relationship between the two types of institutions has both common points and different points (Table 6). The specific analysis is as follows:

| Factor Group       | Factors                        | Data sources and calculations                                                                 |
|--------------------|--------------------------------|-----------------------------------------------------------------------------------------------|
| Population subsystem | \( x_1 \), Population density | From “China Population and Employment Statistical Yearbook” (person/km\(^2\))                  |
|                    | \( x_2 \), Population urbanization | From “China Population and Employment Statistical Yearbook” (%)                                |
|                    | \( x_3 \), Population aging    | From “China Population and Employment Statistical Yearbook” (%)                                |
| Economic subsystem  | \( x_4 \), GDP per capita      | From “China Statistical Yearbook” (Yuan)                                                      |
|                    | \( x_5 \), Non-agricultural industry ratio | From “China Statistical Yearbook” (Yuan)                                                      |
| Topographical conditions | \( x_6 \), Topographical conditions | Self-made variables (level)                                                                |

Note: this table was compiled by the authors. The Topographical conditions are self-made variables. In this paper, according to the distribution of the three-step ladder in China, the classification of the top and bottom of the topography is divided into three levels. Superior areas: Beijing, Tianjin, Hebei, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Guangdong, Hainan; good areas: Shanxi, Inner Mongolia, Henan, Hubei, Hunan, Guangxi, Guizhou, Sichuan, Yunnan, Shaanxi, Gansu, Ningxia, Xinjiang; poor areas: Qinghai, Tibet.

| Institutions | Population density \( q(p) \) | Population urbanization \( q(p) \) | Population aging \( q(p) \) | GDP per capita \( q(p) \) | Non-agricultural industry ratio \( q(p) \) | Topographical conditions \( q(p) \) |
|--------------|---------------------------------|-----------------------------------|-----------------------------|-----------------------------|------------------------------------------|----------------------------------|
| Primary2010  | 0.772 (0.036)                   | 0.315 (0.432)                    | 0.380 (0.167)               | 0.343 (0.349)               | 0.321 (0.295)                           | 0.407 (0.000)                    |
| Primary 2014 | 0.804 (0.018)                   | 0.455 (0.190)                    | 0.219 (0.354)               | 0.459 (0.282)               | 0.488 (0.221)                           | 0.364 (0.003)                    |
| Primary 2018 | 0.759 (0.052)                   | 0.513 (0.101)                    | 0.316 (0.100)               | 0.540 (0.106)               | 0.450 (0.295)                           | 0.362 (0.003)                    |
| Hospital2010 | 0.792 (0.016)                   | 0.675 (0.005)                    | 0.220 (0.369)               | 0.701 (0.002)               | 0.595 (0.008)                           | 0.448 (0.000)                    |
| Hospital 2014 | 0.812 (0.014)                  | 0.660 (0.010)                    | 0.168 (0.494)               | 0.680 (0.011)               | 0.641 (0.031)                           | 0.407 (0.000)                    |
| Hospital 2018 | 0.804 (0.030)                  | 0.668 (0.012)                    | 0.309 (0.114)               | 0.654 (0.022)               | 0.666 (0.023)                           | 0.352 (0.007)                    |

Note: this table was compiled by the authors.

The conclusion of the time heterogeneity of the factors is as follows: From the perspective of the significance of the factors, in terms of commonality, the population density and topographical conditions have basically a significant impact above the level of 0.05% for the two types of institutions for three years. In terms of different points, the population urbanization, GDP per capita, and non-agricultural industry ratio above 0.05% are only significant to the hospital. Population urbanization, GDP per capita, and the population aging have had an impact on the primary healthcare institutions at a significance level of 0.1% only in 2018. From the point of view of the magnitude and change of the influence of the factors, the common point is that the response intensity of the hospital to the influencing
factors is basically greater than that of the primary healthcare institutions (excluding the topographical conditions in 2018). At the same time, population density is the primary factor that affects the coupling coordination of the two types of institutions. In addition, the influence of the topographical conditions on the two types of institutions has declined. Finally, the impact of the population density on the two types of institutions shows a slight fluctuation trend.

The conclusion of the spatial heterogeneity of the factors is as follows: Since the spatial differences of the factors in 2010, 2014 and 2018 are not obvious, this paper selects the factors that have a significant impact in the two types of institutions in 2018 and uses ArcGIS 10.4 software for spatial matching analysis, make the spatial matching distribution map of coupling coordination degree and various factors (Fig. 6). There are 9 types of coupling matching. The study found that the spatial heterogeneity of factors in primary healthcare institutions and hospitals is basically the same. Except for the analysis results in Gansu province, the results are the same in the remaining provinces. The matching factors of population density, population urbanization, GDP per capita, and topographical conditions types at the hospital level in the Gansu province are all low coordination and low factors. Fig.6 shows the matching of the four factors at the primary healthcare institutions level in Gansu province, but not at the hospital level. The areas of high coordination and high factor level and high coordination and medium factor level of primary healthcare institutions and hospitals are basically distributed in the eastern region. The population density, population urbanization, population aging (primary healthcare institutions), GDP per capita, and non-agricultural industries ratio (hospitals) in these areas are higher, and the topographical conditions are superior. These factors have obvious effects on the positive interaction between healthcare resources and service utilization. Some areas in Northwest, Southwest, and Northeast have just low levels of these factors, and they have become the main areas with low levels of coordination and factor.

**Fig. 6** Spatial matching between the coupling coordination degree of healthcare resource allocation and service utilization and factor level in 2018

**Discussion**

Population distribution and structure play a leading role in the allocation of healthcare resources and service utilization. Generally, population density is the first factor, and its improvement has a direct impact on the allocation of healthcare resources and service utilization. At present, the characteristics of the spatial differences in the spatial distribution of China's population make the per capita level of healthcare resources allocation in the Northeast, Inner Mongolia and other regions higher, and the spatial allocation in the eastern region higher. The problems of per capita and space accessibility of healthcare resources allocation still need to be resolved. Urbanization level can also promote the rational allocation of healthcare resources and improve the utilization rate of healthcare services, especially to improve the utilization of healthcare services in hospitals, but it will also lead to inequity in urban and rural resource allocation, aggravate environmental pollution, increase health costs and other issues. Therefore, we need to dialectically view its impact. The study found that the impact of population urbanization on primary healthcare
institutions in 2018 only reached a significant level of 0.1%. This may be due to the fact that primary healthcare institutions are relatively insensitive to population urbanization, while hospitals are more sensitive. In particular, the “siphon effect” of large hospitals on regional healthcare services has exacerbated this sensitivity. At the same time, it may be related to the effect of advocating the order of first-level primary healthcare consultations in recent years. As the level of urbanization increases, the contradiction between healthcare resources allocation and service utilization will become more prominent.③ As the aging process is accompanied by family miniaturization and empty nesting, the population aging will also have a certain impact on healthcare resources allocation and service utilization. The study found that The aging of the population only affects the primary healthcare institutions at a significance level of 0.1% in 2018, which is similar to the findings of existing studies[16]. This may be related to the aging of the population only playing a supporting role in the process of increasing healthcare costs[49]. However, in the future, the use of integrated healthcare and nursing services for the elderly population, such as chronic disease management, elderly care, and convalescence, will require more primary healthcare resources. The study also found that the impact of aging population on hospitals is not significant, but it is gradually approaching the significant level of 0.1%, which may be related to the large number of elderly people who still solve common and chronic diseases in primary healthcare institutions. Considering that the aging of the population has a significant impact on hospitalization costs[50], as the aging population continues to increase, the influence of hospital will gradually increase.

The level of economic development is a decisive factor in the investment of regional healthcare resources. It plays an important role in attracting more capital and talents in the region. At the same time, it also has a greater role in stimulating the healthcare service demand of residents in the region. However, due to the strong concentration and weak diffusion effect of healthcare services capabilities in economically developed areas, the loss of healthcare resources and service utilization in the less developed surrounding areas has resulted. This situation has exacerbated the contradiction between resource space allocation and service utilization. Due to the fiscal decentralization system, local governments have reduced healthcare investment[51], fiscal transfer payment methods and government budgetary expenditures have become the main ways to improve the allocation of healthcare resources[52][53]. In recent years, the higher-level government creatively uses the financial transfer payment method, the basic rigid regulations and subsidies for local governments to increase healthcare investment have enabled the level of resource allocation of primary healthcare institutions to be improved. The study found that the impact of economic indicators on the coupling coordination of primary healthcare institutions began to be significant at the 0.1% level in 2018. This may be explained by the fact that before the local government's medical investment was mainly tilted towards the hospital, and in recent years it has gradually tilted towards the primary healthcare institutions. The study also found that economic indicators have a significantly greater impact on the hospital level than primary healthcare institutions, especially the proportion of non-agricultural industries ratio only has a significant impact on the hospital level. This shows that the agglomeration of hospital healthcare resources and service utilization is affected by economic development and the upgrading of industrial structure. At the same time, this influence is still being strengthened. High-quality resources are still expanding and gathering in large healthcare institutions, but it is difficult to sink to primary healthcare institutions, which is not conducive to the coordinated development of healthcare resources allocation and service utilization.

In general, the more complex the topographical conditions, the more difficult it is to improve the level of healthcare resources allocation, and the lower the utilization rate of residents' healthcare services. In the mountainous area with complex terrain and high altitude, due to the strong spatial dispersion, the cost of healthcare service input is high, but the benefit is low. Although the government has adopted fiscal transfer payments in recent years to alleviate the problem of per capita allocation of healthcare resources in economically underdeveloped areas, the problem of space access is still very difficult. At the same time, due to the weak spatial correlation in the mountainous areas, the healthcare service radius of each spatial unit is small, and there is a situation of surplus healthcare resources and wasteful coexistence, resulting in a contradiction between the supply and demand of healthcare resources in
mountainous areas. The mountainous areas with complex terrain in China are basically distributed in the northwest and southwest inland areas. Although the per capita allocation of healthcare resources in these areas is higher than that in the eastern plains and coastal areas, the spatial accessibility of healthcare resources is still far from the eastern area. However, there is still a large gap between the spatial accessibility of healthcare resources and the eastern plains and coastal areas. The study found that the influence of topographical conditions on the coupling coordination of the two types of institutions gradually decreased. This may be because on the one hand, in recent years, the country’s social and economic development has continuously strengthened the construction of grassroots facilities, improved the construction of transportation networks, and increased the per capita and spatial accessibility of healthcare resources allocation. On the other hand, as residents’ income growth, the demand for medical services was released.

Conclusions

The conclusions of this paper mainly include the following:

○ From 2010 to 2018, China's healthcare resources allocation and service utilization coupling coordination system changed from slight imbalance to general coordination. The lag of healthcare resources allocation has gradually improved. However, the problem of spatial inequity in the allocation of healthcare resources and the slow increase in service utilization of primary healthcare institutions still need to be resolved.

○ The coupling coordination degree basically shows the spatial distribution characteristics of higher in the eastern area, central in the central area, and lower in the border areas in the northwest, northeast, and southwest. The average situation of the spatial pattern of the coupling and coordination relationship of the primary healthcare institutions is better than that of the hospital. The lag problem of hospital healthcare resources allocation is still more serious than that of primary healthcare institutions.

○ The coupling coordination degree has a significant spatial agglomeration characteristic, but it has weakened. The study found that there is a change in the overall pattern of the coupling coordination hotspot area, and also formed hotspot and coldspot areas centered on the middle and lower reaches of the Yangtze River and the Tibetan Plateau respectively. The local spatial concentration effect of primary healthcare institutions is stronger than that of hospitals.

○ The lag of healthcare resources allocation is the main reason for lowering the level of coupling and coordination between healthcare resources allocation and service utilization in China. The spatial differentiation of coupling coordination degree is influenced by population distribution and structure, economic development level and topographical condition factors, and has obvious spatial and temporal heterogeneity. Population distribution and structure are the dominant factors common to primary healthcare institutions and hospitals, but the impact intensity and significance of other determinants are different.

This article only uses the provincial level as the research unit, and if it can be further refined to use the city and county as the research unit, it will help to enhance the reliability and pertinence of the research. At the same time, this article only makes a two-level hierarchical analysis of healthcare institutions, and other scholars can consider subsequent more detailed research.

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