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Aspects of public health development in China's western region

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Abstract

The public health level in a country is closely related to national development and quality of life. In order to appraise the level of health services in the western region of China, panel data of 124 prefecture-level units covering the period 2011 to 2021 was used together with a health evaluation index system based on four dimensions: quality of life, environmental situation, the level of health services and longevity. To assess this, we used entropy weights, standard deviation and coefficient of variation together with the geographical detector model that measures the stratified spatial heterogeneity. The results show that although public health services have improved overall, the various dimensions are still not balanced as longevity did not match up everywhere. While the developmental level of the various health dimensions presents a pattern of a relatively smooth increasing gradient in the west-central-east direction, the situation with respect to the north-central-south is more uneven with both ups and downs. However, a trend of continuous enhancement of all health dimensions was found with a significant positive correlation of spatial clustering, with hotspots and 'sub-hotspots' contracting from north to south, while coldspots and 'sub-coldspots' expanded from west to east. This can be seen as the result of multiple factors, with the level of urbanization and economic level as the dominant factors and government guidance, agglomeration capacity and industrial structure being auxiliary.

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Introduction

Persistent health inequities have been identified as a global public health problem. Strengthening public health practices and promoting health equity have become an important quest to achieve quality and sustainable development in both developed and developing countries. Since the implementation of the strategy for the development of the western region, the economic and social development of the western region has made great achievements, but the imbalance and inadequacy of development in the western region and the large gap between the western region and the eastern region are still prominent. It is therefore important to reshape the pattern of public health development in the western region and to expand China's economic and geographic regional development through scientific public spatial planning and integration of the health resources.

Life expectancy per capita in China has risen from 74.8 years in 2010 to 78.2 years in 2021 and maternal mortality rate has declined from 30.0 per 100,000 to 16.1 per 100,000, while that of infants (here counted as children up to their first year of life) has declined from 13.1% to 5.0% and from 16.4% to 7.1%, for children under 5 years of age. The main health indicators now rank among the top of those for middle- and high-income countries. However, the overall situation is unbalanced, with insufficient developments in some regions including a complex health situation without a clear connection with the factors that influence health. Compared to the central and eastern regions, there is room for strategic economic and geographic expansion towards better quality in the West. Population, resources and environment are not well connected and there is an insufficient supply of health services and limited knowledge of what is available. Considering the growing demand for a better quality of health services in the western region, an improved national health policy is needed.

Overseas papers on public health discuss the development towards high quality in ecological protection, technological progress, social welfare and population health, with emphasis on economy (Longhurst *et al.*, 2016; Gryshova *et al*., 2019). Also in China, similar discussions have been carried out (Han & Zhong, 2021), particularly with regard to goal requirements (Zhang *et al*., 2019) and paths to realization (Yao & Wang, 2023). Other papers focus on public services at the provincial and municipal scale at different parts of the country (Yan & Hu, 2022; Chen *et al*., 2023; Hu *et al*., 2023; Wang *et al*., 2023; Wei *et al*., 2023). Many papers account for important economic areas along the Yellow River and the Yangtze River Basins (Yan & Zhang, 2022; Zhang & Qi, 2023), while others refer to major urban agglomerations, such as those in the Yangtze River Delta, in Harbin-Changchun and in Chengdu-Chongqing (Du *et al*., 2022; Yin *et al*., 2023; Yang *et al*., 2023); There are also those who deal specifically with the economy (Shan & Li, 2022), agriculture (Liu *et al*., 2020), tourism (Liu & Tang, 2022), education (Ji *et al*., 2023) and public services (Yang & Cao, 2022). United Nations' Sustainable Development Goals (SDG) have emerged as important for the exploration of high-quality health systems (Kruk *et al*., 2018). Hou *et al*. (2021) adopted the Delphi method and conducted a comprehensive evaluation of the development level of health care in Jiangsu Province, while Luo *et al*. (2021) analyzed the development of public health in the central region of China from four aspects: lifestyle, production, environment and healthcare. Li & Zeng (2022) constructed an exploratory urban health evaluation index system based on available public health, environmental exposure risk and public health performance to measure the level of health-related developments in 284 Chinese cities above the prefecture level.

The study of the factors influencing public health discuss the effect of the climate (Qiu *et al*., 2020), transport (Amer & Bergquist, 2021), economic development and urbanization (Black & Black, 2009), the level of education and income (Wang, 2014), accessibility of medical and health resources (Shaltynov *et al*., 2022) and public health expenditures (Sunhee & Wang, 2019). Li (2002) point to the impact of health policies, health technologies and health inputs and argue that public health has different degrees of facilitating and constraining effects on socio-economic development. By developing a causal model, Booysen *et al.* (2021) feel family functions are affected by, and contribute to, health and health-related behaviour, while Straker *et al*. (2021) suggest that occupational sport activities for disadvantaged groups enhance health and reduce socio-economic health disparities. Still others have analyzed the coupling and coordination of healthcare services empirically considering economic development and the factors influencing it (Yang *et al*., 2024).

We note that research on public health in China often has a national scope or is focused on the central and the southern regions, with only few studies from the western part of the country. Our objective was to contribute to modernization of the health services in China's western region and assist implementation of the national *Healthy China* strategy.

Materials and Methods

We investigated 124 prefecture-level administrative units during the 2011-2021 period using a comprehensive evaluation index system of public heath development based on four dimensions: life quality, environmental features, accessibility of health services and longevity (Table 1).

Study area and data sources

China's western region is located in the central part of the Asian continent. It comprises five south-western provinces and municipalities (Chongqing, Sichuan, Yunnan, Guizhou and Tibet), five north-western provinces and regions (Shaanxi, Gansu, Qinghai, Xinjiang and Ningxia), Inner Mongolia and Guangxi autonomous region, with a total of 131 prefectures and municipalities under its jurisdiction. The total area is about 6.86 million km^2 accounting for 71.5% of China's land area, with a population of 383 million according to the seventh national census, which amounts to 27.1% of the country's total population (Figure 1). The region is characterized by large elevations with significant climatic variations, rich material resources but unevenly spread economy with much ethnic and cultural diversity.

Despite uneven and not well coordinated development, the western region is an important economic corridor under China's *Belt and Road initiative*, which cuts across from the East to the West and also connects the South with the North. Seven cities:

Table 1. Evaluation index system of the public health development in China's western region.

Target dimension	Feature	Indicator property	Weight
General quality of life	Per capita consumption expenditures on tobacco and alcohol	−	0.0295
	Per capita expenditure on health care	+	0.0887
Environmental characteristics	Forest coverage rate	+	0.1284
	Proportion of days with good air quality	+	0.0169
	Application of agricultural fertilizers (pure method)	−	0.0107
	Non-hazardous treatment rate of domestic waste	+	0.0224
Health services	Number of health-care facilities per 1,000 population	+	0.0802
	Number of beds in health-care facilities per 1,000 population	+	0.1032
	Health technicians per 1,000 population	+	0.0792
	Number of practicing (assistant) physicians per 1,000 population	+	0.0796
	Registered nurses per 1,000 population	+	0.0981
	Number of village health units per 1,000 population	+	0.1051
	Number of rural doctors and health workers per 1,000 population	+	0.1078
Longevity	Maternal mortality rate	−	0.0267
	Under-five mortality rate (including infants)	−	0.0113
	Infant mortality rate	−	0.0123

Positive indicators represent growth and negative indicators the opposite.

Naqu and Ali in Tibet; and Haibei in Qinghai; and Hami, Tacheng Hetian and Kezilesu in Xinjiang Province were excluded due to missing data, so the study included only 124 municipal units. The specific analyses were not presented year by year but five-year time sections around the Twelfth, the Thirteenth and the Fourteenth Five-Year Plan, *i.e.* 2011-2015, 2016-2020 and 2021-2025, respectively. The data come from the China Urban Statistical Yearbook; the statistical yearbooks of the 12 western provinces; the health and sanitation yearbooks; the statistical yearbooks of prefectural cities (autonomous regions, districts, and alliances); the statistical bulletins of national economic and social development; the statistical bulletins of health and sanitation development; and the bulletins of the state of the ecological environment. For a small amount of missing data, trend extrapolation, substitution of neighbouring years and interpolation were used to make up the reference. The Outline of the *Healthy China 2030 Plan* points out the need to comprehensively promote better health by optimizing services, perfecting protection and developing health facilities. The connotation of the public health system in the development context was based on previous analysis and existing relevant representative research results referring to health-related policy documents (Xu, 2020; Luo *et al.*, 2021; Liu *et al.*, 2021; Li & Zeng, 2022; Yang, 2022).

Variables

Health comprises psychological balance based on reasonable diet, moderate exercise, non-smoking and limited alcohol habits (Wei *et al.*, 2022). We therefore selected i) the per capita consumption expenditure on tobacco and alcohol and ii) the per capita expenditure on health care as indicators of life quality. For the environment four variables were chosen:i) surrounding land coverage; ii) air quality; iii); use of agricultural fertilizers; and iv) waste treatment. Various entries, expressed as number 1,000 population, were chosen to define the level of health development: i) healthcare facilities; ii) hospital beds; iii) technicians; iv) assistant physicians; v) nurses; vi) village health units; and vii) rural doctors and health workers. The average life expectancy was expressed as i) the maternal mortality rate; ii) the under-five (including infants) mortality rate; and iii) the mortality rate in infants only.

Statistical approach

The entropy method

An objective assignment method was used to determine the degree of variable dispersion (Chen *et al.*, 2009). The entropy and weight of each variable were calculated and the composite score computed as follows:

$$T_{ij-pos} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} + 0.0001, (i = 1,2,\dots,n; j = 1,2,\dots,m) \quad \text{Eq. 1}$$

$$T_{ij-neg} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} + 0.0001, (i = 1,2,\dots,n; j = 1,2,\dots,m) \quad \text{Eq. 2}$$

where $T_{ij\text{-}pos}$ is the standardized positive indicator; $T_{ij\text{-}neg}$ the standardized negative indicator; x_{ij} the value of the i evaluation object under the j indicator, n for any value of i; m for any value of j; max (x_{ij}); and min (x_{ij}) are the maximum and minimum values in order to eliminate the effect of 0 and negative values. The data obtained would be shifted by 0.0001 values as a whole and the m indicators and n regions selected.

The entropy value of the j indicator was calculated as:

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} P_{ij}\ln(P_{ij}) \quad \text{Eq. 3}$$

where $0 \leq e_j \leq 1$; ln the natural logarithm; n any of the i values mentioned in equations 1 and 2; and Pij the weight for the i evaluation object under the j indicator

$$= x_{ij}/\sum_{i=1}^{n} x_{ij}.$$

The weight of the j indicator is

$$W_j = g_j/\sum_{j=1}^{n} g_j \quad \text{Eq. 4}$$

where g_j is the coefficient of variation for the j:indicator

$$= 1 - e_j$$

Then the composite score s_i can be calculated as

$$= \sum_{j=1}^{m} W_j \times x_{ij} \quad \text{Eq. 5}$$

Standard deviation index and coefficient of variation

The standard deviation (SD) index and the coefficient of variation (CV) are used in the paper to indicate the absolute and relative gaps in the level of public health development among the cities in the west, respectively, and are calculated by the formula (Zhang & Cuminbibra, 2020):

$$V = U/S_0 \quad \text{Eq. 6}$$

where V is relative gaps in the level of public health development; U the absolute gap in the level of public health development

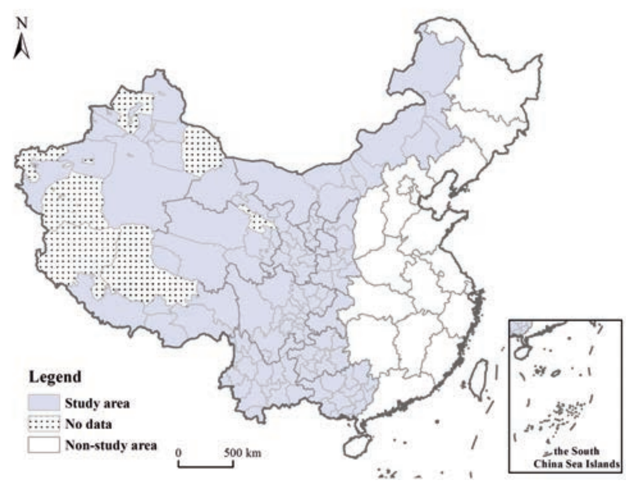

Figure 1. The spatial distribution of prefecture-level cities in the study area.

$$=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - S_0)^2}$$

S_i the level of public health development in i municipality; and S_0 the average level of high-quality development of public health in the municipalities in the western region. Higher U-values indicate higher absolute difference; and higher V-values larger relative differences.

Exploratory spatial data analysis

Exploratory spatial data analysis (ESDA) was used to mine data for spatial correlation features. It is categorized into global spatial autocorrelation and local spatial autocorrelation (Li & Zeng, 2022). Global Moran's I was used to measure the overall degree of spatial correlation of public health levels in the western region, calculated using the formula:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \quad \text{Eq. 7}$$

where n is the number of prefectures; w_{ij} the spatial weight matrix; x_i; x_j the observed values of prefectures i and j, respectively; $\bar{x}$ is the mean value of observations; and S^2 the variance of the attribute values. The value of I ranges from [-1, 1], $I > 0$ indicates spatial positive correlation, the closer to 1, the more the observations tend to be spatially clustered; $I < 0$ indicates negative correlation, the closer to -1, the more the observations tend to be dispersed; $I = 0$ indicates random distribution.

Local spatial correlation analysis was used using Getis-OrdGi*, which identifies coldspots and hotspots in the spatial concentration of a certain geographic event and to describe the spatial correlation between different geographic spatial units and their neighbours. The formula is:

$$G_i^*(d) = \sum_{j=1}^{n} W_{ij}(d)x_j / \sum_{j=1}^{n} x_j \quad \text{Eq. 8}$$

where W_{ij} (d) is the spatial weight; x the public health level score of each prefecture-level city.

Geodetector

According to the geodetector model and principles (http://www.geodetector.cn/), the data of the five detecting factors were discretized by the natural breaks method, and the data for the years 2011, 2016 and 2021 and the yearly averages converted into serial data. The resulting data were used as input for the geodetector software to derive the degree of influence of each factor on the public health developmentin the western region according to the formula:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h\sigma_h^2}{N\sigma^2} \quad \text{Eq. 9}$$

where L is the stratification of the influencing factor; N_h and s^2_h the sample size and variance of stratum h; N and σ^2 the sample size and variance of the whole district, respectively; and q the explanatory power of the influencing factor, with a larger q indicating stronger explanatory power.

Results

Temporal evolution

The weights of the indicator variables were calculated according to the entropy method (Table 1) including the overall and sub-dimension scores on the basis of these weights. Furthermore, the SD indices and CV of the public health levels in each city were further calculated for the target years of 2011, 2016, 2021 and the results plotted as dot line graphs together with a bar diagram of the four health dimensions (Figure 2). As can be seen, a substantial growth trend of public health development appeared, with the comprehensive score increasing from 38.175 in 2011 to 46.963 in 2016 to 57.406 in 2021, with an average growth rate of 22.6% and a total growth rate of up to 50.4%. However, the development was not balanced since the four dimensions showed different degrees of positive development trends during the study period. The index for each of the four dimensions (health quality, the environment, health services and longevity) rose from 4.970, 11.307, 17.754; 4.144 to 8.084, 13.190, 30.751; and 5.381, respectively, during the past 11 years, in which health services became the core driving force of high-quality development, with an increase of 73.2%, while longevity rose only by 29.9%.

Regional differences in the level of high-quality development of public health were further measured by SD indices and CVs. The SD indices for 2011, 2016 and 2021 were 0.061, 0.059 and 0.061, respectively, showing a decreasing trend followed by recovery (a V trend) indicating that the absolute differences first narrowed but then increased, though the magnitude of changes was low. The CVs for 2011, 2016 and 2021 amounted to 0.198, 0.157 and 0.131, respectively, with an initial strong decline followed by a slow one (an L trend) but indicating that the relative differences between regions continued to diminish at a sunstantial rate (33.8%).

Spatial differentiation

To further reflect the spatial differentiation characteristics of

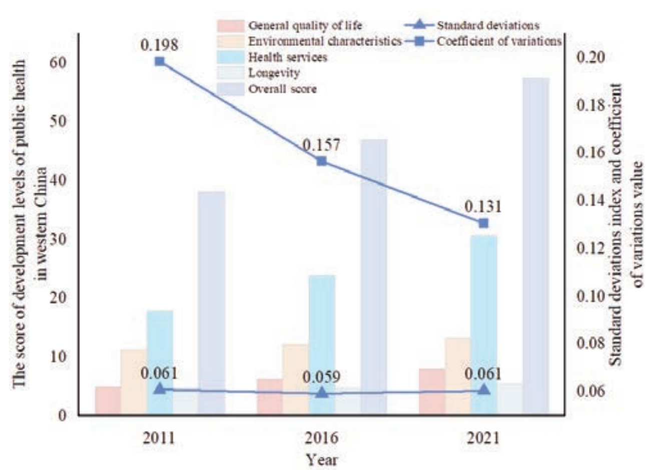

Figure 2. Scores, standard deviations and coefficients of variation of the development levels of public health in China's western region. The tall blue bar to the right for each year indicates the sum of the four dimensional scores for that year.

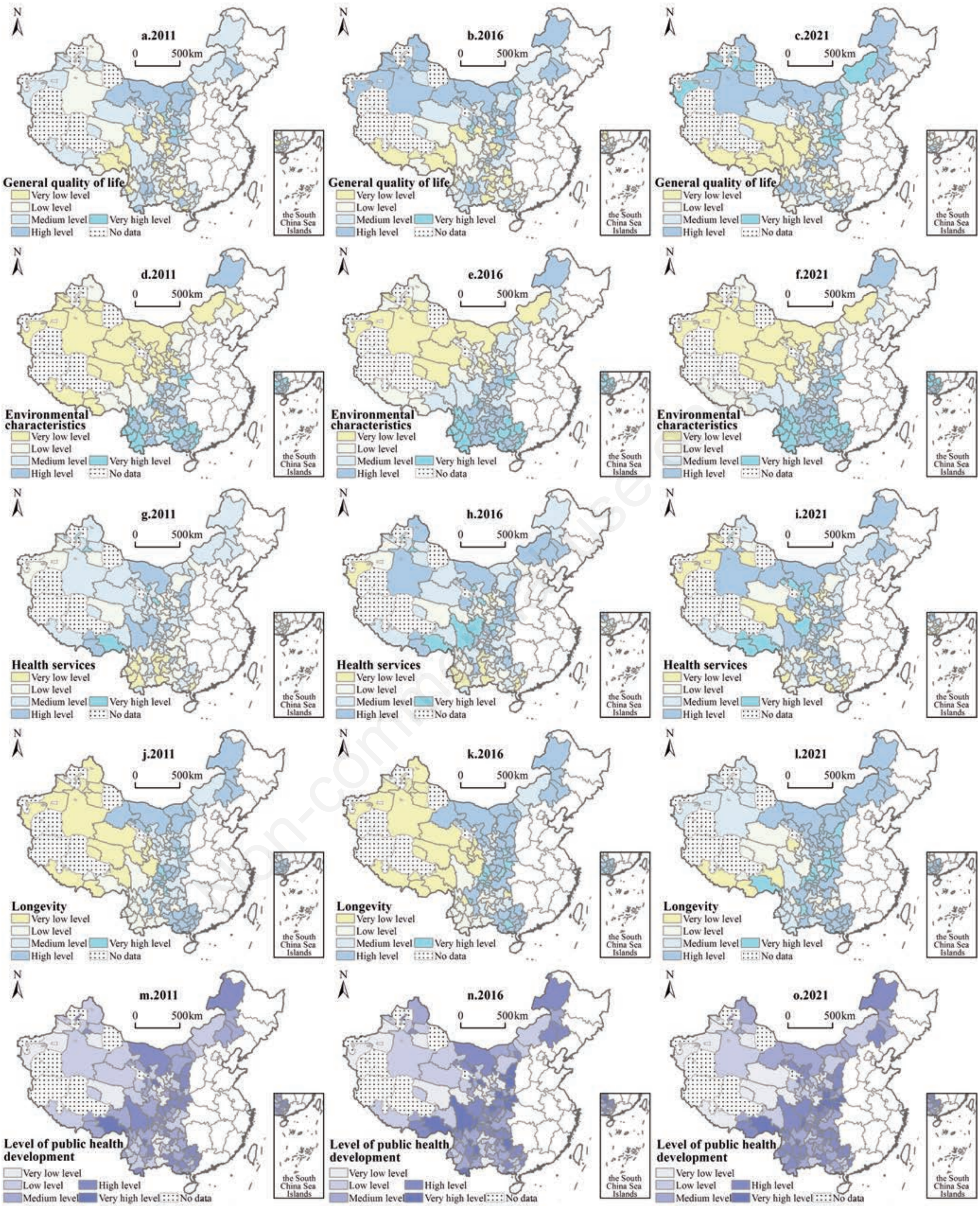

Figure 3. The spatial patterns of the sub-dimension levels of public health development in China's western region.

the level of development in the public health area from 2011 to 2021, the overall result of the 124 prefecture-level units was divided into 5 levels (very low; low; medium; high; and very high) using the natural breaks method (Figure 3).

Characterization of spatial differentiation by dimension

We found a T-shaped evolution of general quality of life characterized by a horizontal axis consisting of Northern Xinjiang-Gansu-Inner Mongolia, and a vertical one made up of the areas Ningxia-Shaanxi-Eastern Sichuan-Chongqing-Yunnan-Central-Southern Guangxi (Figure 3A, B, C). From 2011 to 2021, the municipalities with strong general quality of life were found to mainly be concentrated along the geographical areas of this T shape. Those with medium levels were found to be sporadic without specific distribution, while those with lower developmental levels were mainly found in southern Tibet and its peripheral regions due to the health awareness of residents there and the level of economic development.

The north-south spatial differentiation in the development of the environmental characteristics showed a significant collapse in the north-western part of the region, which is strongly correlated with natural geographic factors (Figures 3D, E, F). From 2011 to 2021, with the exception of Hulunbeier, Xingan and Chifeng City in the North-east, the prefectures and cities with higher levels basically concentrated in the South-east, such as the Yunnan-Guizhou Plateau (the western part of the two hilly regions) the Sichuan Basin, the Qinling Region and the south-central part of the Loess Plateau. This was deemed to be due to the unique ecological and environmental advantages of these places, with a high rate of forest coverage, a large number of days of good air quality, a small amount of agricultural fertilizers applied, and a high rate of domestic waste disposal. Further, a gradient of medium, low and very low levels extended north-westward, with low values occurring in areas, such as the contiguous region of Xinjiang-Gansu-Qinghai-Ningxia, the south-eastern part of the Qinghai-Tibetan Plateau and the Inner Mongolian Plateau.

The development of health services is mainly characterized by a highly uneven spatial distribution within the districts (Figure 3G, H, I). From 2011 to 2021, the number of cities with health services at very high and high levels were found to gradually increase, with a total of 13 cities: Xining in Qinghai; Tongchuan in Shaanxi; Karamay in Xinjiang; Lanzhou, Wuwei, Jinchang and Zhangye in Gansu; Ziyang, Guangyuan and Aba in Sichuan; and Lasa, Shannan and Linzhi in Tibet moved up to the high level in 2021, while the remaining cities in the medium, low and very low levels both increased and decreased. On the whole, the changes in the development of health services in regional capital cities and central cities were small, which may be due to the fact that with the accelerating process of urbanization, the population of such areas continued to increase, resulting in a low per capita share of medical and health resources making the health service score lag behind that of other areas.

The spatial differentiation of the longevity roughly coincided with the law of dividing the three major terrains in China, with significant east-west differences, bounded by the demarcation line of the first and second terraces (Figure 3J, K, L). During the past 11 years, the cities and municipalities where the development of the longevity was at very high and high levels were mainly located in the province-wide areas of Inner Mongolia, Ningxia, Shaanxi, Chongqing and Guangxi, as well as in the areas of north-central Gansu, south-central Sichuan, north-central Guizhou and eastern Yunnan, where the level of quality of the health services was higher than in the West, and consequently the level of the health of the population and the per capita life expectancy were also higher.

Characteristics of spatial differentiation at the general level

There were obvious differences with respect to development in the spatial distribution of the 124 prefecture-level cities, which basically showed an west-central-east gradient and north-central-south more uneven progress, with both ups and downs even if some degree of alignment between them was noted (Figures 3M, N, O). We found that i) the distribution was high in the East and low in the West, high in the South and low in the North. In 2011 and 2016, Gansu and Ningxia regions and the junction of Yunnan, Guizhou and Sichuan provinces showed an obvious collapse under the driving effect of Chengdu-Chongqing, Qianzhong and Dianzhong urban agglomerations. The development of the junction area of the three provinces achieved a large growth rate in 2021, with Gansu and Ningxia regions still at a low level. The increase of development changes in the north-western region during the total study period is not large; ii) most of the areas with high values of public health in the whole region are near provincial capitals or regional centres as well as important city clusters. The Yangtze River Economic Belt Upstream Development Zone, and the Yellow River Basin Upstream Ecological Protection and High Quality Development Zone synergize and drive public health development significantly. Low-value zones were mostly found to be concentrated in remote areas such as Tibet, Xinjiang, Qinghai and other areas with complicated topography, inconvenient transportation, harsh climate environment and weak economic development where life is difficult; iii) the number of municipalities at a very high and high levels was 36, 50 and 51 in 2011, 2016 and 2021, respectively; the number of municipalities at the medium level was 42, 29 and 39, respectively; and the number of municipalities at a very low and low levels was 46, 45 and 34, respectively. This reflects a continuous increase in the number of municipalities with very high and high levels of public health, a gradual decrease in the number of municipalities with very low and low levels, fluctuating changes in the number of municipalities with intermediate levels of public health development, but there were also erratic movements during the study period.

Spatial correlation

Based on the index of the level of public health development in each prefecture-level city, Global Moran's *I* values for the level of development of public health in 2011, 2016 and 2021 obtained using ESDA to be 0.103, 0.157, and 0.256, respectively. The *Z* scores ranged between 1.65 and 1.96 in 2011, while they were above the critical value of 1.96 at $p<0.01$ both in 2016 and 2021 (Table 2). This indicates that there was a positive development of public health in the western region during the period of 2011-2021. In addition, there was significant spatial clustering of prefecture-level units, both with respect to high levels of public health and low levels, with an overall trend of continuous enhancement.

Getis-OrdGi* was applied to explain the spatial correlation of the public health level of specific municipalities and their neighbouring municipalities. Figure 4 shows that the hotspot and sub-

Table 2. Global Moran's *I* index of public health development in China's western region.

Year	Moran's *I*	Z-score	p
2011	0.103	1.816	0.069
2016	0.157	2.698	0.007
2021	0.256	4.327	0.000

hotspot zones of the developmental level of public health in the western region contracted from north to south from 2011 to 2021. The coldspot and sub-coldspot zones expanded from the West to the East indicating that the trend of clustering of high-level units tended to weaken, while that of low-level units tended to strengthen. In 2011, hotspots and sub-hotspots were mainly distributed in the central and northern parts of Inner Mongolia, northern Gansu, southern Tibet, Shaanxi, Guangxi, Sichuan and Chongqing, however with a sporadic distribution pattern, while the coldspots and sub-coldspots were mainly distributed in the vicinity of Xinjiang, Qinghai, southern Gansu, southern Ningxia, western Yunnan and the Yun-Gui-Chuan confluence area, where they presented clustered distribution patterns. In 2016, the hotspot and sub-hotspot areas gradually shifted to the South, roughly forming a high-level agglomeration area headed by the Guanzhong Plain Urban Agglomeration and the Chengdu-Chongqing Urban Agglomeration, where the advantages of the gateway location of the beginning western areas and connecting the North and the South became manifest. Most of the coldspot and sub-coldspot areas expanded along the Xinjiang-Qinghai-Gansu-Ningxia belt, while small aggregations were particularly seen in the western and eastern parts of Yunnan, the western part of Guizhou and the southern part of Guangxi. In 2021, hotspots and sub-hotspots continued to be contiguous and concentrated in the South, while the Northwest and the Beibu Gulf urban agglomerations formed stable coldspots and sub-coldspots.

Influencing factors

Health inequities are not only the result of differences in natural factors, but also of inequities in human factors such as economic development, public health expenditures, accessibility of healthcare resources, environmental quality and urbanization levels (Zhao *et al*., 2017). In 2016, China's rural economic and social development entered an important strategic period of poverty eradication, and the continued improvement of the level of indicators in the main areas of basic public services is a notable feature of this period. This continued in 2021, with an understanding that public health needed to expand. In addition, the urbanization level increased leading to the formation of the spatial pattern of public health development, particularly in the western region, where government guidance, agglomeration capacity and industrial structure became auxiliary factors.

Since natural factors take a relatively long time to form and are difficult to change in a short period, this paper draws on previous relevant studies (Wang, 2014; Zhao *et al*., 2017; Sunhee & Wang, 2019) constructing an indicator system to analyze the impact of key human factors with regard to the development of public health in the western region, We considered economic level, governmental guidance, urbanization level, agglomeration capacity and industrial structure, where the primary industry refers to agriculture, forestry, animal husbandry and fisheries; the secondary to mining, manufacturing, heat, gas and water, electricity and construction; while the tertiary involves other sectors, such as education, health and transportation. (Table 3). Specifically: i) the gross demestic product (GDP) per capita was chosen to characterize the level of regional economic development since it affects the accessibility of health products and services and indirectly influences the effectiveness of preventive health services and disease control, eventually resulting in health inequity (Zhao *et al*., 2017); ii) the proportion of tertiary industry was chosen to reflect the regional industri-

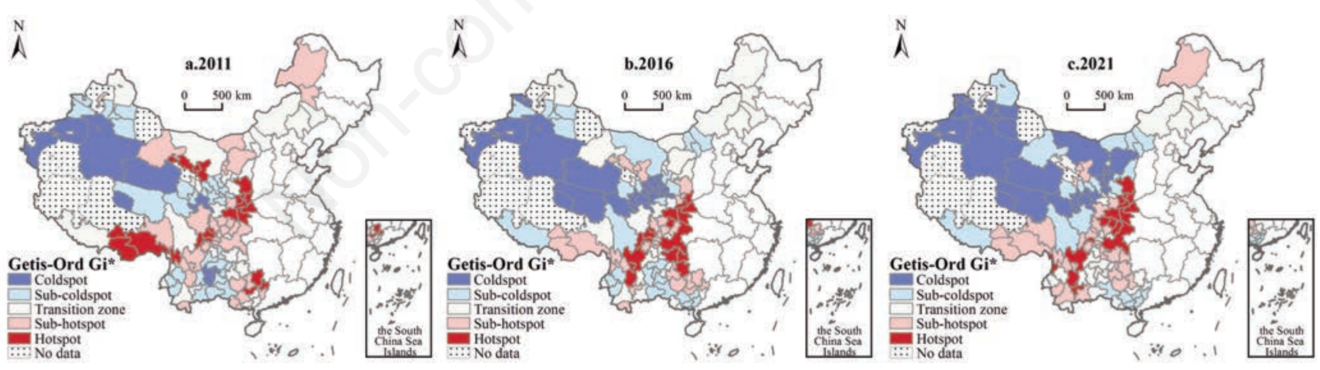

Figure 4. Analysis of hotspots of public health development in China's western region.

Table 3. Index system of influencing factors of public health development in China's western region.

Dimensional indicators	Specific indicators	Indicator properties
Economic level	X_1: GDP per capita	+
Industrial structure	X_2: Proportion of tertiary industry	+
Governmental guidance	X_3: Per capita fiscal health expenditure	+
Urbanization level	X_4: Urbanization rate	+
Agglomeration capacity	X_5: Population density	−

Positive indicators represent growth and negative indicators the opposite.

al structure, which is an important indicator to measure the strength of the regional economy as it implies a stronger driving and spill-over effect on the development of public health; iii) the per capita fiscal health expenditure was used to characterize the government's ability to guide. As one of the important means of government macro-control, fiscal health expenditure can be used to measure the degree of government control and utilization of public health resources; iv) the urbanization rate was selected to characterize the level of urbanization. Urbanization can bring fundamental changes to residents' healthy production, healthy life and health services thereby becoming an important driving force for developing public health; v) population density was chosen to characterize the agglomeration capacity of each prefecture-level city since the effect of population density is conducive to the construction of reasonable human-land relations and the agglomeration of human, material and financial resources for public health. On the other hand, over-agglomeration of population brings about negative impacts such as resource depletion, environmental damage and reduction of per capita occupancy index, a limiting factor for high-quality development of public health.

The degree of influence of each factor on the public health development was derived as shown in Table 4. Overall, there were obvious differences in the explanatory power of different influencing factors on the level of development of public health in the western region, among which the urbanization rate and GDP per capita were stronger, with q-values of 0.153 and 0.142, respectively. The degree of influence of the average year of the five detecting factors is shown as urbanization rate ＞GDP per capita ＞fiscal health expenditure per capita ＞ population density ＞proportion of tertiary industry.

Discussion

This study provides a Chinese model that can be utilized for the development of public health and wellness in other developing countries or similar regions based on China's experience in the development of public health area. Derived from our findings presented here, we make the following recommendations.

Policy-oriented efforts should be made to enhance the supply of public medical services in north-western cities, such as Ulumuqi and Lhasa, advocate healthy lifestyles and improve the immediate environment to achieve synergistic development. Public health development coordinates healthy living and healthy environments, while focusing on improved health levels and dealing with shortcomings. Capitalizing on the role of the *Belt and Road initiative*, construction of new land and sea corridors in the western part of the country should be accelerated and lead to the radiating positive effects of the city clusters on the northern slopes of the Tianshan Mountains, such as those involving Lanxi City, the Ningxia area along the Yellow River City, the cities of Hubao, Eyu and Elm, Guanzhong Plain City, Chengdu-Chongqing City , Qianzhong City, Yunnan-Chongqing City and Beibu Gulf City. The spatial distribution of access to public health can be optimized and regional disparitie snarrowed by encouraging geopolitical and resource endowment advantages in the West.

Base on the increased development in China since 2021, efforts should be used to promote a new type of urbanization in the western region with a better balance of health resources for all including an appropriate increase of the proportion of the tertiary industry so that it can play a role for the equalization of public health development.

The academic community has not yet formed a set of fixed evaluation indicators for the development of public health due to lack of sufficient literature and limited availability of data. Protecting public health and improving people's health and well-being is a systematic long-term project, and it is the focus of research and judgment by academics and all sectors of society. The research in this paper provides a scientific basis for national or local government departments to formulate health care policies, but there are some limitations. For example, we focused on the supply side of the selection of indicators but suffered from a dearth of relevant indicators reflecting the demand side. We further admit that there is a lack of comparative studies with other economic regions in China and we have not yet carried out a micro-analysis of the differentiation within each province with finer precision, which would make the generalization effect ineffective. Because of the relatively small number of sample data and time points selected, the findings may not adequately reveal the temporal and spatial patterns of change in the high-quality development of public health and wellbeing in the western region. The interaction and coupling mechanism between natural and human factors deserve further debate in the future. However, subsequent studies will examine the spatial and temporal patterns of regional public health and health quality development and the mechanism of dynamic multi-scale evolution to explore regional quality development enhancement.

Conclusions

During the past 11 years, the cities and municipalities where the development of the health level has been at a high level were mainly located in Inner Mongolia, Ningxia, Shaanxi, Chongqing and Guangxi, and in the areas of north-central Gansu, south-central Sichuan, north-central Guizhou and particularly in eastern Yunnan. Some of Xinjiang's prefectures and cities moved into the medium level in 2021, while the rest of them remained at very low levels,

Table 4. Results of geographical detection of influencing factors of public health development in China's western region.

Detection factor	q-value （2011）	q-value （2016）	q-value （2021）	q-value （average year）
GDP per capita （X_1）	0.191	0.187	0.143	0.142
Proportion of tertiary industry （X_2）	0.088	0.072	0.017	0.021
Per capita fiscal health expenditure （X_3）	0.038	0.078	0.102	0.061
Urbanization rate （X_4）	0.230	0.153	0.050	0.153
Population density （X_5）	0.021	0.041	0.051	0.032

q, the explanatory power of the influencing factor, with larger values indicating greater explanatory power.

due to extremely complex terrain, inconvenient transportation conditions and comparatively low economic development.

The overall level of development of public health in western China has been increasing during the study period, but the development of each dimension is still not balanced. The absolute differences between the prefecture-level cities during the study period first decreased and then increased. Obvious differences in the spatial distribution of the overall level of development of public health in the western region were also noted, basically presenting a development pattern of west-central-east gradient, north-central-south uneven layout. In terms of dimensions, the development of healthy living is roughly characterized by a T-shaped evolution distribution with northern Xinjiang-Gansu-Inner Mongolia as the horizontal axis and Ningxia-Shaanxi-Eastern Sichuan-Chongqing-Yunnan-Central and Southern Guangxi as the vertical one. The north-south spatial differentiation in the development of the health environment was found significant, with significant collapse in the Northwest. The development of health services was seen as mainly characterized by a scattered distribution, with a highly uneven spatial distribution within districts. During the period of 2011-2021, there was a positive correlation between the level of development of public health in the western region, and the phenomenon of spatial clustering was significant and showed a trend of continuous enhancement. The hotspot and sub-hotspot areas contracted from North to South, with coldspot and sub-coldspot areas expanding from west to east. The spatio-temporal divergence of the level of development of public health in the western region is the result of the combined effect of multiple factors, and in terms of the key human factors, the explanatory strength of five important factors manifested itself as the urbanization rate > GDP per capita > fiscal health expenditure per capita > population density > proportion of tertiary industries.

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